# 15th Meeting of the HL-LHC Parameter and Lay-out Committee

**Participants:** G.Arduini, C.Adorisio, V.Baglin, M.Bajko, A.Ballarino, I.Bejar Alonso, M.Bernardini, O.Brüning (Chair), J.P.Burnet, R.Calaga, J.P.Corso, R.deMaria, B.Di Girolamo, P.Feracin, P.Fessia, S.Gilardoni, R.Jones, J.Jowett, C. Magnier, M.Meddahi, V.Mertens, Y.Papaphilippou, M.Pojer, H.Prin, S.Redaelli, F. Rodriguez Mateos, L.Rossi, G. Rumolo, F.Savary, H.Schmickler, J.P.Tock, E.Todesco, S.Weisz, R. Van Welderen, D.Wollmann.

**Excused:** L.Bottura, S.Fartoukh, M.Giovannozzi, G.Iadarola, G.De Rijk.

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

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

Indico link: https://indico.cern.ch/event/396467/

O.Brüning opened the meeting by mentioning that the minutes of the 14th PLC are not ready and they will be approved in the next meeting. He proceeded with the introduction of the agenda of the meeting.

## Heavy Ions during HL-LHC, J. Jowett – slides

J.Jowett first recalled the overall performance of the ion run of 2011, where the peak luminosity reached $0.5 \times 10^{27}$. This is half of the baseline peak luminosity but because this was achieved at half the energy, it would have corresponded to actually twice the peak luminosity at the nominal energy. The integrated luminosity was around 150 $\mu b^{-1}$ (6-7 $pb^{-1}$ nucleon-nucleon luminosity) during 2011 for ALICE, CMS and ATLAS. L.Rossi asked why at the start of the 2013 p-Pb run, ATLAS and CMS had more luminosity then ALICE. J.Jowett answered that this corresponded to the initial request of ALICE for minimum-bias data-taking but was compensated later in two long “catch-up” fills where luminosity was delivered only to ALICE. In the HL-LHC era, the letter of intent of ALICE assumes a peak luminosity of $6 \times 10^{27}$, and an average luminosity of $2.4 \times 10^{27}$. It assumes an integrated luminosity of 10 $nb^{-1}$ for Pb-Pb at the top energy. It also assumes one p-Pb run with 50 $nb^{-1}$, a special Pb-Pb run with lower magnetic field and a reference pp run (1 month of ion run/year). In the present timeline, the pp reference run is included during 2022. B.DiGirolamo commented that this is not a good idea, as this is followed by LS3 and it will not leave enough time for cool-down to the experiments.

After mentioning the requirements by ATLAS and CMS for ions, J.Jowett explained how the injected beam parameters in LHC were specified for LIU, in order to fulfil ALICE requests in the HL-LHC era. This is based in an ideal scenario of equal bunches, with initial bunch intensity (in stable beams) of $1.9 \times 10^{8}$ and initial normalized emittance of 1.5 μm, assuming three luminosity sharing scenarios between the three experiments: only ALICE with β*=0.5 m, ATLAS and CMS at 1 m and ALICE at 0.5 m and equal sharing, with all IPs at 0.5 m. The analysis started from simulations runs by T.Mertens using the CTE program.

There is a strong dependence of the evolution of the beam parameters on the luminosity sharing scenarios, because of the strong luminosity burn-off. In all scenarios, it is assumed that 1100 bunches are colliding in ALICE and 1160 in ATLAS/CMS. Filling schemes with fewer bunches would require larger single bunch intensities, but there are brightness limits in the injectors. Bunches may also suffer from faster IBS blow-up in the LHC, thereby 50 ns bunch spacing is essential, and it may be interesting to find a way to provide 25 ns from the injectors (although this has other implications in the LHC).

The integrated luminosity (assuming similar levelling in all experiments) is indeed higher for ALICE when the experiment runs alone, whereas the equal luminosity gives the maximum summed over all experiments (although ALICE would receive less in this scenario). O.Brüning mentions that ALICE would get twice as much integrated luminosity if it runs as a stand-alone experiment and this is indeed a message to pass to the directorate. J.Jowett finally stresses that stochastic cooling might give up to 90% of luminosity efficiency (rather than around 60%) for reaching ultimate luminosity in fills of similar length, as the emittance would be dramatically reduced by cooling.

