# 16th Meeting of the HL-LHC Technical Committee

**Participants:** G.Arduini, V.Baglin, A.Balarino, I.Bejar Alonso (Chair), H.Burkhart, D.Berkowitz-Zamora, R.Calaga, F.Cerutti, S.Claudet, B.Delille, R.De Maria, I.Efthymiopoulos, E.Jensen, P.Fessia, M.Giovannozzi, I.Laugier, T.Lefevre, Y.Papaphilippou, H.Prin, S.Redaelli, L.Rossi, F.Savary, H.Schmickler, E.Todesco, S.Weisz, R.van Weelderen, D.Wollmann, J.Uythoven

**Excused:** C.Adorisio, S.Baird, O.Bruning, J.-P.Burnet, L.Bottura, F.Caspers, G.De Rijk, R.Jones, M.Lamont, L.Tavian, M.Zerlauth

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

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

Indico link: https://indico.cern.ch/event/369701/

I.Bejar Alonso opened the meeting by briefly introducing today's agenda. The minutes of the previous meeting remain to be finalized and will be approved during the next meeting.

S.Claudet introduced a new fellow, D.Berkowitz, who joined the TE/CRG group for reviving the heat-load working group, the main task of which is the identification of thermal loads due to beam losses and interaction with machine components. The objective would be to provide a clear view on the needs for the dimensioning of the refrigerating and distribution systems for HL-LHC (principally P4 and P1/P5).

## Impact of layout modifications (gradient change/L*/ etc.) on performance, R.De Maria – slides

R.De Maria briefly introduced the parameter space affected by the layout and optics of the HL-LHC triplet upgrade for IR1 and IR5, i.e. the beam size @ the triplet ($\beta^*$ reach), crab cavity voltage and optics, natural chromaticity, BPM effectiveness (in presence of beam-beam long range interactions). The optics (and layout) depends on the quadrupoles' gradient, their length and drifts in between them and the IP. A recent request for parameter changes involved the increase of $L^*$ and interconnects' lengths (longer drifts) and decrease of gradient. Two points are addressed: the impact for an unchanged triplet layout while varying the gradient and for the newer layout following the requested changes.

R.De Maria stressed that the simple consideration of the invariance of the integrated quadrupole gradient while changing drifts and gradients is only approximately true due to very stringent optics boundary conditions: phase advance constraint of ATS optics, maximum β at crab-cavity location, minimization of $\beta^*$ of the pre-squeeze (reducing β function blow-up in the arcs for preserving dynamic and mechanical aperture). This is illustrated in the following two scenarios, while varying triplet gradient: a) keeping the Q7 gradient between 99 and 100% of its nominal value for different $\beta^*$ and b) increase of Q7 gradient up to 130% of its nominal value for constant pre-squeezed $\beta^*$. There is only up to 1T/m margin in the triplet gradient for the first scenario, while recovering the $\beta^*$ by a maximum 30% blow-up in the arcs (or reduced energy) with direct impact on reduced aperture margin in the arc and dynamic aperture. The second scenario demonstrates that there is an approximately linear increase of the Q7 gradient while reducing the triplet gradient (10-30% increase of Q7 corresponds to 1-3T/m reduction). After a discussion between L.Rossi, M.Giovannozzi and E.Todesco, it was not clear whether all MQMs ever reached their ultimate gradient of 216T/m, i.e. 8% higher than the nominal (the following reference by R.Ostojic et al., shows that all of them reached ultimate current during their training tests. On the other hand, it is not clear if they were ever tested up to this current after installation in the machine, see reference by N.Catalan Lasheras et al.).

R.De Maria elaborates the impact in $\beta^*$ reach for the different changes requested, i.e. $L^*$ and interconnection length increase, additional drift between Q2a and Q2b (the option of splitting each Q2 magnet has been mentioned, but E.Todesco stressed that this is a back up solution, not in the baseline), and triplet gradient reduction. The increase of L* by 1m produces a 3.5% increase in $\beta^*$, while the impact of the interconnection length increase by 0.15cm is marginal (0.8%). Including the Q2a and Q2b split by (9.4cm) or considering only the triplet gradient reduction to 131.25 T/m gives an increase in $\beta^*$ of around 4%. Finally, including all the changes gives an increase of 11.3% in $\beta^*$ (or 8% without the Q2a/Q2b split). R. De Maria points out that $\beta^*$ scales inversely proportionally to $\beta_{max}$ (chromaticity scales with $\beta_{max}$) and the IR optics flexibility is severely reduced with the lower gradients and $\beta^*$ reach can recovered by stretching more and more the ATS scheme.

