M.Zerlauth

7th Meeting of the HL-LHC Parameter and Layout Committee

Participants: Gianluigi Arduini, Vincent Baglin, Krzysztof Brodzinski, Roderik Bruce, Oliver Bruning (chair), Helmut Burkhardt, Samy Chemli, Cristina Collazos Gonzales, Stephane Fartoukh, Paolo Fessia, Brennan Goddard, Rhodri Jones, John Jowett, Helene Mainaud, Riccardo de Maria (remote), Herve Prin, Stefano Redaelli, Ralph Steinhagen, Jorg Wenninger, Daniel Wollmann, Markus Zerlauth (scientific secretary)

Excused: Francesco Cerutti, Roberto Kersevan, Rob van Weelderen

The slides of all presentations can be found on the website and Indico pages of the PLC:

HL-LHC PLC homepage: https://espace.cern.ch/HiLumi/PLC/default.aspx

Indico link: https://indico.cern.ch/event/281880/

O.Bruning opened the meeting by approving the minutes of the previous meeting and reviewing the agreed actions:

- The action on n1 clarification & alignment and budget errors is on today's agenda.
- A first discussion on IR4 space integration is equally on today's agenda.
- It was agreed to ask the leaders of WP3-6 to nominate an alternate for the PLC member list in order to guarantee the presence of each WP for the PLC meetings.
- Concerning the list of needed renovations/upgrades which cannot be done during LS1 but need to be postponed to a later shutdown a first iteration will be done together with I. Bejar Alonso.
- Simulations studying the radiation impact on crab-cavities just stared before the Daresburry and should be discussed in a future meeting.

G.Arduini commented that he is – as an outcome from the RLIUP workshop - working on an update of the Hi-Lumi parameters for the injected beam. This will be put on the agenda of the next meeting.

Action: R.Garoby requested a definition of the bunch length to be added to the HL-LHC glossary.

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Progress with HL-LHC optics – (R.de Maria - slides)

The version HLLHCV1.0 was presented as the present baseline model for layout and optics, which are frozen for this version and under validation for energy deposition, specification of magnetic elements, mechanical integration, collimation performance, powering needs and heat loads.

A proposal to reduce the length of D1 from 6.7m to 6.25m has been recommended by WP2 and will be proposed by WP3 for approval in the next PLC meeting.

The new beam screen layout in the inner triplet has now been taken into account - assuming a SEY of 1.1 this would lead to some 200W of heat deposition by the multipacting of electrons (on top of the 600W from collision debris).

An efficient protection against collision debris in IR1 and IR5 is still undergoing detailed studies and includes a redesign of the TAN apertures as well additional masks on both beams and TCLs on the outgoing beams in front of D2, Q4, Q5 and Q6.

The field quality to be expected for the D2 magnet has significantly improved thanks to QP3, but further improvements of the b2 and b3 components are still necessary. It would be of interest to further shorten D2 (=higher field) while remaining compatible with the required field quality - length-field optimisations are currently on-going.

Discussions for Q5 started before the Daresbury meeting and continued in a recent meeting organised by M.Giovanozzi. Two options are being considered, an MQY at 200T/m if operated at 1.9K, or alternatively having two or longer MQYY magnets (which is anyway foreseen for Q4). Currently both options are being studied in parallel.

For the Q5 in IR6 the most favourable solution is adding a second MQY@4.5K to Q5 to double the present strength. Only studied in previous optics version SLHCV3.0.

A number of optimization studies are currently being pursued:

- Tracking tools for HL-LHCv1.0 to be finalized è high priority
- β*>6m optics solutions (injection and VDM for Q5 limits)
- Orbit corrector strength and length to comply with hardware and functional requirements.
- Possible reduction of D1-D2 distance for crab voltage optimization. -> Would imply a stronger D1 and D2 where we are currently limited.

- Phase advance optimization to avoid additional MS in Q10.
- Optics transitions during leveling (interplay IR8/IR1 and IR5 optics).
- Impact of power converter ripple.
- Specification on longitudinal alignment errors. -> Is needed to make sure that we specify the triplet with the needed degree of accuracy.

Discussion:

O.Bruning asked whether HLLHCV1.0 includes already all dispersion suppressor collimators in all IRs? R.de Maria replied that this still as to be done.