Optimization of the fill length based on a turn-around time of around 3 h was carried out. Using this, together with standard assumptions on operational efficiency, the final yearly-integrated luminosity performance was projected for the three scenarios, ranging from 4 to 2.9 $nb^{-1}$ for ALICE and 0 to 3 $nb^{-1}$ for ATLAS/CMS. S.Gilardoni asked whether these projections imply that LIU will need three specification tables. O.Brüning explained that the reference scenario should be the one with the equal luminosity sharing for all experiments as it matches the ALICE request

J.Jowett continued by presenting the specification table at the LHC injection, of $2.1x10^8$ ions and 1.3μm mean transverse emittance, for 1170 bunches at 50 ns bunch spacing. S.Gilardoni asked if there are any parameters that could be relaxed, if possible. J.Jowett answered that the intensity could be reduced and this reduction should be compensated by a larger number of bunches of moderate intensity. He further stressed that these numbers were computed backwards from the requested integrated luminosity and that realistic estimates, given the known performance of the injectors and reasonable expectations for future improvements, were given at RLIUP and still stand. He proceeded by summarizing the luminosity projection for different bunch spacing scenarios as presented during the RLIUP. G.Arduini asked about the possibility to run with 25 ns, and J.Jowett answered that this is followed up by LIU.

J.Jowett spent the last part of his presentation on the DS collimator evolution and related studies. He explained that DS collimation for heavy-ions at LHC emerged at Chamonix 2003 but it was too late to modify the original design. DS collimators were later envisaged not only for ions but also for pp debris around ATLAS and CMS during HL-LHC and for cleaning losses in the collimation insertions. The original solution (moving magnets to make space) was dropped in favour of the scheme replacing the standard MB dipole magnet with two 11

T dipoles and a TCLD collimator, for all potential locations. Following the 2013 collimation review, it was decided to install 2 TCLD units for ALICE Pb-Pb in LS2, subject to confirmation after the 2015 Pb-Pb run and experience with the alternative bump mitigation techniques. Further installations can take place elsewhere in LS3, depending on experience at higher energy and luminosity, quench test results, etc. The bump mitigation is less effective in IR2 than in IR1/IR5. However, because of the form of the dispersion function in IR2, there is a possibility to combine (different) bumps with an alternative location for the TCLD in the connection cryostat (where there is no MB). This scheme allows a gain in peak luminosity limit for heavy-ion beams with two TCLDs in the connection cryostats of IR2 and no new 11 T dipole magnets. TCLDs and 11 T magnets may still be needed in IR7.

O.Brüning asked if the alternative solution could be also applied in IR1 and J. Jowett confirmed that it could not but that the previously tested mitigation with orbit bumps alone was expected to be quite effective. S.Redaelli said that although the bump was proved to be already efficient (2011 experiment), one should wait for the high-energy operation to fully assess it. O.Brüning agrees and adds that it would be important to test magnet quenches with ions, coupled with FLUKA simulations. J.Jowett stressed that collimation inefficiency is much worse in IR7 for ions, and two to four additional collimators may be needed. O.Brüning pointed out that in that case, the total intensity increase (25ns bunch spacing) to allow for lower bunch intensities might not be possible.

I.Efthymiopoulos pointed out that if there are ions after LS3, one should consider that the tungsten part of the TAN (ZDC) will be replaced for the HILUMI with Cu bars. This means that during subsequent ion runs the D2 is not protected. Then, any change will necessitate remote handling due to very high activation. O.Brüning said that it is indeed very important to have a clear indication from the management side for the ion run schedule in the HL-LHC era.

