10th Meeting of the HL-LHC Technical Coordination Committee

Participants: C. Adorisio, A. Apollonio, A. Bertarelli, C. Bracco, R. Bruce, R. Calaga, F. Cerutti, S. Claudet, B. Delille, P. Ferracin, P. Fessia, J. Hrivnak, A. Lechner, T. Lefevre, H. Mainaud Durand, E. Metral, D. Missiaen, Y. Papaphilippou, V. Parma, H. Prin, S. Redaelli, L. Rossi, F. Sanchez Galan, F. Savary, L. Tavian, R. Tomas, l. Valdarno, R. Van Welderen, J. Wenninger, D. Wollmann, M. Zerlauth (chair).

Excused: G. Arduini, O. Brüning, M. Giovannozzi, J. Jowett.

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/TCC/Default/Home.aspx

Indico link: https://indico.cern.ch/event/515633/

No comments were received to the minutes of the previous meeting, they are therefore considered approved.

M. Zerlauth reminded WP leaders to send proposals for plenary talks for the next HL-LHC general meeting in November to L. Rossi and O. Brüning by the 30th of June. Proposals for parallel sessions should be sent to R.Tomas by 7th of July (as well as the proposed list of participants).

Following the discussions in the 9th HL-TCC, P. Fessia will give an update on the updated assumptions for civil engineering on July 21st.

Energy deposition studies for IR6 protection devices and the dump core (A. Lechner - slides)

A.Lechner presented a first assessment of the energy deposition in IR6 protection devices, magnets, septa and dump core for HL-LHC beams and optics (optics version 1.2 was taken as a reference). This analysis allows identifying possible issues with present absorber materials and equipment protection. All calculations presented assume adiabatic conditions, they therefore have to be considered as conservative estimates.

Concerning beam parameters, the conservative assumption was made to not consider any emittance growth and no intensity loss in the ramp.

A.Lechner recalled the layout of IR6 protection and highlighted the elements whose material robustness has to be studied (TCDS, TCDQ, TCDQM, TCTs and TDE core and window) and those for which protection must be ensured (MSDs, Q4, Q5, DS magnets, IR1/5 triplets and D1). The worst case scenarios for each device from the optics point of view were selected. Results for Run 2 optics were also presented for comparison.

A.Lechner presented a plot showing the maximum dose in CfC as a function of β, highlighting that a certain change of β could be tolerated as the effect on energy deposition is small. The peak energy density depends strongly on the transverse distance between neighboring bunches when swept across an absorber surface. This applies both for asynchronous beam dumps (beam swept across the TCDQ/TCDS) and for dilution failures (reduced bunch spacing at TDE).

A.Lechner presented the considered failure scenarios:

1) single MKD module pre-firing (load on TCDQ and Q4/5).
2) single MKD module pre-firing (load on TCDS and MSDA).
3) dilution failure during beam dump (load on TDE core).

The TCDQ was upgraded in LS1, from two modules to three (Gr/Cfc) modules (see slide 10 for details). The upgrade was already based on FLUKA and ANSYS simulations for HL-LHC beam parameters. Nevertheless, new observations in 2015 and 2016 require an update of the assumptions and new simulations. New MKD erratic's observed in 2015 indicate that the particle density on TCDQ can be a factor two higher than previously assumed, increasing also the load on the magnets. In 2016 several magnets (but not Q4-Q5) quenched during an asynchronous beam dump test.

L. Rossi commented that it could be expected that Q4 and Q5 wouldn't quench, given the lower current. A. Lechner agreed but added that further studies are nevertheless justified for a detailed assessment of the peak energy density in coils.

The effect of the so-called 'Type-2 erratic's (worst case scenario) was then presented. The horizontal β determines the position of the TCDQ, the smaller is the gap, the higher the load on the TCDQ itself and on downstream magnets. For HL-LHC standard beams the stresses induced by a type2-erratic could be close to the present material limits, as the peak energy density goes up to 3 kJ/cm^3. A further confirmation by thermo-mechanical studies is required. The impact on Q5 coils is more pronounced than for the Q4 magnet, reaching up to 40 J/cm^3. For magnet coils a margin of a factor three with respect to damage limits should be assumed. The damage limit for NbTi coils for ultra-fast losses is nevertheless not precisely known (so far assumed to be 87 J/cm^3). Tests by TE/MPE are foreseen in HiRadMat for a better quantification of the damage limits, as confirmed by D. Wollmann (one at warm in 2016, one at cold in 2017). Depending on the outcome of these important tests, improved protection might be required. The studies are planned to be extended to the DS in the future.