S.Redaelli commented that R.Bruce in collaboration with other colleagues has prepared a script to replace any dipole with a DS collimator (with a primary focus on IR2 for ions and IR7 for protons). The collimation team worked so far in the assumption that there is no constrain to the number of 11T+TCLD units that can be added without affecting the DA. This relies on the previous statement by B.Holzer that there is no problem with the dynamic aperture. A meeting is planned for WP11 where B.Holzer will present the latest results. R.de Maria mentions that simulations should be repeated taking into account the full machine.

S.Fartoukh comments that all the DA studies have been done only with injection optics and still need to be looked at with the ATS optic.

O.Bruning requested that we should agree on what contents are made available in a given layout version to make sure it is the most useful to everyone.

P.Fessia added that currently we only have an optics defined, but not yet the according layout drawings (including all surrounding equipment). -> This can only be done efficiently once the optics has been frozen.

G.Arduini concluded that it seems reasonable to have a first stable version of the optics by Spring 2014 to allow for a first layout integration with this version V2.0.

P.Fessia added that the region between D2 and Q4 is currently already quite compact – in order to keep everything reasonably close to each other we have to envisage a continuous cryostat with a common cross-section. This will have an impact on maintenance of magnets vs. crab-cavities.

Requirements for the power converter ripple of the inner triplet converters need to be discussed according to O.Bruning on the same timescale as the new optics.

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MQW-MQB upgrades – (P.Fessia - slides)

The two ECRs (LHC-MW-EC-0001 and LHC-MW-EC-0002) have been modified according to comments and updated with new computations. For collective dose optimisation RP has requested to perform the intervention in the tunnel (VSC interconnection time). VSC has performed the necessary modifications of the backing strip wiring on all MQW. The activity on MBW needs to wait for shielding for personnel, which are currently under design (expected to complete by March). The component fabrication is ongoing as expected (should receive first components end of this week).

The current layout features a series connection of the 4 MBW magnets as well as a series connection of 5xMQWA and 1xMWQB on either side of the IP. The trim quadrupole MQWB is operated at only very low currents in the HL-LHC optics, which will be made use of for the proposed consolidation.

The dose evaluation has been performed as follows: Starting point is the FLuka model predication so ~ $1.15*10^{16}$ p lost per interaction point IR3 and IR7) for 7TeV operation. This is scaled to the dosimeter readings (which were installed during TS2 on critical locations), the HL-LHC integrated luminosity and the increased slope dose/luminosity. The final values are then retrieved by normalizing to the total losses/IR and scaling to the Left and Right side using the RP survey.

The estimated doses as a function of the integrated luminosity for all MBW and MQWA/B magnets in IR3 and IR7 were presented, highlighting in yellow magnets which may suffer from aging of the resin, in orange magnets where the resin could fail due to the fibre filling, and in red magnets were the resin will not work anymore. In summary the situation looks OK for IR3 to go up to LS3 without major modifications (unless losses are transferred from IR7 to IR3 after LS1), however in IR7 the situation is more critical.

As a first protective action, the shielding will be increased by adding additional Tungsten or Inermet IT180 inserts. Despite the limited space a reduction factor of 3-10 (first to last magnet) can be achieved, also providing additional downstream shielding. Studies are ongoing to assure that the inserts do not perturb the field quality; they have been tested to be non-magnetic and proven to have a negligible effect on the multipole components.

The second mitigation is an optics change, removing the first MWQA (replacing it by and absorber), and reconverting MWQB into an MWQA to recover for the strength loss.

For reasons of ALARA and effectiveness the proposed shielding campaign has start already in LS1. Very high dose dosimeters shall be installed systematically in point 3 and 7 to better benchmark computations and verify the symmetry effect -> Tbd done during LS1 still. A campaign of irradiation of resins shall be performed with the real used resins and the relevant fillers in order to have realistic values when magnets will reach damage level. For HL-LHC 4 MBW shall be reassembled with saddle type heads. This will solve the issue without needing special development. P.Fessia suggests launching the program to build a NC magnet with extremely high radiation resistance (>300 MGy). It is and it will be more and more needed and today we do not have a valid design at hand.

