G. Arduini
R. De Maria
S. Izquierdo Bermudez
M. Modena

44th Meeting of the HL-LHC Technical Coordination Committee (special meeting in preparation for Chamonix 2018) – 18/01/2018

Participants: G. Arduini, A. Apollonio, V. Baglin, I. Bejar Alonso, M. Bajko, A. Ballarino, L. Bottura, O. Brüning (chair), H. Burkhart, R. Calaga, B. di Girolamo, F. Cerruti, P. Chiggiato, S. Claudet, D. Delikaris, A. Devred, R. de Maria, P. Fessia, D. Gamba, G. Iadarola, S. Izquierdo Bermudez, R. Jones, M. Martino, H. Mainaud Durand, P. Martinez Urios, R. Martins, E. Metral, M. Modena, T. Otto, Y. Papaphilippou, V. Parma, A. Perin, M. Pojer, S. Redaelli, F. Rodriguez Mateos, L. Rossi, F. Sanchez Galan, F. Savary, J. Serrano, L. Tavian, A. Tsinganis, E. Todesco, R. Van Weelderen, D. Wollmann, S. Yammine, M. Zerlauth.
Excused: M. Brugger, M. Giovannozzi

Session 4: HL-LHC developments in Baseline - S. Izquierdo Bermudez (Sc. Secretary) ¶

This is the second out of the three special TCCs dedicated to the preparation of the Chamonix 2018 sessions which will serve as a technical review of the HL-LHC project by the CERN Machine Advisory Committee (CMAC). The aim of the meeting is to review the content, the main results, issues and conclusions on each specific system.

HL-LHC IR magnets (WP3) - E. Todesco - slides

The charge for the CMAC is to evaluate if the magnets are mature enough and with adequate margin to operate safely with good availability. The talk for Chamonix will be divided in 4 sections: 1) Overview on the layout and required magnets 2) Test Status 3) Magnet Status 4) Options and Changes.

E. Todesco gives an overview of the layout for HL LHC, emphasising the non-negligible degree of complexity due to work on eleven magnets spread on five collaboration and nine laboratories. The status on the magnet tests is summarized:

- MQXF: Two out of the three short models tested reached performance with good temperature margin since the quench current at 4.2 K is greater or equal than the quench current at 1.9 K. The test of the first prototype (MQXFAP1) is on-going.
- D1: One short model tested, which reached the required performance after increasing the pre-stress
- High order correctors: Sextupole, octupole and decapole magnets reached the required performance with wide margin.

- D2 corrector: One short model tested which reached ultimate current after one quench.

The next part of the talk is focused on the status of the magnets, describing the main technical concerns:

- MQXF: Training of the short models showed good features such as very good memory (better than Nb-Ti) and large margin (quench current at 4.2 K is greater or equal than the quench current at 1.9 K). Nevertheless, the training is long (longer than in Nb-Ti), some events of detraining are observed and there is an intrinsic variability on the models built on the same design (as in Nb-Ti). The specific training performance of each magnet is described. A large range of pre-stress from 75 to 150 MPa have been explored with the short models, demonstrating a good control of pre-stress.
- D1: A second magnet is under construction to verify the field quality and performance reproducibility in KEK. The main challenges are the end-geometry and displacements and the large contribution of the coil ends to the field quality in the straight section. It is planned to build a third model, to be tested end of 2018 to check reproducibility. The Japanese contribution for prototypes and series is under discussion.
- D2: The short model is under manufacturing in ASG. The main challenge is field quality (compensation of cross-talk among apertures through left-right asymmetric coil) and the tight schedule. The test is foreseen in summer 2018.
- MQYY: A model is under construction in Saclay, even if the magnet is not in the baseline for HL-LHC. Six coils have been done. Collaring will be done at CERN and it is expected to be tested in summer 2018. The plan is to build two full length prototypes in EU industry through the QUACO initiative. The first phase (conceptual design) is completed, the second phase (engineering design) is on-going.
- MCBXF: A model is under construction in Saclay. It is a complex coil (large number of turns) and mechanical assembly (nested magnet). Winding has started and a collaboration agreement for the series is signed.
- High Order Correctors: Sextupole, octupole and decapole prototypes were successfully tested at INFN demonstrating wide margin. The dodecapole and skew quadrupole prototypes are expected to be tested in 2018. A collaboration agreement for the series is signed.
- MCBRD: The short model has been successfully tested and a prototype is under construction at CERN.