For comparison, A. Lechner showed the load on D1 (most exposed magnet) during injection failures. The peak energy density in the coils for HL beams reaches up to 30 J/cm^3. The solution is in this case to add shielding inside the isolation vacuum, reducing the peak energy density by a factor 2.

The simulated peak energy density in the TCDS for a type-2 erratic for HL beams amounts to 2.5 kJ/cm^3, still requiring thermo-mechanical studies to be performed for a final assessment and confirmation of the current baseline choices. The simulated energy deposition in the MSD confirms instead that no problems are expected.

The composition of the dump (TDE) consists of segments of high and low density graphites. In case of a dilution failure, the nominal sweep cannot be produced and the consequent impact on the dump core has to be quantified. The conservative assumption used in this case is to have all RF buckets filled (no filling scheme assumed), leading to an overestimate of the peak energy density by around 10-15 %. The results for the case of two horizontal kickers failing at the same time is presented. The hot spot is reached approximately at the location where the vertical dilution changes direction, confirming that failures of horizontal kickers are more critical. The longitudinal peak dose and temperature can reach significantly high values for this failure case, possibly leading to damage of the dump core.

L. Rossi asked if the saturation of the blue curve in slide 25 is an artefact of the simulation. A. Lechner confirmed it is an artefact, but added that above ~3700°C the sublimation phase is reached, therefore no temperature increase is expected. M. Calviani commented that more than the dump core, the critical part is the window. A. Lechner added that a complete failure matrix, accounting for the likelihood of kickers failing and consequences on the TDE core and window, should be developed.

A. Bertarelli commented that for the TDE case, the temperatures reached are such that hydrodynamic tunnelling could be expected. A. Lechner mentioned this is a known phenomenon, nevertheless the assumption of filling all RF buckets is pessimistic, so the temperatures are overestimated. A given assumption on the filling scheme could change the figures by 10-15 %. M. Zerlauth commented that it is clear that this kind of failures will become more critical for HL-LHC operation, as we will be operating much closer to the damage limits of materials, justifying thermo-mechanical studies in the coming months.

ACTION: A. Lechner should come back and present the need for mitigations of failure cases for protection elements in IR6 after conclusions from the thermos-mechanical analysis are available.

A. Lechner stated that changes of the optics can have an impact on the studies. C. Bracco commented that the dependency on β shown in the presentation is not very significant for the TCDQ. Some inputs in this respect will be given in the presentation by C. Bracco on August 4th.

Update of dose estimates at the level of the cold diode for the 11 T magnets (A. Lechner - slides)

A.Lechner recalled the experience from RHIC, where a shorted quench protection diode was found, possibly due to accumulated dose. The dose measured was 0.1 kGy, but no details are available on how far the radiation monitor was from the diode. This event could be relevant for HL-LHC, as it is necessary to estimate the long term dose in 11 T magnets 9and close by dipole magnets) due to showers from DS collimators.

The relevant locations for the study are DS L/R of IR7 and IR2 (11T in point 2 is not anymore part of the baseline). On both sides of the IP, the diode is located on the left side of the collimator, hence, in the DS left of the IP the diode is downstream of the collimator.

Assuming 10 nb^{-1} as the target integrated luminosity for ALICE for HL-LHC, the peak dose in the coils of the 11 T magnet is less than 1 MGy. For the diode it is less than 1kGy.

In IR7, assuming 10^{18} protons lost, the peak dose in the coils is estimated to something less than 2 MGy, whereas for the diode it amounts to a few kGy.

S. Redaelli asked if there's an estimate for how much the diode could get with the present LHC layout. A. Lechner explained the situation could change significantly with the present dipoles. M. Zerlauth commented that present diodes are qualified to some 50 kGy. V. Parma mentioned the ongoing discussion concerning the need for shielding inside the connection cryostat to be installed in the DS next to IR2, required for the installation of a dispersion suppressor collimator for ion operation. A. Lechner commented that the preliminary conclusions are that shielding is not needed, but it has to be checked if this is acceptable from the radioprotection point of view. V. Parma stressed that this has important implications on the design of the connection cryostat.

