SUMMARY OF SESSION 4: LHC: CHALLENGES AND STRATEGY FOR RUN 2

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ABSTRACT

The session aimed at addressing the challenges and overall strategy for the second operational period of CERNs Large Hadron Collider, expected to restart beam operation in early 2015. While the main focus was the identification of a strategy for the commissioning year 2015 (concentrating on 6.5 TeV, 25 ns/2800b per beam), the presentations provided as well an outlook for plans to reach the nominal machine performance by further decreasing β* and by maximizing the luminosity output of the machine as of 2016, while maintaining the pile-up at the level currently acceptable for the LHC experiments.

STRATGEY FOR THE FIRST TWO MONTHS OF THE 2015 BEAM COMMISSIONING

The main target of the first two months of the 2015 beam commissioning is to establish collisions in all 4 experiments of the LHC with 2-3 nominal bunches. Around two months are foreseen for this period, providing the basis for the following intensity ramp up with 50 ns, respectively 25 ns. The following main commissioning steps have to be completed during this period:

- Establish the key beam commissioning steps like first threading, beam capture, orbit and optics corrections, IR bumps, aperture (β*), polarities, energy ramp (combined ramp & squeeze) and collisions.
- Commission with beam the key accelerator systems like feedback systems (FB), transverse damper (ADT), collimation (+ embedded beam position monitors, BPMs), radio frequency (RF), injection, dump and diagnostics taking into account the many system changes during LS1, hence expected to be very different to the very fast 2012 re-commissioning.
- Execute all relevant machine protection (MP) commissioning, as all MP-related systems must operate in their final configurations by the first Stable Beams. It should be noted that changes during the run might become very time consuming, hence special runs should be scheduled early on.
- Validate the machine configuration with the relevant optics measurements, as the challenges of Run 2 require new measurements compared to the standard commissioning of previous years.
- Start preparation of the scheduled β* change planned for mid-end 2015 to speed up the later optics re-commissioning.

In addition to this standard commission, measurements for the insertion region (IR) should be performed such as aperture at injection and top energy, if possible, (providing already a first estimation of the β* reach), local orbit and optics corrections in the IRs to conclude on the feasibility of levelling scenarios and the orbit stability/BPM signals as the basis for a good reproducibility and stability of the machine.

In view of the additional overhead to repeat a complete validation at a later stage, the initial optics measurements and corrections as well as the aperture verification with squeezed beams are ideally already performed and verified down to the final target value of β*=40 cm in order to validate the feasibility and understand the margins of this configuration early on in the commissioning program.

OVERALL STRATGEY FOR RUN 2

The start-up configuration of the LHC for 2015 has been discussed at a recent LMC meeting, confirming to concentrate on operation at 6.5 TeV, 25 ns/2800b per beam and opting for reduced complexity by adopting a relaxed β*=80 cm. A similar strategy has already been applied during Run 1, during which β* could be reduced twice due to the excellent stability and increased understanding of the machine, first in 2011 from 1.5 m to 1 m and a second time in early 2012 from 1 m to 0.6 m as shown in Figure 1.

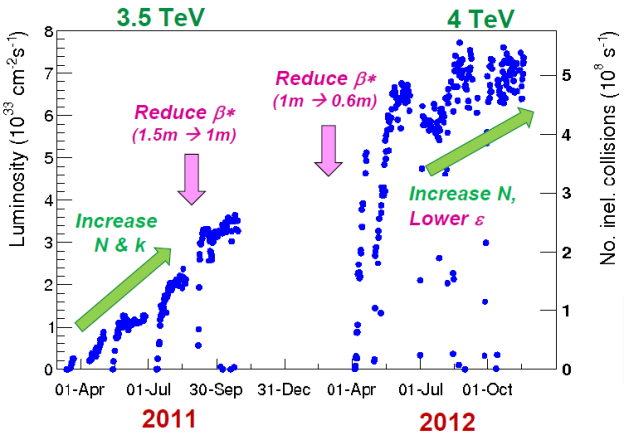

Figure 1: Evolution of machine performance during Run1.

