KEY CHALLENGES AND LIMITATION SESSION

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INTRODUCTION

The experienced gained in 2015 allowed to asses if the prefixed operational goals could be achieved with the upgrades implemented in LS1. Leftovers and new observations can be used for extrapolation to operation at higher energies and whit higher intensities. Main operational challenges and key limitations for LHC operation during Run 2 and in view of the HL-LHC era are presented.

B. AUCHMANN: UFOS, ULO, BLMS

Periodic ULO scans showed that the size of this object changed in time. The local orbit bump, which was applied to avoid beam loss induced quenches of the MB.B15R8 dipole, could be increased by a factor of two. No limitation is expected for the rest of the run.

The UFO rate initially scaled with the beam intensity. A clear signature of conditioning and saturation was observed when reaching $\sim 2 \cdot 10^{14}$ accumulated protons. A further reduction cannot necessarily be expected with the next steps in intensity.

Observations during 2015 run seem to prove that the strategy of decreasing the BLM thresholds to avoid UFO induced quenches did not pay off (high number of unnecessary dumps). The new proposal is to increase the present thresholds, for the short running sums, by a factor of two (excluding five magnets with problems at the quench heaters).

The knowledge on quench levels in the UFO time range got improved and a good agreement was found with the estimated values. On the other hand steady state quench levels were found to be a factor 2-3 lower than expectations, following a preliminary analysis of the BFPP quench test.

Discussion:

N. Holtkamp asked if the UFOs have any effect on the luminosity. **B. Auchmann** replied that only local losses appear, the effect on the intensity is measurable but very small while there is no visible effect on the luminosity.

F. Bordry asked if the geographical locations of the UFO changed with respect to Run 1 and if new hot spots could be identified. **B. Auchmann** answered that the picture is very similar to the previous run and UFOs are uniformly distributed around the machine. The only exception concerns the MKIs which disappeared from the 2015 UFO map.

L. Bottura affirmed to be surprised by the factor 2-3 discrepancy found for the steady state quench levels. **B. Auchmann** commented that the heat extraction through the insulation is an important ingredient in these calculations. He added that including the cooling channels in the simulation model is very difficult.

E. Elsen asked if the size of the UFOs changed over the years. **B. Auchmann** answered that the size of the UFOs is so heterogeneous that detecting any variation is almost impossible.

J.M. Jimenez commented that a further conditioning of the UFO rate while increasing the beam intensity should not be totally excluded due to the cleaning effect of the electron bombardment.

N. Holtkamp pointed out that the estimated lost time due to UFO induced quenches is of the same order of the expected gain when optimising the operational cycle (pre-cycle at 2 TeV and combined ramp-and-squeeze). He thus asked if, instead of increasing the BLM thresholds, it could be possible to improve the diagnostics to catch only the UFOs which would induce a quench and minimise the number of unnecessary dumps. **B. Dehning** answered that an upgrade of the FPGA in this direction is indeed planned but it will not be ready before LS2.

M. Lamont asked how much room there is for further vertical movements of the orbit around the ULO. **B. Auchmann** answered that an increase by a factor of two of the present bump would still leave an aperture of 10 σ (the present aperture at injection is 12 σ).

G. IADAROLA: ELECTRON CLOUD EFFECTS

In 2015 two periods of scrubbing (1+2 weeks) were allocated to prepare the machine for the intensity ramp-up in physics, with 50 ns beams at first, and with 25 ns beams later on. During the scrubbing, about 2500 nominal 25 ns spaced bunches could be accumulated at 450 GeV. The main limitations came from e-cloud instabilities, transients on beam screen temperatures and vacuum at the TDI and Q5-MKI interconnect in point 8. An unexplained large discrepancy was observed between the heat loads in the different sectors. E-cloud was not completely suppressed but physics with 2244 bunches was possible.

Scrubbing seemed to be preserved after short TS while signs of deconditioning were observed after operation with very low intensity beams (MDs or special runs).