The last part of the talk outlines the possible options and changes. The first option is to keep the same Q4 and Q5 as today in the LHC. Estimates on energy deposition are on-going to verify if is feasible to decrease the aperture of Q5 from 70 mm to 56 mm. The big advantage of this option is that will significantly reduce the work load, since it will not be required to build 16 additional MCBY correctors and 4 additional cold masses. The reduction of orbit correctors can be compensated through full remote alignment or additional resistive magnets (D. Tommasini performed a full estimate of the cost of this option). This has also implications in the powering, since local feedthrough is not needed but the DSL needs to be anyway modified since the position of the magnets will be different. G. Arduini points out that there is a MCBY corrector installed in the machine with a non-conformity that should be fixed for HL-LHC.

Cold Powering System for HL-LHC, A. Ballarino - slides

The charge for the CMAC is to evaluate if the SC-link based on MgB_2 technology is mature enough and with adequate margin to operate safely with good availability. A. Ballarino will present during Chamonix session an overview of the powering circuits and will provide description of the system and its components. All aspects will be covered, including protection and electronics.

The advantage of using MgB_2 as superconductor is the large temperature margin. On the negative side, since it is a new technology, more development is needed to have a fully qualified solution. A. Ballarino will show that allocations are properly allocated within the magnet group in order to finalize the required development. L. Rossi insists on pointing out the good developments that have been down and the potential to use this technology in other applications (powering grid).

The present baseline is robust, fully integrated in the circuit and the magnets. There is a new cable geometry, not reflected in the TDR but approved by the TCC. Some key developments such as the splices need to be still done but specific programs are stablished.

The presentation in Chamonix will be focused on the Triplets and D1 circuits. The layout in the matching section is only preliminary, so the baseline will be only briefly discussed. The discussion on the recovery of existing hardware (DFBL and DSL) will be summarized in only one slide and kept as simple as possible (details to be kept as spare slides). A. Ballarino will not covered any cost-related aspect since it will be addressed by A. Devred in a specific presentation.

HL-LHC Cold Powering: Are There Viable Options? A. Devred - slides

The charge for the CMAC is to evaluate if the present baseline, based on MgB_2 superconducting links is technically adequate to the scope and more advantageous with respect to more classical solutions. A. Devred will study in detail the advantages and disadvantages of the present baseline (MgB_2), a Nb-Ti variant and a copper variant.

MgB_2 superconducting cable in a flexible cryostat cooled by a forced flow of helium gas at 4.5 – 17 K is the present baseline. It is a viable and innovative option, with a great potential for generating technological spin-offs. There are still design changes and developments to be completed by end 2019. The proposal to have a consolidated manufacturing and installation plan by end of 2020 have to be re-discussed. All the technical issues need to be addressed before the cost and schedule review in end of 2019.

Nb-Ti cable in rigid cryostat cooled by forced flow of supercritical He at 4.5 – 5.5 K is considered a viable option relaying on well proven technologies. The extrapolation from LHC DSL experience is not straightforward. The presented design has limited operating margin, with a high risk to quench the inner triplet magnet string. Consequences on machine operation have to be assessed. Performance may be improved by reducing cable losses and/or more efficient cooling, but requires a 2-year development plan. The rigid cryostat design, manufacturing and insertion of the cable needs to be developed and qualified. Safety aspects also need to be carefully studied. V. Parma started the study and for the moment no showstoppers have been identified. In order to keep this back-up option available, one needs

to assess what to do in terms of design studies and R&D. A decision shall be taken before the cost and schedule review at the end of 2019 in order to be able to have a solution ready to be installed in LS3. S. Claudet points out that the cost saving on going from MgB_2 to Nb-Ti needs to be compared to the expected investment on MgB_2 development unit end of 2019 (date where the decision needs to be taken). If the investment on MgB_2 in next couple of years in larger than the saving due to the use of Nb-Ti, the argument on cost saving does not hold.
The copper variant is not consider a viable option as this stage of the projects since it requires additional civil at the exits of the vertical shafts into the LHC tunnel (due to the fact that present civil engineering, layout and ancillary equipment have been optimized for a superconducting link option and that if a copper option had been considered from the start, the optimization would have likely led to a different configuration). In additional, the power consumption is high (4 MW, i.e., 8000 MW.h/year). It would require extra capacity of cooling and ventilation. In addition, due to the activation of the DFBC area of the tunnel, maintenance becomes an issue.
A. Devred will present a very rough cost comparison providing only order of magnitude and conclude with the statement that MgB_2 is a challenging but viable option, fully supported in terms of resources by the TE-MSC group. The non-return point for the back-up Nb-Ti option is the cost and schedule review by end of 2019.

