SUMMARY OF SESSION 6: HL-LHC

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Abstract

This paper summarizes the HL-LHC session of the 2014 Chamonix performance workshop that took place from 22^{nd} until 25^{th} September 2014 in Hotel Les Aiglons in Chamonix.

HL-LHC SESSION LAYOUT

The HL-LHC session featured 6 dedicated individual presentations:

- A summary of the HL-LHC parameter and layout baseline by Paolo Fessia;
- A presentation of the HL-LHC Roadmap for magnet development by Ezio Todesco;
- A presentation of the HL-LHC Roadmap for SC RF development by Rama Calaga;
- A discussion of alternative scenarios for the HL-LHC parameters and layout by Rogelio Tomas;
- An outline of the Roadmap for the HL-LHC Collimations and Machine Protection (MP) by Stefano Redaelli;
- A summary of Down-Selection criteria and requirements for Machine Development studies in the SPS and LHC prior to LS3 by Gianluigi Arduini.

HL-LHC PARAMETER AND LAYOUT BASLINE

Paolo Fessia started the presentation with a summary of the HL-LHC baseline parameters for operation with 25ns bunch spacing and compared the parameters to the nominal LHC, the BCMS parameters for operation with 25ns bunch spacing and a 50ns backup option for the HL-LHC and highlighted that all HL-LHC equipment should not only be designed for the nominal HL-LHC parameters, but rather for the most demanding parameters that arise from the various options that are currently studied in addition to the HL-LHC baseline (e.g. higher than nominal beam brightness due to bunch schemes with lower emittances). This part of the presentation triggered the need for a clear identification of what maximum beam brightness the HL-LHC equipment should be designed for. The discussions concluded that a first iteration should identify the maximum acceptable parameters for the current equipment designs. These discussions should be carried out in collaboration with the LIU team.

Concerning the HL-LHC harder modifications, Paolo divided the activities and required changes for the HL-LHC upgrade into three separate categories: changes for equipment that will act on the beams, other equipment in the LHC tunnel and equipment changes on the surface. He presented the main required modifications for the HL-LHC baseline and for some of the potential variations. The layout discussions for the HL-LHC have mainly been focused on the IR1 and IR5 insertions and Paolo presented detailed studies for both of these insertions including discussions on the options for underground and on-surface installations of the power generators for the new Crab Cavities and variations coming from flat beam versus round beam operation (e.g. implications on the TAXN design).

The presentation triggered the following main questions and comments:

- Questions about the baseline scenario and budget lead to the following statements
  - The crab cavities are in the baseline, including the engineering work. The crab kissing is not in the baseline.
  - Everything of the baseline is included in the budget, except for the civil engineering work in the underground areas.
- Considering the issue of the event pile-up limitations in the detectors and the resulting limitation on the peak luminosity, it is important to quantify the required availability for all systems to reach the HL-LHC performance goals.
- Concerning the question of stochastic cooling it was stated that this is not part of the HL-LHC baseline.
- Concerning the request for new, large aperture Q5 magnets in the experimental insertions, it was observed that this configuration is not compatible with large β^* configurations ($\beta^* > 40m - 50m$).
- In light of the current number of quenches expected in the machine, is it realistic to plan for an operation at 'ultimate' performance for the HL-LHC machine? Yes, this is important for the system design point of view and should be considered like an operational margin for the HL-LHC equipment.

HL-LHC MAGNET ROADMAP

Ezio Todesco summarized the magnet design evolution for the HL-LHC triplet magnets within the USLARP program and presented the new triplet layout with the 150mm coil diameter Nb_3Sn magnets. The layout features two

magnet lengths: 6.8m and 8.0m. The magnets will operate at a gradient of 140 T/m. The 150mm diameter magnets use an Al shell with bladders and keys and two strands (PIT and RRP) with identical specifications. The new triplet requires the production of 16 magnets plus 4 spares. Half of the units will be produced as an external contribution from the US and the other half by CERN. The production planning foresees prototype production from 2016 to 2018 and series production from 2018 to 2021. Ezio also presented the status and plans for the triplet corrector magnets (orbit corrector and nonlinear field corrector magnets), for the new, superconducting D1 and D2 separation and recombination dipole magnets, for the new large aperture standalone quadruple magnets and for the 11T dipole magnets for the dispersion suppressor collimator installation.

