# INTENSITY RAMP-UP: 2011 EXPERIENCE – LIMITATIONS, MITIGATIONS, RISKS, STRAGETY TO PUSH IN 2012 TO 1380 BUNCHES IN 3 WEEKS?

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*Abstract*

This paper will discuss the experience with ramping up the beam intensities in the early days of the 2011 run and after the subsequent technical stops. Weak points and limitations are being identified and their possible mitigations evaluated. In view of the risks and drawbacks of a too aggressive approach, possible improvements of the applied strategy whilst maintaining the required validation points for the various equipment and machine protection systems (MPS) are being discussed.

## INITIAL PLAN AFTER 2010 RUN

At the end of the 2010 run, 368 bunches were injected and ramped to 3.5 TeV in the LHC, still using a bunch spacing of 150 ns. Operation in 2011 was initially planned to restart with a bunch spacing of 75 ns and a beta squeeze to 1.5 m in the high luminosity interaction points IR1 and IR5. As these new parameters were expected to accentuate effects related to electron clouds, R2E … a staged approach for the ramp up in beam intensity before the first TS and the 1.38 TeV run was proposed and endorsed as follows:

- Completion of MPS tests and loss maps with <=3 bunches
- Start luminosity operation with 3 bunches per beam (for the validation of the full operational procedure)
- Intensity ramp-up (8b, 32b, 64b, 136b, 200b)

In order to validate the full operational cycle as well as to reveal longer-term effects during nominal physics conditions, a baseline of three fills per step with an accumulated time in stable beams of at least 20 hours was defined as the baseline before proceeding to the next step. Depending on the observations, the restricted Machine Protection Panel (rMPP) could propose a reduction of either the number of steps or the hours in stable beams.

## STARTUP 2011 AND FIRST INTENSITY RAMP-UP

Following the timely re-commissioning of the LHC magnet powering system, 1st circulating beams were established on the 19th of February 2011. After two more weeks of cold checkout and beam commissioning, the first collisions at 3.5 TeV where re-established with the new parameter set on the 3rd of March. Apart from smaller issues with a noisy tune signal no bigger issues were encountered during these early days and the final Machine protection tests were completed on the 13th of March, achieving stable beam conditions with 3 nominal bunches in each beam to mark the end of the beam commissioning period. This allowed for 10 days of intensity ramp-up before the planned medium energy run at 1.38 TeV. During this phase the number of bunches was increased to 200 bunches per beam thanks to a very good availability of the machine and the associated equipment systems as shown in Figure 1.

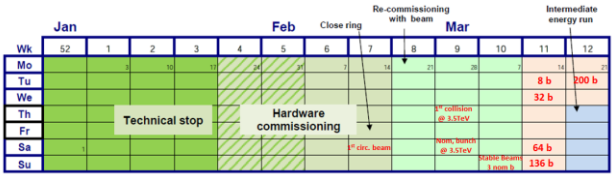


Figure 1: Milestones and initial intensity ramp up before the intermediate energy run and TS #1

The only noticeable downtime during this phase was caused by a problem in the Master Timing Generator, resulting in the transmission of wrongly time-stamped events which required around two days to be corrected.

## INTENSITY INCREASE TO 1380 BUNCHES

Recovering from the first technical stop in 2011 was overshadowed by a transformer problem in UJ76, delaying the start of the scrubbing run by two days. The following week of scrubbing was again interrupted for roughly two days due to an inversion of HTS protection cabling towards the quench detection system. While scrubbing was first performed with 96 bunches and 75 ns bunch spacing, after only a day of setup the intensity was quickly increased in steps up to 1020 bunches using 50 ns bunch spacing.

Following the scrubbing run a considerable decrease of vacuum activity was observed and thus the bunch spacing of 50 ns was decided to be the baseline for the remaining 2011 run. The intensity value achieved prior to the technical stop was re-established within only three days, and in the following the intensity was further increased in steps of 200 bunches as shown in Figure **2**.