Discussion:

O.Bruning requested how many spare MWQ magnets are available. P.Fessia replied (in a later mail) that there are 2 fully conform MQW magnets + 2 more with con-conformities (out of which at least 1 is believed to be recoverable). The change in IR7 would potentially yield 2 additional spare MQW magnets. For the MBW< 4 fully conform spares are available.

D.Tommasini has already started working on a program for the design and production of magnets with a high radiation tolerance. This is not yet a formally approved project but should be manned soon with a Fellow in March 2014 to have a closer look into high radiation solutions + HL-LHC integration.

BBC – (R.Steinhagen - slides)

The motivation and working principle of the Beam Beam Wire compensator (BBC) were recalled as one of the mitigation options to reduce the effect of long-range interactions. As additional side effects the system would allow for more relaxed collimator settings and an improved physics-debris loss pattern at the TAN.

First experiments at the SPS (wire-wire) and RHIC (beam-wire) yielded encouraging results; a full proof of principle will however require a truly long-range beam-beam limited machine, hence the installation of a BBC prototype into the LHC is required ahead of HL-LHC.

The initial proposal was to place the BCC at the ideal distance of around 105m from the IP where the beta functions are symmetric.

As the SPS and RHIC designs are incompatible (too risky) for installation in the LHC, a two stage plan is proposed, starting with a proof of concept prior to LS2 to benchmark simulations for a potential use in the LHC, before undertaking the final design. For the initial benchmarking, the wire-in-TCTP-jaw design seems the most

feasible (but has drawbacks due to the non-ideal positioning in terms of phase advance and wire-to-beam distance).

S.Redaelli commented that concerns about impedance/frequency have been expressed for the presented design that should be verified with N.Mounet.

For the final design several options are under study for HL-LHC, all of which are challenging w.r.t. design and integration:

- Wire-in-jaw design → scaling TCTP experiment and integrating it between D1-TAN -> this is not impossible but appears very difficult to realize as one would ideally have to target a 6-7σ distance, making it basically a primary collimator next to the experiments.
- For reference only: Simulate the 'wire' effect through external fields -> would also have to be ‘movable’ in case the orbit moves or when the Xing angle changes.
- Simulate 'wire' field through e-beam running in parallel to the p-beam, similar to existing e-collers or (hollow) e-lenses, but with an offset e-beam. Would also require large solenoid fields to stiffen the e-beam rigidity

S.Fartoukh clarified that for the latest optics the need is around 370Am/beam/IP side.

In conclusion, a nominal BBC (between D1-TAN) may allow for a crossing angle reduction by ~2σ. A BBC proof-of-concept is to be deployed in the LHC to confirm predictions prior to LS2 – however: a test would require

- ε = 3.5 - 3.75 um vs. nominal ε ≈ 2.0 um
- larger phase-advance between long-range encounter and TCTPs
- limited min. wire-in-jaw-to-beam distance

Efforts are being pursued to deploy 2 wire-in-jaw based BBC before LS2 with the aim to confirm simulation scaling and gain experience for the nominal design. The necessary infrastructure will be prepared during LS1, whereas the BBC-TCTP will be installed during the first long stop after LS1. This will be followed by an assessment of the BBC prototype prior to LS2, with two possible outcomes

- best case: scale wire-in-TCTP design for HL-LHC
- back-up option: integrate LR-BBC at nominal location (D1-TAN)

Need to start full-system design/integration for HL-LHC soon, especially in case an e-beam is considered as such a device may require a length reservation of up to 15m instead of the 1.5m wire-based design.

Discussion:

S.Redaelli commented that in addition a layout incompatibility needs to be solved as there is no vertical slot for a collimator on the right of IR1 (could only re-use one the existing TCTH slots).

R.Steinhagen confirmed that a full compensation requires one unit on either side of IR1 and IR5.

O.Bruning stressed that practical steps need to be defined, aiming to agree on a proof of principle before LS2.

R.Jones replied that the only option looking still feasible is the in-collimator design; the next step is to decide to eventually insert two devices in one IP (in case H/V is not possible). It might be sufficient to demonstrate the effect in one plane (would require new simulations and a suboptimal way of performing the MD).He added that a type test is less important than the final solution which bears even more issues to be resolved (e.g. one cannot accept an element as close as 6σ to the beam in the IR region).