**Action: The PLC approves the equal luminosity-sharing scenario as the HL-LHC ion baseline. The corresponding parameter table in the PLC web site should be updated accordingly, including explicit references to the ion running periods.**

## Additional Q5 in IR6 (status of cold-mass and integration study), R.De Maria – slides, H.Prin – slides, C.Magnier – slides

R.deMaria reminded the reason for considering an additional Q5 in IR6, namely the need of flexibility to reduce β* by a factor of 4. The present Q5 of 160 T/m is limited to a reduction of a factor of 2. This is clearly shown in a sketch of the quadrupole strengths, as a function of β* reach. The 12th PLC approved the doubling of MQY strength, whereas the 1.9 K option was discarded, as technologically challenging and expensive. The IR6 optics needs to be fully validated for HL-LHC and LHC in case of a change in LS2. S.Redaelli asked if there are changes close to Q4 and the dump region. R.deMaria answered that there is indeed a small variation around these areas but the beam size at the dump and phase advances are within the specifications. S.Redaelli asked if this is also the case for the beam trajectory. R.deMaria answered that the trajectory is essentially the same, but the collimator should also be centred. S.Redaelli stressed that the dump experts should validate this. S.Weisz asked if the quadrupoles should be symmetric. R.deMaria answered positively as IR6 does not have enough knobs. He further explained that, stronger optics constraints are in the left side, however the quadrupole left region cannot alone absorb them completely and this results in varying optics condition in the dump region that needs to be fully validated. E.Todesco asked if a gradient of 200 T/m would be enough. R.deMaria answered that this gradient is just about right.

H.Prin reviewed the timeline for the additional Q5 magnet fabrication. Regarding cold masses everything is almost finished. The feasibility study for the cryo-assembly is currently on-going. R.VanWelderen stressed that the mechanical design of the cryostat should be checked carefully, and in particular if there are issues with the tunnel slope. H.Prin mentioned that tooling is recovered from a spare magnet. First, five cold masses will be finished and then the welding press will be upgraded for proceeding with the assembly. The cryostat integration looks feasible. The current schedule includes six months to assemble two cold masses, two months for cyrostating per CM, five weeks for cold tests, and less then one month for stripping. In conclusion, there are no major issues to report. R.Jones asked if there are BPMs in these quads. H.Prin answered positively and that it should be checked if the same or upgraded ones could be put in these magnets. R.Jones said that these are large aperture BPM and the orientations should be checked. O.Brüning concludes that in principle there seems to be no issue in production and testing. L.Rossi asks if the magnets are powered in series. E.Todesco points that this is a matter of quench protection and the inductance should be verified.

C.Magnier started by reviewing the actual situation in point 6 presenting schematic and 3D pictures. The new layout proposal for including the new Q5 maintains the service module and jumper in their actual location. The cold mass is shrunk for leaving enough passage to the dump line. P.Fessia mentioned that the QQS has a special diameter. C.Magnier said that it is indeed a bit special but she is working with D.Ramos and it seems feasible. There are also modifications on vacuum and the instrumentation of the dump line but nothing catastrophic. The DFBM remains at its place but the magnet alignment changes. In conclusion there is no particular problem for the left side. On the right side, the operation is a bit more complicated, as the QQS should be displaced. There is a solution that necessitates the elongation of the cryostat for 3670mm. L.Rossi asks if this is also the case for point 6. H.Prin replies that the elongation there is more important, of around 10m. C.Magnier explains that there is another option where the DFBM remains in its actual place, but the link is elongated. Indeed a compromise between the two options may be also considered. R.VanWelderen mentions that an elongation of the link will probably create more vapour and it is more sensitive with the slope, due to the two phase Helium flow. Maybe the solution is to consider a wider pipe. A.Ballarino adds that it is worth to look on alternatives and this should be followed up with R.VanWelderen. D.Wolman states that in principle moving the current leads is not a problem from the machine protection point of view, i.e. the regulation cards can be definitely moved. P.Fessia mentions that there may be some possible space to be recovered near to the MKV but this will necessitate a detailed study and preparation.