Different to previous (re-)commission periods the 2015 commissioning will include two intensity ramp-ups, first with 50 ns beams (following an initial scrubbing run with 50 ns and 25 ns beams) to re-establish stable machine operation after the two yearlong shutdown. This phase will be limited to ~3 weeks and will mainly serve as a

debugging phase for operations, since various equipment systems will be exposed for the first time again to higher beam intensities and bunch trains. In the following, a second scrubbing run (using 25 ns beam and eventually doublet beams) will be used to prepare the machine for the following 25 ns operation, which will be taking place in two periods around the 2nd technical stop of ~45days each. If the previous measurements and experience allow for it, the 2nd 25 ns block could eventually take already place at a slightly reduced β* value.

The year will be concluded by the traditional ion run, for which a slightly lower energy of 6.37 TeV is preferred by the experiments. Due to the limited time available for an already very dense program, the overhead of other special runs like LHCf, high β* and VdM scans has to be carefully weighed against the priority of establishing stable 25 ns operation and to prepare an organized path to lower β*, which will entail mastering considerable new challenges like electron clouds, instabilities and reduced quench margins in presence of the expected increase of UFO rates.

MPS STRAGEY FOR COMMISSIONING AND OPERATION

Machine operation at 6.5 TeV and 25 ns bunch spacing will increase the energy stored in the LHC magnet system and beams well beyond the levels mastered during the first operational run. The main challenges for machine protection will be to achieve reliable operation of the magnet system at higher energies (and hence much reduced quench margins) in presence of higher beam intensities and the expected beam instabilities and increased UFO rates.

In addition, the levels of the so-called 'Setup beam flag' (representing the beam intensity as a function of energy at which no damage should be possible to any accelerator equipment in case of full beam impact) will be as low as 1.1×10^{10}p (~intensity of a probe bunch) at 6.5 TeV as shown in Figure 2.

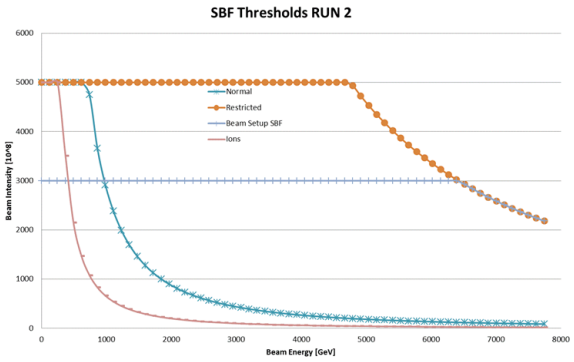

Figure 2: Setup Beam Flag values for Run 2.

For the initial beam setup (including loss maps, finding collisions…) a special equation will be available in the Safe Machine Parameter (SMP) system, allowing under certain conditions and for limited periods of time the use of up to 3 nominal bunches in order to allow for an efficient machine setup.

After a first full commissioning of the machine protection systems for the adopted start-up configuration, any changes in the machine configuration will require the requalification of the relevant machine protection elements (collimator settings, asynchronous beam dump, loss-maps…). The restricted Machine Protection Panel (rMPP) will closely follow and validate the intensity ramp-up periods and stable beam periods through dedicated check-lists for the main equipment and protection systems.

MACHINE DEVELOPMENT PRIORITIES

The machine development (MD) priorities for Run 2 will be largely determined by the overall strategy and commissioning plan for the machine in 2015. The assessment of many of the known and expected new operational challenges such as single and multi-bunch instabilities, optics, β* and aperture… will require considerable time early on in the commission program to confirm the adopted roadmap. It has been decided that any measurement which is vital for machine operation will hence be part of the Run 2 commissioning and not of the limited MD blocks. MD time will be allocated instead for (long-term) performance improvements of the machine. High priority MDs will include studies related to the change of intensity limits, the modified impedance and beam stabilities, long-range beam-beam effects with 25 ns bunch spacing, collimation hierarchy and impedance, β* levelling and collide & squeeze tests.