The virtual luminosity is inversely proportional to $\beta^*$ but in HL-LHC scenarios, integrated luminosity expectations are more sensitive to leveled luminosity and beam currents (i.e. burn-off and leveling time dominates integrated luminosity). Thus, the reduction to the integrated luminosity per day for different $\beta^*$ and different leveled luminosity is small (from 1.7 to 4.3%). It becomes more important for lower beam currents, and in addition, the lowest $\beta^*$ is relatively risk free.

Finally, R.De Maria stresses that in the new layout 3 BPMs in between Q1, Q2a and Q2b and Q3 have lost their ideal position and have to be reshuffled. T.Lefevre points out that the precision lost is around 10% (from directivity) and depends mostly on the mechanics of the BPMs and less the electronics. G.Arduini adds that the non-centering of the BPMs should play an additional detrimental factor and T. Lefevre replies that this is indeed taken into account in the estimated precision loss. These BPMs are very important for machine performance (center of crab cavities, crossing angle, etc.) and their precision loss can impact the ability to control the collision conditions.

E.Todesco asks if the orbit corrector can be moved from the left part of the cold mass of Q2a to the right part of the cold mass of Q1b (the American magnet), in order for that BPM to recover a “good” position. P. Fessia suggests looking into the details of the mechanical drawing because this sketch may be misleading.

In summary, it is stressed that freezing the length of the quadrupoles will will prohibit to find optimal layouts if other layout constraints are not frozen at the same time. The proposed changes increase $b^*$ by 8% and result in 2% integrated luminosity loss. Further studies need to address the optimization of the BPMs positions and the effect of an additional beam-beam long-range encounter inside the D1 separation dipole. For updating the layout / triplet parameters (in particular length), it needs to be understood whether $L^*$ can be maintained and clarify the layout and length for Q2a/Q2b. In particular, if Q2a and Q2b are split, a 3% higher gradient is needed (75% of the maximum can become 78%).

## Discussion:

L.Rossi mentions that the split of Q2 has impact on cost and schedule, as for example there is no available tooling. He suggests keeping the present layout but only demonstrating that there is an alternative. It is indeed regrettable that one magnet (Q7) drives the design.

P.Fessia suggests to proceed into a detailed study of the BPM position for determining the shifts needed to put the BPMs in the “good” area. T. Lefevre mentions that indeed these “bad” and “good” areas shown in the slides are not “step-like” functions in the BPM performance. H. Schmickler suggests treating the performance issues of the BPMs in a future PLC.

Action: The performance issues of the triplet BPM system with respect to their position will be treated in a future PLC meeting.

E.Todesco suggests to have an intermediate case studied for $L^*$ of 23.5m. I.Efthymiopoulos stresses that it is pointless to increase $L^*$ by less than 1 m. He also suggests that the shielding of Q1 should be re-evaluated for the new $L^*$.

E.Todesco stresses that there is a need to fix the triplet length, as the LARP collaborators have to know soon. G.Arduini and M.Giovannozzi asked whether some margin can be left at this stage and E.Todesco replied that the length should be defined within ±1%. The issue is not the magnetic measurements, i.e., the test station, but rather the tooling. The prototype will be ready in 2017 and we cannot wait for these tests for a decision. R.De Maria pointed out that 1m of $L^*$ increase has impact on optimal triplet lengths.

## Conclusions:

- The maximum gradient of all the triplet quadrupoles will be reduced from 140 T/m to 130 T/m (75% on the load line instead of the previously considered 80%)
- The following changes in quadrupole inter-distances will be considered for the new layout as they are inevitable after thorough evaluation:
  - Q1a to Q1b: from 0.5 m to 0.65 m
  - Q1b to Q2a: from 3.7 m to 3.627 m
  - Q2a to Q2b: from 2 m to 2.094 m
  - Q2b to Q3a: from 3.7 to 3.627 m
  - Q3a to Q3b (same as Q1a to Q1b): from 0.5 m to 0.65 m
- No split for the Q2 magnets. This will be reviewed later and it will imply readjusting

the gradient (reducing actual margin).