ACTION: an AOB on the need for shielding in the connection cryostat should be scheduled in one of the next HL-TCC meetings.

Alignment and internal metrology for HL-LHC (H. Mainaud Durand - slides)

H. Mainaud Durand gave an overview of the available alignment and adjustment system for LHC and the improvements proposed for HL-LHC.

Due to high radiation levels in the tunnel and to limit exposition of personnel, remote alignment of the triplet is proposed. The alignment error for the triplet with respect to the main elements of the LSS is within ± 0.1 mm (1 σ). For the alignment of the machine with the experimental caverns any fiducial mark of the cavern reference network is expected to range from 0.5 mm to 1.2 mm RMS.

The present system allowed achieving relative monitoring with an accuracy of few microns, monitoring of left side with respect to the right side in the order of 0.15 mm and an adjustment resolution of less than 10 µm.

Experience has shown that LSS1 and LSS5 are not stable up to Q5 and that significant misalignments are observed on the D1. L. Rossi pointed out that experimental caverns seem to move less than the machine. D. Missiaen explained that the movements are still driven by civil engineering works performed in the 1990's, as adjustments are still ongoing. Also the caverns are subject to these movements, these are however well within LHC alignment capabilities.

Smoothing is difficult to perform due to shielding, ventilation and permanent systems. It could be considered extending the permanent wire up to Q5 to perform smoothing remotely.

The relative monitoring showed good reliability, but some fixation issues have to be solved. Integration could be improved for facilitating the access to the interconnection and remote stretching of the wire could be considered. A place for training to perform the remote actions would be needed.

Thanks to the sensors, cryostat misalignments could be monitored. As an example a direct correlation between a measured misalignment (July 2008) and the signal from a pressure probe was shown. V. Parma commented that during quenches movements up to of 150 µm can be observed.

H. Mainaud Durand explained that the present system also helped the operations crew to diagnose problems, as for example the triplet movement in IR8 observed in 2015, later discovered to be correlated to the thermal shield temperature.

For HL-LHC operation, considering the increased radiation doses, remote alignment of components is important to limit exposure of personnel and mitigate the risks of helium releases.

For HL-LHC, an extension of the alignment systems up to Q5 is proposed in combination with a monitoring of the triplet cold-mass position, driven by machine performance considerations. This will also allow limiting the doses taken by the personnel (solving the smoothing issue between Q1-Q5) and it will provide a better understanding of the relative alignment of cold mass and cryostat. R&D work is on-going concerning the monitoring of the crab cavities (to be applied on the cold mass monitoring) and on the alignment sensors.

V. Parma asked more details on the assumed fiducialization (± 0.1 mm, 1 σ). R. Tomas confirmed that the requirements imposed by optics are at the level of 0.5 mm. H. Mainaud Durand explained that the values are given for the position of the cryostat, but no information on the position of the cold mass with respect to the cryostat is available. V. Parma commented that it might not be strictly needed and that the value-to-cost ratio of this solution should be evaluated. H. Mainaud Durand mentioned that the cost for the upgrade is 700 kCHF. D. Missiaen pointed out that as an example during cool-down and warm up of cold masses movements of the order of 40 µm can be experienced, and this would be seen with the new system. For comparison, V. Parma recalled that a change of 1 °C in the tunnel temperature determines a change of 10 µm for 1 m of steel. These numbers have to be compared with the required accuracy for triplet alignment (± 0.5 mm). M. Zerlauth pointed out that a 10 µm displacement is already seen by the beam.

R. Tomas asked about longitudinal alignment tolerances. H. Mainaud Durand confirmed that longitudinal alignment is much less of a concern and no changes are expected for HL-LHC.

M. Zerlauth asked whether the cited cost of 700 kCHF is already included in the WP budget. H. Mainaud Durand explained that only two items are not in the budget (collimators and the remote determination of the position of intermediary components along the LSS).

L. Rossi stressed that the HL-LHC project aims at the reduction of radiation levels to personnel.

M. Zerlauth asked how long of the realignment campaign could last. This could last several hours/half day, and the time is especially dedicated to the Q1.

Triplet movement and beam separation (J. Wenninger - slides)

J. Wenninger recalled the observations on the triplet movements in 2015. It is now known that the triplet position is sensitive to the temperature of the IT thermal shields. In this respect, the worst case was observed in R8. The orbit feedback was used to keep in place the orbit while in stable beams. In 2016 changes are much slower and the more critical triplet is in R1.