Following the experience during Run 1, strict procedures and formal written requests will be required for each MD as this has shown to increase the efficiency and success of the allocated testing time.

BLM THRESHOLD STRATEGY (VS UFOS AND QUENCHES)

One of the major challenges for Run 2 is to define BLM thresholds for operation of the cold and warm elements of the LHC machine at 6.5 TeV, which will protect critical machine elements from any damage while optimizing the availability of the magnet powering system by avoiding unnecessary quenches after e.g. UFO events.

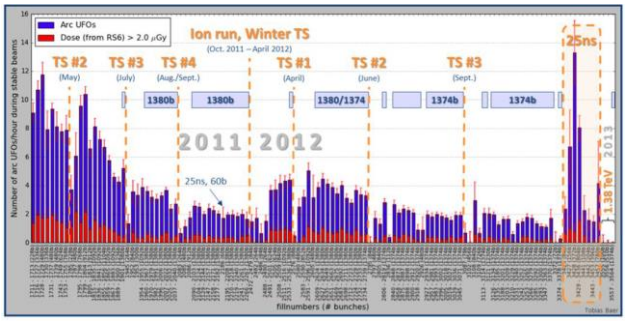

Figure 3: UFO rates during 2011 and 2012.

While in known sensitive locations, like the MKIs, mitigation measures have been adopted to decrease the UFO rate during Run 2, the UFO rates in the arc are

expected to increase again after the long shutdown and due to the 25 ns operation (as already observed during Run 1 – illustrated in Figure 3). As counter-measure, 2 out of the 6 BLM monitors on the arc quadrupoles have been relocated into the interconnections between two arc dipole magnets, which will allow for efficient protection against such UFO loss scenarios without unnecessarily decreasing the BLM thresholds on the arc quadrupoles.

Considerable efforts are currently going into the analysis of the recent quench tests and the benchmarking of simulation codes with these results in order to establish new reference values for the quench levels of the LHC magnets in the relevant running sums of the beam loss monitoring system. First results are encouraging as they suggest that the true quench levels are a factor of 5-10 higher than previously predicted in Note 44. These new findings will be the basis for an efficient tuning of the BLM thresholds in preparation and during Run 2. As a consequence of this optimisation, a number of UFO/beam-induced quenches are however to be expected during the second operational period of the LHC.

R2E AND AVAILABILITY

Besides the beam parameters chosen for the Run 2, the availability of the machine to allow for luminosity production will be another decisive ingredient to reach the ambitious goals of Run 2 as shown in Figure 4. Machine availability during Run 1 has been dominated by equipment failures (accounting in average for more than 2 out of 3 beam dumps).

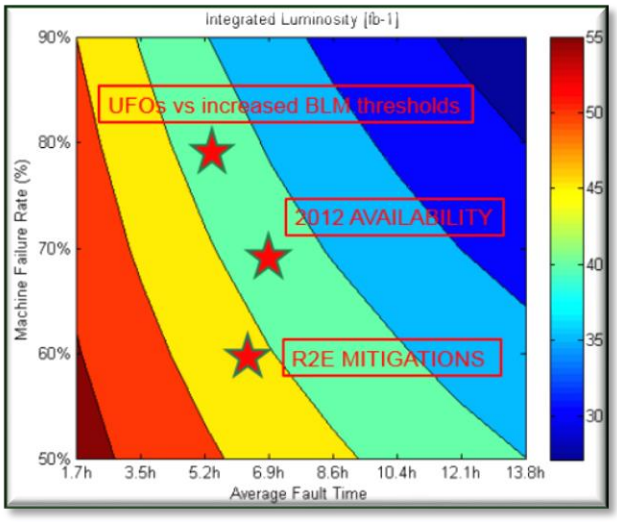

Figure 4: Simulated integrated luminosity/LHC operational year as a function of machine failure rate and fault time based on 2012 availability and variations due to R2E mitigations and increased UFO rates/new BLM thresholds.