Experience with doublets confirmed the e-cloud enhancement but, due to strong instabilities, the beam could not be kept in the machine and the scrubbing was inefficient. The e-colud suppression effect when operating with 8b+4e scheme was also proven.

The proposed strategy for 2016 is to perform short scrubbing runs and then accumulate further dose in physics (possibly optimised filling schemes). Doublets should be used only after having accumulated enough scrubbing.

Discussion:

E. Elsen asked if the deconditioning observed after operation with low intensity beams could be attributed to the

different cryo performance due to the lower beam induced heating. **G. Iadarola** explained that two mechanisms take play: e-cloud and synchrotron radiation. The latter has partially a cleaning effect but determines also some gas desorption. At high intensity the desorption is cleaned by the electrons while this is not the case at low intensity (no e-cloud). This might explain the observed deconditioning.
F. Gianotti reminded that, even if this could be a solution in case of strong e-cloud limitations, the 8b+4e scheme is not ideal for the experiments due to the pileup rate. **O. Brüning** commented that the original baseline for HL-LHC foresaw operation with 50 ns spaced bunches in case of too high e-cloud. This option was discarded and 8b+4e became the new backup solution since 50 ns beams are even worse for the experiments.
M. Lamont asked what the estimated reachable intensity is after the first 4 days of scrubbing at the beginning of 2016 run. **G. Iadarola** answered that, if no other limitation appears, the machine could be quickly filled with 2244 bunches. Instead, it is not possible to extrapolate and say when operation with 2740 bunches will be possible. **G. Arduinini** confirmed and added that the SEY as a function of the dose is different in the lab with respect to the machine. In particular, the heat load discrepancy between the sectors is a key issue.

B. SALVANT: BEAM INDUCED HEATING

After the changes applied in LS1, all the non conformity issues related to beam induced heating were solved with the exception of the TDI (not possible to coat the jaws with Cu). An abnormal vacuum behaviour and a significant heating were observed at the TDI in point 8 causing serious limitations during the scrubbing run. The visual inspection revealed that the Ti coating of the jaws of the TDI in point 8 was heavily compromised. Blisters were also present in the Cu coating of the block supports. Measurements confirmed a much higher impedance at the TDI in point 8 than the one in point 2. A new hardware (graphite instead of hBN blocks and Cu coating) was installed during the YETS and no further operational limitation is expected (impedance measurements to be performed during the commissioning period).

Temperature and vacuum at sensitive equipments plus beam spectra should be constantly monitored during 2016 to precociously identify issues. An active control on the bunch length should be implemented to be ready to mitigate further RF heating effects.

Discussion:

N. Holtkamp asked if TDI impedance measurements were performed before LS1 and could be used to determine if the non conformities were already there. **B. Salvant** explained that only measurements on the sides of the jaws were performed and cannot be used for comparison. Nevertheless all the jaws were inspected in LS1 and the coating was intact. He reminded that different hBN blocks were mounted on the TDI in point 2 and point 8. **N. Holtkamp** asked if the problem with Ti could reappear with the Cu coating. **B. Salvant** answered that other elements are Cu coated (i.e. the TCDQ) and no issue was encountered up to now. Moreover, graphite has a much lower impedance than hBN and a significantly lower heating is expected also in the eventuality that the coating is removed. **S. Gilardoni** remarked that the heating problem has to be considered solved only if the TDI hBN blocks were the cause of it. If the origin seated somewhere else this could still be an issue.

P. Chiggiato asked where the removed film was deposited and commented that the coating detachment should have been seen in operation. **S. Gilardoni** explained that the coating seems to be relocated on the jaw surface and losses were indeed seen during operation.