**Action: The PLC approves the proposed layout but expects a follow-up study by A.Ballarino et al. regarding the different options, in particular on the left side.**

## Test plans and HL-LHC STRING, M. Bajko – slides

M.Bajko first presents the timeline of the tests, which is the same since the review. From this timeline, the test readiness requirements were defined (see next presentation of V.Mertens). The timeline is made out of single magnet tests designated to a test bench with requirements for cryo-cooling and electrical powering (shared services). For a dedicated test bench this corresponds to over 7 weeks including thermal cycle. For the magnets made in the US, the thermal cycle is not included, reducing the test cycle to 5 weeks for series and 6 weeks for prototypes. From these consideration, it was defined the number of test stands and integrated service (demineralised water, cryogenic, electricity etc) capacity and availability for a given period.

An important aspect is coming from the performance of the test, the magnet dimension and the configuration of the test station. There is detailed information on web-pages of WP3 (excel sheet of E.Todesco) with the nominal and the acceptance value of the current. It should be noted that the model magnets will be tested up to the absolute limit (short sample limit). These considerations define the program of the cluster D test stand for magnet model tests.

Regarding the test distribution over the years, the period between 2017 and 2019 is the most difficult. An alternative test stand is under study in Uppsala for 50% of the magnet tests (only the correctors). O.Brüning asks what the total number of 100 LHC magnets to be tested corresponds to. M.Bajko answers that these are the spares and it is just a guess but it is indeed necessary to be included in the estimate anticipating any problem with the present LHC.

The IT string scope is focused to the setting up of a full technical and integrated test of HL-LHC between Q1 and D1. The STRING test is planned to be in SM18. The string test will be located in the actual area of the SC link test station. The short-term activities include the setting-up of a team and modus operandi, the definition of the complete list of ingredients, timeline, work of tests and budget. The actual setup is still under planning.

The IT string ingredients include magnets, power supplies and distribution, cryogenics, protection and vacuum. It is necessary to proceed to an upgrade of the existing services (part of the SM18 upgrade plan). In particular, an additional cooling plant is under study for upgrading or replacing the existing one and use it also for the SC link tests.

Regarding the timeline, the Phase1 can start at the end of 2019 for all prototypes apart from Q3. A decision has to be made if this makes any sense. The Phase2 cannot start before mid 2021 due to late arrival of the 1st series of D1. O.Brüning asks if the SC link will be available and A.Ballarino answers that this is indeed the case and in principle, it will have the same length as in the tunnel. L.Rossi stresses that it is clear that the preferred scenario is to do the full test as in the tunnel but this needs to be reviewed and adapted.

M.Bajko presented the preliminary test plan and the preliminary budget with the help of the WPs responsible (budget holders) for the different ingredients. She concluded by summarizing the main points presented and stressing that work has started but is still in a preliminary phase. All services but electrical powering have been defined.

## SM18 readiness for tests of HL magnets, V.Mertens – slides

V.Mertens focuses on the SM18 magnet test not RF (as reflected by the title). SM18 is being continually used and underwent already several modifications. The major magnet parameters are defined, the test program is known but also evolving. It is important to stress that there are also concurring activities imping on the planning of the upgrades (LS1). The total budget available is 13 MCHF from consolidation and potentially 10 MCHF from the HL-LHC project. The state of the project does not permit yet a full cost and schedule review.

V.Mertens presents the project structure, with three technical coordinators and some assistance for overall coordination and planning. O.Brüning asks if the "FAIR" test stand will be ready to start by mid-2016 and V.Mertens replied positively. He proceeded in summarizing the test planning (as in M.Bajko's presentation), with the series of modifications necessary to accommodate the different tests.

A schematic of the vertical test stand zone was presented with the High-field magnet (HFM) station, which is planned to get ready in May 2015 with budget coming directly from HL-LHC. A problem with a cryostat may produce delays. It will be on time for FReSCa2 but seven months late for Q2 models. HFM was supposed to be a backup for those, with cluster D being the main test stand. This last has a cost of ca. 5.6 MCHF. CE work has started and shall be completed in September 2015.

There is also need to upgrade the demineralised water station. The order is ready to be placed and it should be delivered by the end of this year.

The crane will be upgraded for 25 tonnes, its integration is sorted out and just a few details remain to be settled. L.Rossi asks whether 25 tonnes is the maximum weight as a crane with capacity of 30-35 tonnes would be able to move a dipole. M.Bajko replied that two cranes of 25 tonnes would do the job. P.Ferracin mentions that the maximum quadrupole weight is indeed 22 tonnes.