IR4 available space and incoming requests – (P.Fessia - slides)

As Layout and optics are only loosely coupled, P.Fessia requested to agree on a procedure to define and release an official layout, and as such freeze a specific optics. The ideal target should be February 2014 for a first layout release in April.

In the following the IR4 space status, existing reservations and (known) requests where summarized. The status of space reservation is derived from a cross-check of 3 different input sources, the CDD layout drawings, the layout database for installed equipment and the two beam layout drawings from the layout database. Space reservations are not dynamically linked to these 3 sources, therefore gaps in space and time may occur.

Space reservation in IR4 should be reviewed critically soon as possible because a few of them have to be resized (BGV), some need to be challenged and a few are already obsolete (ACN). Most importantly, the process for space reservation for the HL-LHC era should be reviewed, ideally starting with a functional spec, followed by a formal

approval in EDMS and a proper tool for tracking and linking of the requests with the implementation in the machine.

Layout drawings for both insertion regions of IR4 have been presented, indicating old space reservations and new/obsolete requests. Known space requests include the BGV (both sides both beams between the Q6 and Q7), the BSRT (already installed but potentially requiring modifications), additional BPMs (right side both beams between Q5 and Q6), hollow e-lenses (lefts side for B1 and right side for B2near the D3), 200 and 800MHz RF systems, stochastic cooling for ions, ISC pickups and the High Bandwidth Transverse Damper System.

A first attempt of integrating all these requests into a tentative space allocation has been shown, revealing a number of incompatibilities foe e.g. concerning the 800MHz and the hollow e-lenses.

Action: Complete the equipment survey for IP4 and update the space reservations accordingly. Space reservations should be re-iterated following an adequate procedure to be prepared for the upcoming changed within the HL-LHC era.

Discussion:

J.Jowett commented that for the stochastic cooling the 3rd module would better be located apart from the first 2 modules.

S.Fartoukh added that all proposed positions need to be cross-checked with the latest optics (injection optics…).

K. Brodzinski asked whether the new cavities would operate at 1.9 or 4.5K?! P.Fessia answered that this is not known yet, but that according to his knowledge the RF colleagues were also considering operating at 1.9K.

S.Chemli clarified that the ECR concerning the BSRT alignment is describing the replacement of an already existing alignment system.

Offline-discussion after meeting:

Several e-mail on the above subject where exchanged in the days after the meeting, resulting in an updated version of the slides by P.Fessia. In addition, R.Jones reviewed the complete situation of requests for BI equipment, summarised in the attached memento.

The next steps proposed by P.Fessia will be as follows:

- Release after Christmas the updated version of the drawings LHCLSX__0007 and 0008 to be used as the future reference for the situation as of the end of LS1 (in the slides the 2011 drawings were used).
- In these (new) drawings we will change the reserved areas in the following order: order
    - Modification of reservations already made in the past. This will use the information provided by all equipment teams, which will be summarized in an ECR addressing all the reserved space on either side of IP4. This will also take into account modifications of the RF area (ACN).
    - Create a new reservation for new HL-LHC equipment with another series of ECRs and functional specifications, a proposal of which will be presented in the next PLC meeting.

N1 clarification and alignment and error budget – (R.Bruce - slides)

R.Bruce started his presentation by reviewing the traditional method for aperture calculation using the n1 model, as the available aperture is the limiting factor for the β* reach and hence constrains the freedom of optics designs. Insufficient aperture margins bear the risk of generating beam dumps, quenches or in the worst case damage to accelerator components.

For the LHC design, the n1 model was used to calculate apertures and qualify them for cleaning, whereby the local n1 is the largest opening of the primary collimator, in units of betatron σ, for which the local aperture is still protected from the secondary halo (assuming a number of design tolerances at top energy which have been detailed in the LHC design report and which are added linearly, representing the worst case scenario for protection). The aperture is considered qualified if n1>7.

A rather conservative approach of β*=3.5m was agreed for the start of run1 in 2010. Following local aperture measurements with beam in the IR1/5 triplets and new models to calculate the settings of the collimation hierarchy, the available aperture allowed for β*=1.5m in 2011, followed by an additional reduction to β*=1m after aperture measurements in IR1/5 with squeezed optics.