A considerable fraction of these failures could be traced back to radiation induced effects, hence considerable efforts have been undertaken during LS1 to install additional shielding wherever possible and to relocate further sensitive equipment from exposed areas (UJ14/16, UJ56).

The R2E team is also assisting equipment groups in the re-design of electronic components installed in radiation areas, by using error correction algorithms or radiation tolerant components in the designs. Thanks to these ongoing efforts, the number of radiation induced beam dumps is expected to decrease from an initial value of ~12 dumps/fb^{-1} to less than 0.1 dumps/fb^{-1} for the HL-LHC period.

In parallel, efforts to better quantify, track and improve the availability of the various equipment systems are vital to agree on future priorities of consolidation activities. These efforts are coordinated by the Availability Working Group, and will be supported by new tools to quantitatively measure the availability of the individual LHC systems by tracking in detail the caused down times of the machine. While initially focusing on the LHC machine, this Accelerator Fault Tracking Project (AFT) is expected to be used as well in the injector complex in the future.

SUMMARY

The 2015 run presents us with a fantastic mix of challenges. In parallel to learning how to operate at 6.5 TeV and with 25 ns beams we will have to prepare the future of LHC operation. During the initial commissioning year it will be important to remain focused on the challenges of 25 ns operation and to define an organized path to lower β* rather than searching for immediate performance gains. MD periods are likely to be too short (and very late) for a full program, hence many MD like items will have to be performed during periods of 'operational development'.

Assuming that things move on reasonably, a reduction of β* should be foreseen in the second 25 ns period based on the available information. The traditional ion run at the end of the year and other special runs should be carefully slotted in at an acceptable overhead.

ACKNOWLEDGMENTS

The session conveners would like to express their gratitude for the assistance and numerous discussions with the various members of the Machine Protection Panel, the Availability Working Group, the various equipment groups and the colleagues from BE-OP. In particular, we wish to thank the speakers, S. Redaelli, J.Wenninger, B. Salvachua, J. Uythoven, B. Auchmann and M. Brugger for their excellent presentations, which were well timed and focused on the relevant items that were asked to be addressed.

DISCUSSION

Stefano Redaelli

Strategy for the first two months of the 2015 beam commissioning

M. Lamont asked if the alignment and operation of the Roman Pots would be included in the initial beam setup. M. Deile comments that Roman Pots stations will be used during low beta runs and during high beta runs. For the low beta runs only some 14 individual pots have to be aligned, while for high beta runs the full set of pots will have to be aligned. He points out that the alignment and validation of the pots should be included during commissioning as it will be more time consuming if done later on due to the required additional loss maps. S.Redaelli replies that the operation of the Roman Pots is challenging, as they should be inserted very close to the beam. He reminds that in 2012 the alignment and operation with pots was done only after acquiring a good knowledge of the machine. For the 2015 run period, he thinks that it might be too challenging to operate them as close to the beam right after the first collimator alignment and without the knowledge of machine stability. P.Collier comments that it should be considered the possibility to operate with the pots only after week 23 (after the first technical stop) when the machine will probably need to be re-qualified.

M. Zerlauth comments that one of the limitations during machine validation with beams was the number of fills needed to validate the off-momentum cleaning. He asks if there is something that can be tried during initial commissioning with beam to improve the situation in the future. S. Redaelli replies that in the Machine Protection Workshop in March 2013 (Annecy), a possibility to change the particle momentum in a more controlled way was presented. However, this method stills needs to be verified in conjunction with the RF team but he agrees that it is certainly something that should be planned during commissioning.

Jorg Wenninger

Overall Strategy for Run 2

S. Redaelli enquires about the expected problems during special runs with many bunches. J. Wenninger comments that we will need to wait for the first experiences with the beam in order to evaluate this.