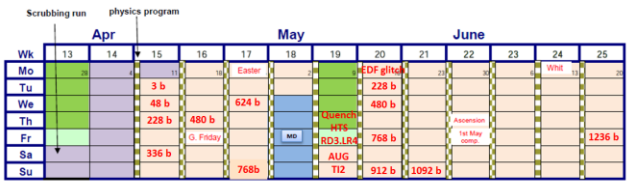


Figure 2: Intensity ramp up to 1380 bunches

The main motivation for the step size of 200 bunches at this level of intensity (with beams that are already well beyond the unsafe limits) being the potential damage to

RF components, which scales to a large extend with the square of beam intensity rather than with the energy, as for example the extracted power by the Higher Order Mode (HOM) dampers. Many of these components had never been validated under nominal conditions, thus mitigations like limiting the external Q value to reduce the maximum induced voltage to < 1.2 MeV and intermediate validations after steps of 200 bunches were put in place. In this way, 768 bunches per beam were achieved before going into the 2nd technical stop of the year, whereas every intensity step was approved by filling in an extensive checklist by the equipment responsible of the main (machine protection) systems (Magnet Powering and QPS, Interlocks, BLM, BPM, Collimation, RF, injection and LBDS). The steps to 624 and 768 bunches indicated already the looming issues with the vacuum and BLM thresholds, as several of the fills were dumped due to vacuum spikes, beam losses resulting from these vacuum spikes or UFOs (mainly in the injection regions IR2 and IR8).

Reaching nominal intensities was due to be achieved only in the next running period before the technical stop #3 (see Figure **2** and Figure **3**). As already observed after the previous technical stops, the intensity increase back to the intensity achieved before the interruption of operation was reasonably quick. The step to reach 912 nominal bunches per ring however required 13 fills in total to reach the desired 20 hours in stable beams. This intensity step set off numerous spurious interlocks in the arc detection unit of the main coupler of the RF, which were quickly allocated to radiation effects on the interlock electronic. In addition, the so far fastest UFO was observed in the arc of sector 78, more precisely at the quadrupole Q28L8.

The following step to 1092 bunches however did proof to be even more time consuming. Not less than 41 fills were brought into collisions, accumulating a total of more than 200 hours in stable beams. The majority of the early fills were dumped shortly after declaring stable beams, mostly due to intensity or luminosity related effects such as UFOs, beam loss or spurious equipment triggers due to radiation effects as shown in Figure **5**.

A number of mitigations were applied during his period to tackle the increasing R2E and UFO problems. These were mainly a series of BLM threshold changes in early June (on injection elements such as Q6L2, MKI2/8, tertiary collimators in IR2/8, individually powered quadrupoles MQY…), the simultaneous increase of vacuum thresholds and the continued deployment of R2E mitigations. For reasons of maximizing the integrated luminosity, even stepping back to 912 bunches was considered at this point. The fill duration however considerable increased again after implementing the described measures, allowing the final two intensity steps to be performed with very little problems before the TS end of June. The final fill with 1380 bunches was dumped after 13.7 hours in stable beams by the operations crew and accumulated ~ 46 $pb^{-1}$of physics data, just as much as the whole luminosity production of the year 2010.

## INTENSITY INCREASE AFTER TECHNICAL STOPS

Intensity ramp ups after the technical stop usually commence with a 1st test ramp with pilot beams, followed by a fill with a single nominal bunch / beam to validate the full operational cycle. After achieving typically 1 hour in stable beams, all loss-maps are systematically repeated (in 2011 the baseline validity of a loss-map was defined to be 4 weeks). The machine protection tests are terminated with an asynchronous dump test, after which the intensity was increased with steps at 84, 264, 480, 840, 1092 and 1380 bunches.

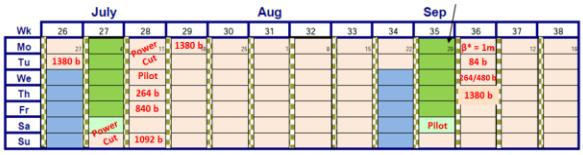


Figure 3: Intensity ramp ups after TS# 3 and TS#4

Both recoveries from the technical stop of early July as well as the one early September were done without major surprises. While the one early July showed an increase of UFO activity around the MKI in IR2 following the technical stop and required around 5 days to come back to 1380 bunches, the recovery from the TS of September was done in only 2 days, clearly indicating the effect of natural 'cleaning' of the machine after several months of operation at nominal intensities (see as well Figure **4**).


Figure 4: Intensity ramp-up after the technical stops #3 in early July (top) and the technical stop #4 in early September 2011 (bottom)