The presentation triggered the following main questions and comments:

- Concerning the risk assessment and mitigation it was commented that one big risk is that the 'series production' comprises only small numbers of magnets which might make it difficult to find companies that are willing to produce them.

- Concerning the absence of quench heaters in some of the new insertion magnets it was commented that this implies an energy extraction system which may be more expensive. It was asked if this is really the best solutions? Ezio replied that different protection options are still being considered and investigated. This is still work in progress.

HL-LHC RF ROADMAP

Rama Calaga gave an overview of the past experience with superconducting (SC) RF development at CERN and presented the HL-LHC RF baseline, featuring 32 new superconducting Crab Cavities (SC CC), making this new system the largest RF installation of the HL-LHC. The SC CC development featured the development of three different conceptual designs that have been developed to prototype construction. Following the successful tests of all prototypes the options have been down selected to only two options in order to assure an in time production of fully cryostated prototypes for installation in the SPS during the technical stop 2016/2017. The operation in the SPS with beam is a vital validation procedure that needs to be completed before one can launch the series production of the SC CC for the HL-LHC upgrade. Rama presented the new cryostat design for the SC CC and presented the experimental setup in the SPS machine. The rather large infrastructure requirements in the LHC tunnel impose rather challenging civil engineering problems that are still being evaluated.

Additional options for the HL-LHC upgrade include either a second higher (e.g. 800MHz) or lower-harmonic (e.g. 200MHz) RF system.

The presentation triggered the following main questions and comments:

- The question about spare cavity modules was raised. Rama replied there is currently no valid spare cavity module for the nominal 400MHz system. However, the removed faulty 400MHz module could be refurbished and prepared as a new spare once the commissioning of the newly installed 400MHz module has been successfully finished.

- Erk Jensen comments that the SC RF development and R&D efforts are not only beneficial for the HL-LHC but serve several potential future developments. Only the SC CC development if entirely funded within the HL-LHC project.

ALTERNATIVE SCENARIOS FOR THE HL-LHC

Rogelio Tomas presented several areas and scenarios where alternative configurations could offer additional performance reach or mitigation of performance limitations:

- Longitudinal coupled bunch instabilities could be mitigated by a second higher or lower RF system.

- Limitations due to the electron cloud effect could be mitigated by special filling schemes (e.g. 8 bunches followed by 4 empty bunches, the 8b+4e filling scheme).

- In case crab cavities are not operational, the performance could be boosted by the operation with flat beams at the Interaction Point (IP), the use of Beam-Beam Long Range Compensators (BBLRC), and a lower-harmonic 200MHz RF system.

- β^* levelling for peak pileup, Crab kissing and flat longitudinal beam profiles via 200MHz, 800MHz or RF phase modulation could improve the HL-LHC performance in case the peak longitudinal event pileup density in the detectors limits the leveled luminosity.

All the above HL-LHC options could, off curse, also be used for boosting the HL-LHC beyond the nominal performance target of $250 fb^{-1}$ per year with an event pileup density limit of 1.2 events per mm per bunch crossing.

The presentation triggered the following main questions and comments:

- The presentation seems to imply that the HL-LHC can accept much longer bunches as compared to the LHC baseline. It was asked what changed with respect to the LHC baseline? Rogelio replied that:
  - The experiments are willing to take longer bunches, but this could create problems. Work is in progress. Nevertheless, longer bunches will not increase the luminous region assuming to be limited by the crab cavity RF curvature.

- In the LHC design phase, 200 MHz superconducting cavities were not an option.

- Concerning the operation with Crab Cavities it was asked if we are sure that a 200 MHz RF system does not increase the non-linearities of the crab-cavities and does not degrade the machine performance? Rogelio replied that current and previous studies do not show any problems due to the Crab Cavity operation with longer bunches.

- It was observed that the performance indications rely on rather complex computations and it was asked how confident we are about the projections? Rogelio replied that the main uncertainty is related to the wire compensation of the long range beam-beam effects. For the wire compensation there will be a task focusing on simulations and experiments. Furthermore, the HL-LHC project plans for an experimental validation of this option in the LHC before LS3 using new prototype wire compensators for MD studies. For the performance projections due to the use of new cavities and magnets, we are rather confident.