M. Meddahi asks, since the priority for operation during Run 2 is the 25 ns option, about the possibility to shorten the 50 ns period or even skip it completely and give e.g. higher priority and time to the scrubbing. J. Wenninger replies that a shorter running at 50 ns can be considered, but currently this serves as a contingency in case of problems. M. Zerlauth adds that the idea for this run is also to accumulate enough machine time during a more controlled period to fully validate the machine protection system.

Belen Salvachua

MPS Strategy for Commissioning and Operation

No questions or comments.

Jan Uythoven

Machine Development Priorities

M. Zerlauth comments that it will be challenging to make sure that all the items quoted in the current talk as commissioning measurements can be accommodated during the initial beam-commissioning phase.

L. Rossi points out that the use of ATS optics should be anticipated in the LHC as soon as possible. He comments that the decision not to use it right after LS1 is understood and that he is in agreement with it, but the possibility to use this optics version in the close future has to be strongly considered as it is the HL-LHC baseline and any problem should be addressed as soon as possible.

R. Schmidt enquires about the plan to use the new instrumentation to measure and interlock for the fast changes of beam current (dI/dt aka BCCM). T. Lefevre comments that the strategy is to test as much as possible already during commissioning and if there is some time left continue during Machine Development periods. M.Zerlauth adds that new hardware has been already produced, so the first tests should certainly be able to start during early beam commissioning in 2015.

J. Uythoven comments that the overall strategy is to complete during commissioning everything that is absolutely essential for physics operation in 2015 and leave for the Machine Developments the studies needed to further improve the performance of the run, like e.g. a step down in beta-star.

V. Kain comments that the assignment of MD time seems quite advanced and asks if there is a deadline for sending MD requests, as she thinks that it will be better to have some experience with the beam before proposing MDs. J.Uythoven replies that written requests are welcome at any time now, however the final decision will be done shortly before the MD period depending of the current needs and operational experiences.

J. Jowett reminds that in 2013 no quench test was performed for ions and asks about the possibility to include this in the agenda for the next quench test period.

R. Jacobsson mentions that for the organization/allocation of commissioning time BE-OP should take into account that systematic commissioning during normal working hours and stable beams during the night is not ideal for the experiments as they also have to complete developments and upgrades during that period.

Bernhard Auchmann

BLM Thresholds Strategy (vs UFO and quenches)

S. Redaelli comments that we should be ready to prepare some BLM factors that we still consider safe for the losses in the Dispersion Suppressor regions (DS and he points out that if UFO losses are under control the DS will very likely be the limiting location.

S. Redaelli asks whether the change of the BLM locations in the arc region is mainly motivated to better

observe UFO's that were not seen before. B. Auchmann indicates that this is indeed the case (in addition to better protection possibilities), as there were potentially UFO's that occurred in the arc and were not measurable in Run 1.

J. Ph. Tock points out that there are some magnets more difficult to replace than others and asks if this can be taken into account when preparing the BLM thresholds to protect them. B. Auchmann replies that his current talk covers, for the time being, only main dipoles and quadrupoles; for other locations we can consider to add a safety factor. J. Ph. Tock replies that indeed he is more worried about other magnets than the main dipoles and quadruples.

E. Todesco comments on arc thresholds as a function of loss duration (slide 14). He points out that the behavior seems linear in the log scale and asks if this is understood. B. Auchmann replies that it is complicated to have an argument to explain the behavior of the thresholds over the full range.

Markus Brugger

R2E and availability

M. Lamont asks if the 0.5 failures per fb^{-1} can be further reduced. M. Brugger replies that these failures due to radiation will disappear but we will observe other types of failures (which are however predictable and understood). M. Zerlauth comments that it is important to start the redesigned of the systems taking into account radiation issues.

Q. King asks about the preferable approach for the power converters. M. Brugger replies that in the next R2E workshop, to be held in October 2014 at CERN, this will be discussed.

P. Baudrenghien comments that most of the effort seems to be on re-location and asks if there is also some effort put on the design of radiation resistant components. M.Brugger replies that there is also a strong effort on redesigning electronics and points out that the QPS group had to design and produce many (types of) cards in a few years.