For 2012 the collimators were set to ‘tight settings’, which in addition to further improvements of the collimator hierarchy model allowed operation at β*=0.6m.

The progressive evolution of performance is mainly based on aperture measurements in physics (as a crucial part!) and OP experience coupled with better

models of collimation hierarchy. The 2012 conditions correspond to a N1 of around 5, hence already significantly failing the conservative n1 criteria.

One reason for this being that the n1 method assumes a linear addition of all errors (worst case), which is a highly unlikely scenario when considering single limiting elements. In addition different collimator settings, lower orbit variations (typically <0.5mm instead of design tolerance of 3mm), off-momentum component and β beat (~ factor of 3 better optics correction at end of Run 1 than foreseen) allowed for this significant gain in aperture compared to the design assumption.

Due to uncertainties when looking towards HL-LHC the current proposal is to assume for now 2mm of orbit uncertainty for HL, 20% of β beat and an off-momentum component of 2E-4 (reduced from 8.6E-4), a relative parasitic dispersion of 0.1 (instead of 0.27) and an emittance of 3.5µm (instead of 3.75µm). In addition the method to calculate apertures should include sufficient margins but not push all parameters to the limit. The proposal involves also to use as calculation output the actual aperture in betatron sigma instead of n1, which can be misleading as it includes assumptions on the collimator settings and halo shape.

O.Bruning commented that one will have to leave sufficient margin for the optics corrections as these cannot be quantified during e.g. ramp/squeeze.

R.Steinhagen enquired whether the RF phase modulation to optimize overall beam loading and leading to 10-15% difference between arrival time of bunches will have an impact on off-momentum contribution?

R.Bruce gave an overview of the different aperture measurements which have been performed using different techniques (kicker method, 1/3 resonance, bump method and ADT method) during Run 1. These measurements are in the following compared with different calculation methods (representing perfect aperture, Run 1 scenario, pessimistic Run 1, current HL proposal and the ‘standard’ n1).

The results show an aperture which is very close to the ideal value in IR1 and IR5 (aperture measurements performed only in one direction though!), only the 2012 measurement is showing a small – yet unexplained – degradation which might be due to using a different technique or a real physical effect/movement. There is also one unexplained measurement point in IR2 which breaks the trend of apertures close to the ideal value.

In conclusion the new proposed n1 tolerances give more realistic but yet still conservative aperture values, and still show conservative results when applied to the 2012 machine. Using another more relaxed set of tolerances allows for an accurate reproduction of 2012 measurements.

When applying the same parameter set to the different HL optics versions (round 15cm, flat 7.5/30cm, round 10 cm, flat 5/20 cm, flat 20/5 cm) it becomes clear that work on all fronts is needed to achieve an acceptable aperture. This includes exploiting the potential of BPM buttons, smaller β beat and 1mm closed orbit tolerance. In all cases the mechanical tolerances need to stay excellent. Experience of Run 2 will certainly be useful to further study the correctability of ATS. Flat and super-flat optics require considerable additional efforts, with the 15cm currently being below what can be currently protected.

It seems not unrealistic to reach an acceptable aperture, but an effort is needed to ensure the smallest possible errors and margins. Detailed aperture measurements will remain the crucial part of the performance validation and must be given according priority.

Discussion:

P.Fessia commented that the cold bore and beam screen should not be confused. For the latter you do not apply ISO tolerances but the overall impact is mostly defined by tolerances of the cold bore. Furthermore it has to be taken into account that the beam screen is very heavy.

S.Fartoukh commented that 118mm of physical aperture should remain the target (only taking into account thickness of layers and small tolerances).

AOB (all)

H. Mainaud commented that the action for defining space reservations for the survey around the crab cavities is still ongoing. She will report back in an upcoming meeting.

Next meeting on 18th of February 2014 with the following agenda:

- D1 length reduction/strength increase (+correctors in LSS magnets) – E.Todesco
- Update of Hi-Lumi parameters following RLIUP – G.Arduini
- New template for conceptual specifications – I.Bejar Alonso
- Procedure for space reservations for HL-LHC – P.Fessia