Heat deposition and radiation dose vs operation mode and mitigation schemes. F. Cerutti - slides

The talk for Chamonix will be divided in three sections. The first one will present heat deposition values in the Triplets and D1, with a description of the mitigation options and hardware improvements. The second part will focus on the Matching Section where the critical item is to study if it is feasible to keep Q5 as today in the LHC, i.e, with an aperture of 56 mm instead of the current baseline (70 mm). The last part of the talk provides an overview of the heat deposition and radiation dose in the dispersion suppressor.
In the Triplets and D1, the critical point in the present baseline is in Q2b, with an expected dose after 4 ab^{-1} of 32-39 MGy (average ± 1σ). A better shielding in the interconnection can reduce this dose to 29-33 MGy. A scheme with 50 % +V crossing and 50 % -V crossing in one insertion and 100 % H crossing in the other insertion by definition does not change the picture in the latter, which for HL-LHC, contrary to LHC, is the limiting insertion. 25 % +V, 25 % -V and 50 % H crossing in each insertion significantly decrease the peak dose (23-28 MGy after 4 ab^{-1}, i.e., 30 % decrease) but it requires a challenging hardware flexibility with optics drawbacks so it is not considered in the baseline. The crossing angle has a significant impact on the dose, with a decrease of 10 % on the peak dose every 40 µrad decrease of the crossing angle. An efficient option is the crossing angle variation along the fill, yielding to a 10 % lifetime increase. In the Matching Section, the dose is in all the cases below 20 MGy so it is not considered critical for the magnets. Despite the weaker TAXN effectiveness, collimators and masks can offer a reasonable protection to the matching section. Q5 at 56 mm is being studied and results will be available before Chamonix. The radiation dose in the magnets is sensitive to the TCL settings so these can be further optimized.

To finalize studies and present a new tentative table with the radiation dose in each magnet. To prepare a summary slide to be discussed on the 25th of January. ACTION: F. Cerutti.

In the dispersion suppression, losses increases with the expected luminosity scaling, with a maximum dose of 20 MGy after 4 ab^{-1} for an ideal aperture profile (i.e., a factor 2 lower than the 40 MGy that were presented in the Collaboration Meeting in Madrid for a 700 micron aperture restriction in the MQMC). The dose is very sensitive to aperture imperfections.

Session 5: HL-LHC open issues and options – G. Arduini/R. De Maria (Sc. Secretaries)

Digesting the LIU high brightness beam: Is this an issue for HL-LHC? - G. Iadarola - slides

The talk focuses on the bunch population limitations (coming from the expected beam induced heat-load increase from impedance, synchrotron radiation, and the e-cloud prediction with the associated uncertainties) and the emittance preservation issue along the cycle due to IBS and other sources.

L. Rossi asked whether it is confirmed that the difference in beam induced heat load among sectors is due to electron cloud. G. Iadarola noted that observations indicate that this is the most plausible explanation but L. Tavian will present the results of the analysis of the task force in Chamonix. Nevertheless the extrapolation to HL-LHC is based on the assumption that electron-cloud plays a key role in determining this difference. D. Delikaris suggested to clarify that this is at the moment a hypothesis. L. Rossi suggested to illustrate the 8b+4e scheme with a plot.

O. Brüning asked whether the quoted value of the emittance blow-up is the maximum value occurring in a beam/plane. G. Iadarola replied that this is the average value. O. Brüning noted that the differences in the blow-up between beams and planes could indicate that the source is not intrinsic and could be potentially identified and mitigated.

O. Brüning suggested to stress in the conclusions that operations at bunch populations close to HL-LHC nominal values during Run III is critical to assess the intensity limitations in HL-LHC and the LHC should be put in the conditions to accept LIU beams as soon as possible.

Long Range Beam-Beam effects for HL-LHC - Y. Papaphilippou – slides

The talk focuses on impact of long-range effects on machine settings (crossing angle, levelling strategies) and performance (lifetime). Following a question from L. Rossi, O. Brüning and Y. Papaphilippou noted that the margin of a factor 2 for the dynamic aperture (DA) without beam-beam effects used for the LHC design is not used for the HL-LHC design. Experimental observations have been used to benchmark the models and therefore no additional margin is added. In reply to a question from G. Arduini, Y. Papaphilippou mentioned that the burn-off lifetime estimates are based on an inelastic cross section of 80 mbarn and not on the total

cross section (~110 mbarn) used conservatively for the performance estimate. Yannis added that the operational experience indicates that a DA target of 6 sigma when multipole imperfections are not included is adequate but with no margin. O. Brüning and G. Arduini noted that the presentation indicates that the baseline scenario for nominal operation contains sufficient margin to be credible and only operation to ultimate luminosity requires more aggressive requirements on DA. It also indicates that dedicated additional beam-beam long range compensation schemes based on wires do not appear to be necessary for the baseline scheme and they should be considered as back-up scenarios in case of issues in the operation of the crab cavities or in case of unexpected high intensity phenomena.