- The distance Q1 to TAS needs to be further investigated.
- The magnetic length of the quadrupoles needs to be defined within +/- 1%
- The optimum lengths of the quadrupoles for a given maximum gradient and for the existing constraints do not scale exactly with the inverse of the gradient, at least within the given tolerances and in particular it depends on L*
- For the final value of $L^*$ (ranging from 23 to 24 m), the length of the magnets has to optimized to an intermediate value that should allow to stay within the tolerances of magnetic length provided

Action: WP2 to provide the new magnet length within the specified tolerances taking into account the reduction of the gradient, the new interconnect lengths listed above and the uncertainty in the $L^*$ length (between 23 and 24 m)

## Preparation for C&S review, B.Delille – slides

B. Delille presented the scope and purpose of the Cost and Schedule review (9-11 March 2015). The 3-day program includes a plenary, 5 breakout sessions (1.5 days), a Q&A session and a closeout with recommendations. The reviewers are distributed in sub-panels for each break-out session. The presentations should include the scope of each WP, resources, schedule, risk, and cost uncertainty.

B.Delille stressed the list of action per week for the preparation of the review. In practice, the preparation includes a few meetings for streamlining the information (especially for scope, resources and schedule) and rehearsal meetings at the end of February (special TCs). He showed the preparation milestones from now until the review, including a global “readiness” table for each work-package.

B.Delille gave examples on the budget structure, the APT Work Breakdown Structure and Work units. APT structure was set-up in January and now needs to be filled. He focused then on the key concepts for Resources (personnel and Material for personnel). Personnel WU are created yearly for each WP. Staff and existing fellows are included in P WUs. It must be nominative for the first 3 years (2 years for APT). mandatory for APT for 2 years) and for the following years until 2025, general needs are expressed. All corrections or changes will be made in collaboration between HL-LHC team and the DPO who has the responsibility for each department.

In addition, one M4P WU will be created yearly for each WP. This includes MPA, FSU and service contracts. For MPA, it will follow the same logic as for personnel (nominative the first 3 years and needs for the following period). GET fellows should be also included in MPA but when hired they are considered as Personnel. A general cost of 67.2kCHF/(person*year) is considered. This is low in particular for GET fellows (corresponding to 120kCHF) but it is used to reflect correctly the full cost, as in some cases DGP budget is used for GETs. For FSUs an average cost of 110kCHF/year should be used. For industrial services, the value should be based on existing contracts and experience from the past (LHC construction). Additional

2kCHF added per person and year for training, travel, etc.

A detailed schedule should be developped but, during the review, the focus should be in a few items for each WP that are considered important and/or critical for the project. The uncertainty allows to evaluate a level of risk on the overall project by documenting where the estimate comes and providing information for the precision of the cost estimate. Regarding interfaces, special care should be taken to avoid overlap but also nothing empty.

In summary, B. Delille stresses that the schedule to get ready for the C&S review is tight. The schedule and resources data should be available by end of next week (W8), leaving 2 weeks to prepare risks, uncertainty, interfaces identification, etc. P resources should be uploaded in APT (in the WUs proposed by the project team). A discussion on interfaces between workpackages should follow during this TC (e.g. WP6A-WP6B-WP9, WP9-WP4 for SPS infrastructure, WP12 with almost all others, WP3-WP11-WP15 for Interconnections). The last two weeks will be used to check the global consistency, chase up interface issues, and finally, reflect on risks and uncertainty.

## Discussion:

G. Arduini questions if the commisioning time should be included in the estimates. L. Rossi replies that hardware comissioning should be included in the project estimates whereas beam commissioning corresponds to operation. Although for optics commissioning this is not the case (as pointed out from G. Arduini), L. Rossi feels that at this point this is a detail.

L.Rossi points out that there is a big interface of the project with consolidation involving mainly beam transfer elements, collimators, RF and beam instrumentation (magnets to a smaller extent). WP leaders have to reflect about the issue and provide feedback.

T.Lefevre asks if the spares are part of the project. L.Rossi replies that they should be part of operational cost (as presently done), but the management of the accelerator sector should take a decision on this point.

E.Jensen asks of how to treat non-baseline items. L.Rossi replies that they should be presented as options but the level of precision can be rough.

Finally, P.Fessia discusses the WP15 scope, which includes integration, installation and de-installation. The information regarding integration is quite complete. For installation and de-installation educated guesses can be used or feedback from specific equipment is needed. This information should be centralized in integration. Regarding collimation, the remote handling is in the responsibility of EN/STI and transport but it should appear clearly in collimation. L.Rossi suggests that the LHC example should be followed where installation cost of certain specific items has to be included in the equipment itself. He thinks though that, at this point, the estimates do not need to be that precise. P.Fessia stresses that de-installation should be discussed with all WP leaders. Regarding radioactive elements, the cost should be reflected in the equipment itself.