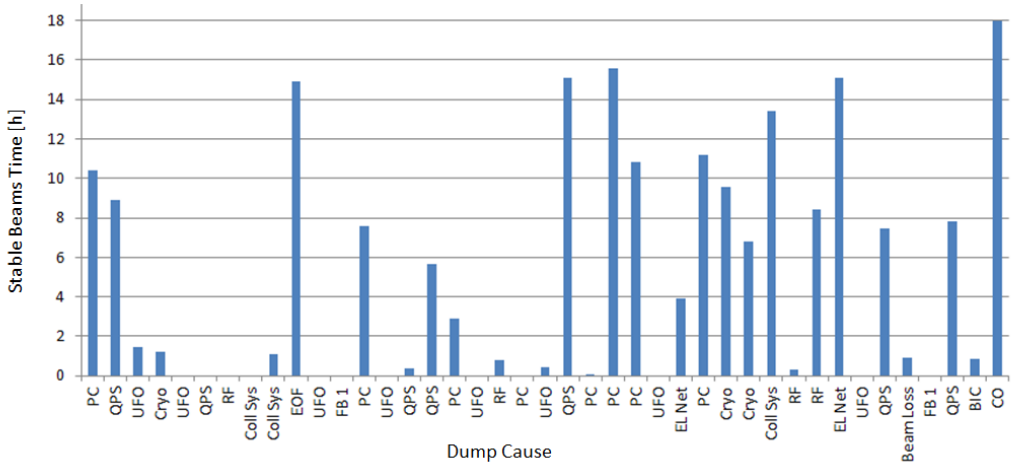


Figure 5: Beam dumps with 1092 bunches in the machine as a function of beam mode for fills where energy ramp started and respective main causes of losing the beams. [1]

## GENERAL OBSERVATIONS AND THE ROLE OF THE RESTRICTED MACHINE PROTECTION PANEL (rMPP)

The majority of the validation and machine protection tests are performed with safe beam, i.e. typically with less than 3 nominal bunches and require comparably little time during the intensity increase. The main driving factor for increasing the intensity up to 768 in 2011 was the machine availability. The necessity of maintaining the 3 fills with 20 hours in stable beams will hence be a point of improvement for future intensity ramp-ups. At the same time, these fills allowed to discover and correct numerous teething problems with the equipment system and the operational cycle at intensities lower than nominal.

Increasing the intensities for the first time to 912 and 1092 nominal bunches per beam set off numerous problems related to the higher beam intensities and/or the higher luminosity levels in the insertion regions, which only could be mitigated by relaxing the respective beam loss and vacuum thresholds as well as progressing with the R2E mitigation measures already during the 2011 run.

The risk with a fast increase in intensity is considered not to be a risk of machine protection, but with a risk to decrease the overall efficiency in terms of production of integrated luminosity. A balanced approach to the intensity increase allows for probing and resolving of looming issues whilst maintaining a certain integrated luminosity for the LHC experiments.

It is proposed that as for 2011, the restricted Machine Protection Panel (rMPP) maintains its role during the 2012 run to propose the strategy for the intensity ramp-up and the operational envelope. During the last year, more than 15 meetings of rMPP took place, whereas the panel was most active during the initial ramp-up [2]. Each intensity step was approved by the involved teams through a detailed checklist, including a number of standard equipment verifications, non-conformities, comments and additional MPS checks that are proposed to safely step up in intensity. The proposals have been mostly endorsed, for 2012 a more formalised ramp-up after the technical stops and a closer follow-up during the intensity cruise will be put in place.

## CONCLUSIONS AND OUTLOOK

The LHC Machine Protection and Equipment Systems have been working extremely well during the 2011 run thanks to a lot of commitment and rigor of operation crews and machine protection experts. The main delays of increasing the intensity in 2011 were devoted to the understanding and mitigation of intensity related effects when reaching 912 nominal bunches per beam. The very fast intensity ramp-ups after the last technical stops indicate that a quicker ramp-up in 2012 will depend on a good scrubbing, changes of machine parameters (E, β*, bunch spacing…) and the amount of relate system changes during X-mas stop. Assuming the most likely scenario for 2012 operation, achieving 1380 bunches in 3 weeks seems within reach, pushing too hard will very likely become counterproductive at some point due to the potential decrease in fill length following premature dumps. Following the experience from the 2011 run it is proposed to reduce to 7 intensity steps in 2012 as follows:

- 3 fills and 6 hours with 48b, 84b, 264b and 624b
- 3 fills and 20 hours with 840b, 1092b, 1380b

This scheme will allow for an efficient but thorough validation of the operational cycle at lower intensities as well as for the resolution of intensity related problems whilst already producing luminosity for the experiments.

## REFERENCES

[1] A. Jalal, M.Zerlauth et al, "Post Mortem Database and Statistics – Web Interface", https://cs-ccr-oas1.cern.ch/pls/htmldb_dbabco/f?p=pmdatabase

[2] rMPP, et al, "EDMS Tree of rMPP", https://edms.cern.ch/nav/P:LHC-0000002890:V0/P:LHC-0000005946:V0/TAB3 .