Possible further simplification of the matching section – R. De Maria - slides

The talk focuses on the possibility to further simplify the matching section and in particular reducing the requirements on the total required corrector strength for Q4 and Q5. As anticipated in the previous Chamonix, this could be achieved by adding additional functionalities to the remote alignment system in the matching section and in particular guaranteeing that the remote alignment can be performed with safe beams from the control room (so-called fully remote alignment system). Alternatively, although this solution is not preferred, warm correctors should be added. The fully remote alignment system would extend the performance reach and avoid a significant hardware work load thanks re-using the existing Q4/Q5 cold mass and avoiding the installation of additional HW (warm correctors). The main assumption is that the new alignment system, contrary to the LHC experience, will be used every yearly technical stop and during commissioning time to realign the machine around the optimal collision point requested by the experiment, saving orbit corrector strength allocated for the purpose and increasing the available aperture that would otherwise be lost. In reply to a question from S. Redaelli concerning the technical feasibility of the fully remote system R. De Maria replied that the technical implementation is briefly presented in the following talk.

To clarify at the next TCC on 25/1/2018:

- Cross check between WP2/WP5/WP10 of the TCL settings and requirements on the TCL alignment. ACTION: F. Cerutti, R. De Maria, S. Redaelli.
- A confirmation from machine protection that remote alignment, with safe beams, is conceivable. ACTION: D. Wollmann, M. Zerlauth.
- Further information on the potential simplification of the QRL. ACTION: S. Claudet.
- Further information on the warm magnet design and powering. ACTION: E. Todesco.

Alignment: Is this an issue for HL-LHC? – P. Fessia - slides

The talk focuses on the hardware changes needed to improve the baseline to significantly reduce the doses per intervention by extending and optimizing the equipment to be aligned by wire and further improve the system to fulfil the request of fully remote alignment needed

by the simplified baseline proposed in the previous talk. The talk also address few other modifications of the vacuum layout to be compatible with the presented functionalities.
O. Brüning noted that the cryostats for HL will be different from the LHC ones and he would expect a reduction of the present cold-mass stability issues. P. Fessia replied that in addition the cold mass position will be directly monitored. P. Fessia clarified that the extra budget required for the vacuum transitions is due to the fact that these components were not costed so far and therefore it is not linked to the possible changes mentioned by Riccardo. L. Rossi mentioned that Chamonix is a technical review and therefore the detailed cost estimates are not required, furthermore the content of the presentations is not protected.
O. Brüning asked whether T. Otto has been contacted to comment on the alignment system and on the impact that this could have on a maximum credible incident. P. Fessia replied that he did not receive any comment from T. Otto on the proposed system.

To provide feedback on the implications (if any) of the proposed alignment system on safety. ACTION: T. Otto.

Session 6: Infrastructure, Test facilities and plans for HL-LHC prior/for LS2 - M. Modena (Sc. Secretary)

11T Dipole update, F. Savary - slides

Frederic proposes to change the title from "Update on 11T Dipole" to "Update on WP11".

- Introduction
- Update on the 11T dipole magnet development

Frederic will highlight main aspects of the development including integration points, solved and still open.

- Results from the models programme

Frederic will highlight the status of investigations to understand the source of limitation of performances, the revised program of models to be done and the set-up of the Task Force. On a Question from Oliver, it is clarified that the Task Force is reporting in priority to WP11 and MSC Group.

- Status of the prototype construction
- Plan for series production

Frederic will underline as a stop in the test activities will happen at beginning of 2019 due to a stop of SM18 test activities.

- Status of new connection cryostats for IR2
- Summary

Question from Oliver about contingency in the project that is around 3 months.
Question from Oliver of eventual Field Quality issues: Gianluigi clarifies as no major issues but could report on the changes/decisions since the last Chamonix meeting (trim circuitand magnets length increase).
Lucio's comment: Describe more about actions taken for performance issues and as there is enough confidence to launch the series production of coils and highlighting that here, we have a major industrial contract starting.