Temperature variations lead to radial displacements of the triplets in the order of of tens of µm. These induce orbit drifts and separation at the interaction points. Upon a question from L. Rossi, S. Claudet explained that the problem of 2015 was identified and solved, it was related to the wrong regulation of a valve. J. Wenninger added that the correlation with the cryogenic system became evident during the technical stop, when the cryostat was emptied.

The movements were observed qualitatively with the wire position system. The orbit feedback represents an effective tool to mitigate the effect of triplet movements, but it cannot correct for interaction point shifts, requiring regular re-optimization.

In 2016 the IP1 triplet thermal shield temperatures varied significantly over time, in particular in R1. This triplet is also in the region with highest e-cloud loads. The triplet L1 was strongly affected by the transformer breakdown due to the beach marten. In this occasion, a large pressure wave and high temperatures provoked a transverse movement of about 170 µm of the magnets, which since then settled on a new stable position. Temperatures are consistently more stable in IR5 instead.

Triplet movements generate deflections leading to orbit perturbations inside the triplet. Such a perturbation can only be properly corrected with the triplet MCBX (HV) correctors. Due to the sensitivity of the QPS system on the MCBX, false trips due to voltage spikes were observed in the past. Since 2010 the MCBX are therefore excluded from the orbit feedback configuration. For HL-LHC it is assumed as a baseline to have mid-circuit/coil voltage taps, which is expected to solve the problem. ACTION: the decision on mid-circuit/coil voltage taps for all HL-LHC magnets should be followed up in the HL-LHC magnet circuit forum (with WP3 and WP7) and become part of the circuit documentation.

The orbit feedback is able to protect the other IRs from the perturbation, but not the IR where the triplet movement occurs.

The evolution of the corrections that have to be applied to bring beams head-on versus time evolve due to ground motion, but also show a correlation with the thermal shield temperature. Typically about 1.5 µm separation per 1 K is observed. During fill 4947, the temperature decreased by 30 K in 30 minutes following a problem of the cryo-plant, yielding a separation change of 55 µm.

The cryogenics team has changed the regulation of the thermal shields during the technical stop and are now maintaining the temperature within a 2K range. Since then, no more problems have been observed.

V. Parma noted that the achieved stability following the technical stop is of a few microns, which is below the noise level. L. Rossi mentioned that due to the different beam size, these considerations could be relevant for HL-LHC. V. Parma introduced the idea of a temperature stability control in the tunnel.

L. Rossi commented it would be interesting to make a detailed analysis of the thermal shields of the present triplets and compare with new triplet for HL-LHC. V. Parma explained that the behaviour is strongly dependent on the 'spider-like' support structure.

CERN Seismic network proposal (M. Guinchard - slides)

M. Guinchard recalled the possible application of the CERN seismic network. This will be used for continuous LHC monitoring and particularly to anticipate the risk of beam instabilities linked to civil engineering activities for HL-LHC. Furthermore, it will allow quantifying the effects of micro-seismicity induced by the Geothermie 2020 program.

Two stations will be installed underground (UJ16 and UP53), plus one station on the surface (building 1173).

Two types of sensors will be installed, with measures of ground velocity and acceleration. The data acquisition system will send the raw data to the Swiss Seismological Service and to the CERN logging database.

A validation test was carried out in TT1, which already allowed the detection of two earthquakes in 2016 (from France and Ecuador).

The budget for the installation will be 115 kCHF, plus 20 kCHF per year for maintenance. The installation is planned during the 2016 EYETS if the proposal is approved.

M. Zerlauth asked what fraction of the costs would be covered by the HL-LHC budget. P. Fessia explained that 30 % would come from HL-LHC and the remaining 70 % is under discussion for present LHC operation.

M. Zerlauth asked if the construction works close to building 1173 will not affect the measurements. M. Guinchard explained that the distance from the installation should be sufficient.

B. Delille asked if a Seismic Station is already present in ATLAS and whether this is included in the seismic network. M. Guinchard replied that he's not aware of other available equipment at CERN, but that indirect measurements with other instruments are possible.

AOB

S. Redaelli asked if ECRs prepared for tests in the LHC - relevant for HL-LHC studies – should be presented in the HL-LHC TCC. M. Zerlauth proposed to include these in the presentation from I. Bejar Alonso scheduled on July 21st.