- Are there any issue of beam instability related to the 200 MHz RF scenario? Rogelio replies this is difficult to predict right now as the LHC RunI operation was already affected by beam instabilities. Answering this requires more machine studies in the LHC.

HL-LHC COLLIMATION AND MACHINE PROTECTION ROADMAP

Stefano Redaelli showed a summary of the collimation performance during LHC RunII and summarized the planed collimation modifications for the LHC consolidation and the HL-LHC upgrade. The modifications address five main areas:

- Impedance issues and collimator robustness.

- Cleaning efficiency and setup time.

- Loss spikes and drops in the beam lifetime and beam halo control.

- Collimation next to the experiments.

Studies options include new collimator materials and coatings, rotatable collimators, the integration of Beam Position Monitors (BPMs) in the collimator jaws, installation of collimators inside the cold regions of the dispersion suppressors, hollow electron lenses for beam halo control, crystal collimators and dedicated collimators (e.g. next to the TAXN) next to the experiments.

Stefano Redaelli also reported on the upgrade plans for WP8 (machine detector interface) and WP14 (injection and dump protection), recalling that, as part of HL, it is planned to change the injection protection devices in IR2/8 (mainly, the TDI's that will be replaced in LS2) and the present TAN that will be replaced by a TAXN at the same functional position.

There was no time for questions after the presentation.

DOWN SELECTION CRITERIA AND REQUIRED MD STUDIES PRIOR TO LS3

Gianluigi Arduini summarized the main points that still require a validation via Machine Development (MD) studies. The main studies are related to:

- Chromatic properties of an optics with very low β^* and identification of the maximum acceptable chromatic aberrations during operation.

- Efficiency of the electron cloud mitigation via beam scrubbing (this will be addressed during the startup of the LHC RunII in 2015).

- Operation with β^* levelling.

- Operation with large beam-beam tune spread (what is the beam-beam limit in the LHC with long-range beam-beam encounters?).

- Possibility of operating the LHC with a combined collide and squeeze process.

- Determination of the dynamic aperture in the machine with flat beam configuration.

- Measurement and experimental demonstration of an active manipulation (depletion) of the beam halo population.

- Detailed impedance measurement at 6.5TeV and estimation of the maximum acce[table beam intensities.

- Experimental demonstration of long-range beam-beam compensation using a wire.

- Operation with flat longitudinal beam profiles (e.g. generated via RF phase modulation).

- Efficiency of Crystal collimators during LHC operation.

Gianluigi Arduini underlined that most of the above studies could already be relevant for the LHC RunII and RunIII. There is therefore a strong case to aim for a validation of most of the above points already during the LHC RunII period.

The presentation triggered the following main questions and comments:

- It was asked if there are any plans to test the Crab Cavities the LHC following the tests in the SPS? Gianluigi Arduini replied that there are at the moment no tests foreseen in the LHC.

- What is the possibility of levelling the luminosity with Crab Cavities? Gianluigi Arduini replies that this method increases the longitudinal pile-up density and is therefore not the preferred solution for luminosity levelling.

MAIN POINTS FROM THE GENERAL QUESTIONS AND ANSWER SESSIONS

The general Q&A period at the end of session raised the following main points:

- It is important to quantify the required availability and efficiency for each component and the HL-LHC machine as a whole for reaching the HL-LHC performance goals (the HL-LHC must be a high reliability machine!).
- Stochastic Cooling (for Ion operation) is not in the HL-LHC Baseline.
- Issue of small series production and risk mitigation (multiple producers).
- Need for clarification of spare RF components for new HL-LHC equipment.
- Interplay of 200MHz LH RF system and 400MHz Crab-Cavities (non-linearity).
- Are there plans for testing Crab Cavities in the LHC after the SPS tests and before HL-LHC? This has been looked at at in IP4 but the implementation would have an impact on LHC schedule!
- Dynamic β^* levelling and NOT Crab cavities adjustment is the preferred luminosity levelling method (pending MD validation).