Question from Stefano: Who has to cover the alignment aspects of the collimator in the connection cryostat in Pt2? Lucio's comment: Decide between you (but it seems more logic that should be Stefano to cover this aspect).

Beam Screen coating for Pt 2 and 8, P. Chiggiato - slides

Paolo will start presenting the rationale behind the proposed activity, highlighting the implication due to the cryogenic limitation with the new HL beams.
He will then present the two possible way to tackle the problem (improvement of cryogenic cooling power or reduction of electron emission).
He will present status for the carbon coating and for laser treatment
The most important slides are the 17 and 18 summarizing the situation.
A risk analysis and conclusions are following.

Question from Lucio about the statement "Operation: no limitation in Run 3" (slide 17): Gianluigi clarifies that eventually there will be animpact on n. of bunches but this is approximately the same for the triplets in 1 and 5 and the triplets in 2 and 8
Slide 20: Lucio's comment: Specify at line 3: "IR1 and IR5's HL-LHC triplet magnets are easier" (to avoid misunderstanding with existing triplets).
P. Fessia's comment: Note that the standalone magnets at IP1 and 5 will anyway be brought to surface.
Slide 21: Lucio/Oliver comments:
At 2nd bullet ("In LS3") better to clarify anyway when treatment will be done in the tunnel and when at surface.
Line -1: To correct (e-cloud instabilities risk if not performed the...)
Following Dimitri's question: Better to clarify where figures in watt are "total" or "per meter".
Dimitri's comment: The upgrade of Cryo at Point2 and 8 is in case still a possible option.
Gianluigi's comment: Q4 in R2 and L8 should also be considered for coating.

HL-LHC String Test, M. Bajko - slides

- Motivation
  - Lessons learned from LHC
  - Test program
- What we can learn and what we can actually not test
- Status today
  - Preparation
  - Integration
  - Proximity Cryogenics and capacity for String
  - Planning
  - Resources

Marta will highlight the aspects as:
- **"What we have learn from the past"**

- **"What we can NOT test in the String"**
- **Aspects like: transport, assembly, alignment, interconnection procedures, protection, etc.**
- **No "tunnel slope" will be implemented.**

After "Planning" and completing the presentation, a "Global cost & resources" is presented.
Comment from Lucio: Better to put ONLY the total resources (personnel) needed but not the cost.
Comment from Oliver: Be ready for a Norbert's question like: "what your tests could still impact/change on the technical aspect/decisions to be taken..."

SM18 Facilities Readiness, M. Bajko - slides

- Testing for HiLumi WPs
- Infrastructure for Test Facility
- Test stand readiness for components
- Test plan and considerations for planning
- Test Facilities outside CERN
- Conclusions

Marta will underline as a lot of components will be produced outside CERN so needing adequate testing phase.
On Lucio's question: Clarified as WP6b test (namely the new 2-Q PC of 18 kA) will be done as part of the "String tests" and not as "SM18 tests".
Oliver/Lucio comment: Decide which WPs to be "framed" in slide 3. Use a coherent approach: all what going through "SM18 test" only, or also what done in "String test". The case of WP15 where Integration of main components will be also tested here.
Lucio's comment: Mention also the cold test of the connection cryostat for IP2 (Vittorio clarified that will be only one cold test: Is this in the IT String?
Lucio's comment: Clarify which of the American magnets will be tested, as baseline.

HL-LHC Cryogenics (Refrigeration) progress & perspectives, S. Claudet - slides

- Introduction
- SPS-BA6 test facility for crab cavities
- P4-RF: towards new baseline
- P1/P5: refined clarification of interfaces
- Other clarification of interfaces
- Schedule and team organisation
- Summary

Serge's main message for Slide 3: Intense industrial contract deal and follow-up done in the last months.
Slide 4: Possible "extra week" of activities needed (but to be decided later)
Slide 13: With the objectives for 2018 will also be central.

Lucio/Oliver comment: Decide with Rama who will report about the SPS Crab measurements results.

Discussion about the "extra week": To be probably decided after Chamonix 2018 but Lucio reminds that Freddy will probably discuss this point in the workshop.

General REMINDER to all speakers:

- **Oliver: Remind to discuss/converge OFFLINE of TCC about details.**
- **Lucio: Attention to explain the critical details to the "not expert" public.**
- **Oliver: Decide and focus clearly the message you want to pass.**

The next special TCC meeting will take place on the 25th of January 2018.