K. LI: INSTABILITIES, IMPEDANCES AND LONG-RANGE BEAM-BEAM

Observations during 2015 operation showed that instabilities were mainly driven by e-cloud and its interplay with impedance and beam-beam. Instabilities were very violent at the beginning of the run. A clear improvement was achieved after scrubbing and by adjusting the machine parameters (chromaticity, octuple current, etc.) and the ADT settings. The e-cloud reduction allowed to achieve a better knowledge of pure impedance contribution, which is also a key element to predict beam stability under change of machine configuration and beam parameters. New diagnostics was available since last year to monitor the beam instabilities (HEADTAIL monitor, ADT OBSBOX and BTF) and proved to be extremely useful.

Due to more relaxed conditions (higher β*,lower brightness, beam-beam parameter etc.), the dynamic aperture (DA) in 2015 was larger than in 2012 (6 σ instead of 4 σ). The machine will be set up to keep the 6 σ DA also for 2016 operation (crossing angles defined accordingly depending on the chosen β*). Attempts should be made to reduce the chromaticity and the current of the octupoles to allow some margin for the reduction of the crossing angles. The effect of using different working points could be investigated. The need of keeping the 12 non-colliding bunches in the filling scheme has to be evaluated.

The mains expected challenges are: stronger e-cloud effects when increasing the beam intensity (in particular in combination with the lower emittance for the BCMS beams, DA is also expected to be smaller) and higher impedance when tightening the collimator settings for operation at 40 cm β*. A good knowledge and control of the machine, a reliable diagnostics and the possibility of adjusting and optimising with some beam parameters (bunch length, emittance, etc.) are the key ingredients for future operation

Discussion:

N. Holtkamp commented that everything seems to work very well and instabilities to be reasonably understood. He asked if there is any room for improvement and if there was any limitation in term of diagnostics and feedback systems. **K. Li** explained that, since the mentioned diagnostics became operational only in 2015, all the different features have stil to be fully exploited and 2016 will be the real test bench. **V. Kain** commented that one of the main limitations will be the fact that emittance measurements with Wire Scanners (WS) at 450 GeV will not be possible with 288 bunches (both in the SPS and the LHC). Also the BSRT is not fast enough to perform bunch-by-bunch measurements. **L.R. Carver** added that at present there is a limit in storage and filtering of bunch-by-bunch and turn-by-turn measurements. **D. Valuch** commented that work is ongoing to produce smaller dedicated buffers of data which will be triggered by events; this feature will be active soon.

P. Baudrenghien noticed that only the option of varying the bunch length is mentioned while there is also the possibility of playing with the RF voltage. He asked if increasing the momentum spread could be interesting for operation. **K. Li** confirmed that this possibility should be explored.

O. Brüning commented that the LARP collaboration is working on the development of an observation box. He asked if there could be any interest in testing and implementing it in the SPS. **K. Li** answered that the present HEADTAIL monitors seem to be good enough to diagnose e-cloud instabilities in the SPS. **G. Arduini** added that, instead of additional diagnostics, an improved analysis tool would be more useful for the SPS.

T. Camoresi asked a clarification about the plans to change the crossing angles and if this should be down during the physics fills. **T. Pieloni** explained that the choice of the crossing angles depends on the other non-linearities. Based on this knowledge the optimum angle has to be fixed before operation while no change is applied during the fills.

F. Zimmermann asked if the doublets are expected to be stable without e-cloud and if it is possible to use the Schottky to monitor incoherent tune shifts. **K. Li** confirmed both.

S. Redaelli asked if impedance could be parasitically measured during standard fills or dedicated measurements are needed. **K. Li** explained that dedicated measurements are preferable.

V. KAIN: CHALLENGES FOR THE SPS AND SPS-TO-LHC TRANSFER FOR 2016

SPS operation with 144 25 ns spaced bunches did not show limitations with respect to the target values but a higher activation was measured in 2015. A 96% transmission could be achieved with $1.15{\cdot}10^{11}$ protons per bunch and an emittance of 2.5 μm. Losses occurred mainly at the beginning of the ramp (uncaptured beam) and just before extraction because of the deliberate bam scraping. A large spread in transmission and brightness was observed and a continuous tune of the machine was needed to maintain the required performance. An improvement in the Transfer Line (TL) stability was observed after reducing the MSE ripple but a component coming from an orbit drift in the SPS still persists.