The current planning for the cluster D upgrade project accumulated a delay of eight months for Q2 models. The possibility to re-use the IT from HFM led to massive speed-up (and cost reduction) for the main cryogenic supplies. The planning for the energy extraction system is quite ambitious due to man-power issues related to LS1. The SM18 shutdown planning 2015/16 is being elaborated and contains a lot of interventions. A lot of material is coming at the same time and some optimization is needed.

The SC link comes later (ready by end of 2016); it will first be supplied from cluster D and Cluster A. System tests using dedicated supplies are foreseen for 2020. Regarding the H benches for testing cryostated magnets (Q2 prototype in 2017 and series of Q1/Q3, Q2, Q4, D1, D2 in 2019/20), there are options for upgrading existing benches which are presently being investigated. An alternative solution, which is more evolved with respect to cost and time, consists of using a combination of 2 benches (so called “cluster Y”).

After passing fast through the IT string test description that was detailed by M.Bajko, V.Mertens proceeded with the preliminary assumption on cryogenics upgrade and the requirements with liquid helium and pumping He at 1.8 K. A version providing reasonable margin would cost around 15.4 M including a new building; it can become ready in 2019. A conceptual study is ongoing. There is also a need to modernize the primary water supply, which will be combined with the reshuffling of reserve thermal power onto the SPS loop where it will be needed for the RF upgrade in BA3. The main requirements were discussed with M.Nonis who worked out a plan with two new cooling towers and a third one, which can be added at a later stage. The idea and planning were discussed at the IEFC in February. The cost of around 4.6 MCH will be borne by EN consolidation, and will be delivered prior to LS2. In conclusion, there is very good work progress, most concepts are in place, but there are many open fronts to achieve the goals and milestones, as well as some areas bearing risks (e.g. faster energy extraction). The feasibility of medium-term goals like H benches has still to be proven. There are a few items not looked at in detail yet, like the electricity upgrade.

L.Rossi asks if we are still on time for the 2nd QXF test (the first one will be done in the US). P.Ferracin states that this is just on time (April 2016). M.Bajko stresses that the energy extraction is the bottleneck and it will be ready only for July 2016. In the question of O.Brüning whether this affects MQXF tests, M.Bajko replies positively, as it affects cluster D and HFM. O.Brüning suggests that there is a follow-up presentation on the FReSCa upgrade by M.Bajko in one of the next TCs, including the progress for MQXF testing and what is needed to avoid delays.

**Action: A follow up presentation on the FReSCa upgrade should be scheduled for one of the next TCs, including the progress for MQXF testing and what is needed to avoid delays.**

## Confirmation/approval of new CE baseline, I.Bejar Alonso – slides

I.Bejar Alonso presented an EDMS document regarding the decision on CE works in P1 and 5 underground. A full list of advantages for the double decker option is included. A.Ballarino questions that the reduction of the SC length will have a big cost impact. In her opinion most of the impact is on installation. O.Brüning stresses that we approve the underground option as a baseline. The details are not to be discussed in the PLC, but in the relevant WPs.

**Action: The HL-LHC PLC approves the new Double Decker underground installation as the new baseline for the HL-LHC project.**

## AOB - Approval of circuit parameters – slides

A table was presented on the magnet circuit parameters. These are a few points to be followed-up:

- The first column in the table on the number of circuits does not seem to be correct and consistent for all entries.
- The ultimate current for the Recombination dipole magnet is equivalent to the PC grading, without any margin. A footnote should be added explaining that decision (would require substantial PC upgrade) and provide a comment that this could still be upgraded at a later point if the machine would start operating at ultimate energy.
- There is need to agree on how this table is referenced. O.Brüning thinks, that it should be referenced to the PLC webpage which implies that E.Todesco removes it from the WP3 website and replaces that entry with a link to the PLC website. This is the only way for assuring proper version tracking across all work packages.

**Action: The HL-LHC PLC decided to list the table with the circuit parameters on the PLC website. A follow-up will take place in the next meeting for the identified issues mentioned above.**

Next PLC on the 16th of July.