For 2016 operation with 288 bunches an intensity of $1.2{\cdot}10^{11}$ protons per bunch in a 2.6 μm emittance can be envisaged. Operation will be more challenging and the continuous tuning will become even more important. Some limitations have to be taken into account during the setup of high intensity beams (energy deposition on the TPSG and MKP4 heating and outgassing). Moreover, the possibility of measuring the emittance at 450 GeV will be more and more limited with 288 bunches. Improvements are required to reduce the re-captured beam which causes high losses at the TDI in the LHC.

Dedicated SPS cycles for LHC filling are technically possible but will impact North Area experiments and the MD program. Only a gain in the filling time and not on the beam setup has to be expected.

Discussion:

N. Holtkamp asked if the achievable brightness and intensity with 288 bunches are exactly those required by the LHC for 2016 operation. **V. main** confirmed.

N. Holtkamp asked if operation in 2015 relied on WS measurements and what the strategy is to get around the fact that they cannot be used with 288 bunches. He also asked if BQM could be used instead for emittance measurements. **V. Kain** answered that WS measurements were regularly performed. BSRT and BGI are installed but not yet operational; moreover the BSRT seats in a non ideal location with high dispersion. The strategy for 2016 is to measure the emittance at 26 GeV and then directly in the LHC. The BQM measures only in the longitudinal plane, so no transverse emittance measurement is possible.

T. Lefevre asked if radioactivity in the tunnel got worse with respect to Run 1 due to the high measured losses. **V. Kain** confirmed that loss spikes higher than in Run 1 were observed in the arcs. Some new activated areas appeared but the dose is still much lower than at the internal dump.

O. Katsunobu asked if TL jitters appeared only in the horizontal plane. **V. Kain** confirmed that the largest drift occurred in the horizontal plane and one source was the current ripple at the extraction septa (MSE). Other possible sources are being investigated.

F. RONCAROLO: BEAM DIAGNOSTICS - KEY CHALLENGES

Performance, reliability and availability of LHC diagnostics were in general improved after LS1 consolidation works. Several systems were upgraded and new tools became available (DOROS, Instability Monitors, etc.). Remaining issues and weak points were identified and solutions are being investigated and put in place. Needed upgrades for the rest of Run 2 concern controls, integration in the interlock and feedback systems, electronics and new functionalities. Studies are ongoing to improve the data filtering for bunch-by-bunch and turn-by-turn measurements in order to optimise the data storage. R&D studies continue and new diagnostics (i.e. coronograph) is being explored in view of the HL-LHC era.

Discussion:

N. Holtkamp stressed that the software upgrade of the BLM FPGA, to catch and properly react to UFO induced losses, is a key element and asked if there is any possibility to have the system ready before LS2. **B. Dehning** answered that with the available manpower the design of the new electronics cards will be probably completed by mid next year. Tests and production will follow so installation can be envisaged only during LS2. **R. Schmidt** commented that the BLMs are the most critical system for machine protection and proved to be very reliable up to now. Any change in the FPGA has to be carefully evaluated and the real benefit quantified with respect to the risk. **B. Auchmann** remarked that the expected number of UFO induced quenches in Run 2 is reasonably low; there is no need to upgrade the system before LS2.

O. Brüning asked why the Lumi monitor in IR8 have to be replaced with Cherenkov monitors since they were supposed to be radiation hard. **F. Roncarolo** answered that operation proved that this was not the case since they died.

Y. Papaphilippou asked on which beam the halo monitor prototype will be installed. **F. Roncarolo** answered that it will be installed on Beam 2.