



## 17<sup>th</sup> Meeting of the HL-LHC Technical Coordination Committee

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**Participants:** C.Adorisio, A.Apollonio, G.Arduini, V.Baglin, C.Bracco, R.Bruce, M.Brugger, R.Bruce, O.Brüning (chair), R.Calaga, F.Cerutti, R.De Maria, S.Fartoukh, P.Fessia, S.Gilardoni, M.Guinchard, H.Mainaud Durand, M.Martino, E.Metral, Y.Papaphilippou, D.Perini, S.Redaeli, A.Rossi, R.Rossi, F.Sanchez Galan, B.Salvachua Ferrando, H.Schmickler, G.Stancari, E.Todesco, R.Tomas Garcia, R.Van Welderen, D.Wollmann, M.Zerlauth.

**Excused:** M.Giovannozzi, M.Gourber-Pace, L.Rossi

O.Brüning opened the meeting by reviewing the agenda.

The minutes of the last meeting have been approved with the comments received by A.Apollonio. The [Indico Page](#) contains the final version. There were two actions: the first one refers to the different options for the Q4 magnet (four correctors, three correctors and MQYY option). They should be evaluated and the impact on costs and performance should be quantified by WP2 and WP3. There was a number of off-line discussions on this subject. WP2 is following this up. A second action was related to the organization of a special meeting (outside the HL-LHC TCC) for a more detailed discussion on the RF quadrupole, with the RF GL, the SRF coordinator and SRF SL. This will be organised by O.Brüning and L.Rossi. The main question is about the resources and how this new activity would impact the other HL-LHC RF-related work.

### Design considerations for an electron-lens test stand at CERN, G.Stancari – [slides](#)

G.Stancari reviewed the design considerations for an electron-lens test stand at CERN, a work supported by US-LARP. Several new applications of electron lenses may benefit the CERN program. The purpose is to transfer experience and knowledge but also develop new techniques. There were several past applications of the e-lens, in particular its use at Tevatron. Presently it is used at RHIC for beam-beam compensation and there is a number of interesting future applications, but also interesting for LHC and HL-LHC, but also GSI (for SC compensation).

An e-lens is a pulsed, magnetically confined, low-energy electron beam. The circulating beam is affected by electromagnetic fields, generated by electrons whose stability is provided by strong axial magnetic fields. Its main components include, a source, a solenoid and a collector. The only operational test stand is located at FNAL. It was the e-lens used at the Tevatron which now is used for testing the performance of e-guns and to study dynamics of intense, magnetically confined electron beams. It has a straight configuration with three solenoids, for beams of 10 keV, with 5 A current and an electrical power of 200 kW. A new hollow electron

gun (25 mm diam.) prototype was designed at Fermilab/ CERN and built at CERN. It has been shipped to Fermilab for testing.

The research objectives for the test stand include the demonstration of magnetized electron beams with currents up to 20 A, the development of new cathodes with higher current densities, the modulation of the electron beam with frequencies up to 10 MHz and the development of new instrumentation and diagnostics.

The main design parameters are the cathode size, the e-beam energy, the choice between resistive and super conducting solenoid and the configuration of the beam path (straight or bent).

The cathode size depends on mechanical constraints but also the material for achieving the maximum current density. A cartoon is shown of a cathode, for which the beam envelope is compressed magnetically and collected for a 0.1 to 0.5 T solenoid. For space charge (SC) or BBLR compensation, typical beam sizes would require for 20 A and 50% of active area, leading to a radius of 32 mm for a conventional cathode.

The e-beam energy is affected by many factors: i) voltage required to extract the current, ii) the SC potential to be overcome, iii) the finite propagation time in the overlap region, iv) the enhancement factor which can be lost for more energetic electrons, and v) radiation protection issues. For typical beam sizes and 20 A, a kinetic energy of more than 25keV is needed.

S.Fartoukh asks why does the source have a specification of 20 A, whereas a copper wire would require 190 A. Giulio answers that this is due to the enhancement factor due to the nonrelativistic velocity regime of the electrons

The solenoid field keeps the e-field stable. The Larmor radius should be small compared to the beam size, but this can be achieved already for 0.1 T field. For the space charge driven axial magnetic and radial electric field, the velocity depends on radius. In order to slow down this sheer motion, a 0.6 T solenoid field is needed, for 20A e-beam of typical beam sizes. This field is indeed feasible with resistive magnets but the range is not good for all beam sizes.

Bends can introduce distortion, where the magnetic field is not ideally uniform but features also a non-vanishing gradient. Some studies have been done both analytically and numerically, but due to the high current, simulations should ideally be verified with experiments. A report with all the design details has been drafted and is ready to be published.

The main recommendation regarding the cathode material is that barium oxide is appropriate but new materials should be also investigated. The energy should be higher than 25 keV. Most of the program can be done with a resistive solenoid but one could go to a super conducting solenoid, which is the preferred solution for exploring magnetic compression. A configuration with at least one bend between gun and main solenoids is recommended for measuring the beam profile.

H.Schmickler pointed out that it is quite dangerous to handle 25 kV times 20 A of DC power, so another recommendation would be to implement pulsed operation, so that, in the case of

failure, the set-up is not destroyed. O.Brüning questions the need of a super conducting solenoid only for studying magnetic compression. G.Stancari answers that if the cathode could be smaller, with better material, the high magnetic field is not needed. H.Schmickler adds that the magnetic compression up to 7 has been demonstrated and for higher compression ratios an experimental verification is necessary. It boils down to the observation that the cathode size plays a crucial role in this question. O.Brüning suggests that the tests should start with a resistive magnet and then explore the super conducting option once the cathode material and size have been identified. He further asks what is already available at CERN. H.Schmickler answers that only the hall is right now identified. S.Redaeli recalls that a solenoid should also be available. H.Schmickler answers that this has a pretty low field of only 600 kG. H.Schmickler suggests as a follow-up action, to present at a later stage to the HL-LHC management a cost estimate, first for the resistive solenoid and then the staged upgrade of the test stand. O.Brüning agrees and asks whether the FNAL e-lens could be upgraded. G.Stancari answers that the collector cannot sustain such a high current. H.Schmickler reminds that the ARIES program has been signed by ATS management and a work –package is associated to e-lens work. O. Brüning comments that one should also expect a financial contribution from the ATS management in this case

G.Arduini asks what is the mechanism for the repulsion of electrons. G.Stancari answers that this is due to the longitudinal component of the electric field of the electron beam. S.Fartoukh asks if a rectangular or only a Gaussian electron beam profile has been considered. G.Stancari answers that most of the calculations were done with rectangular profiles, but comments that studies using Gaussian profiles can be added. S.Fartoukh asks about the level of accuracy, and G.Stancari answers that this corresponds to a few % oscillations. He adds that one of the purposes of the test stand is to test this accuracy.

**ACTION: A cost estimation should be presented at a later stage to the HL-LHC management for the test stand with a resistive magnet, including its staged upgrade.**

## **Analysis of lifetime drops in view of e-lens review, B. Salvachua Ferrando, S.Redaeli – [slides](#)**

S.Redaeli recalls that loss spikes and drops of lifetime are a concern for the LHC. Actually, several collimator reviews recommended to address this problem. In fact, lifetime drops determine the maximum loss rates in cold magnets and define the intensity limit for a given cleaning efficiency. In addition, at full intensity, high steady losses might even exceed the collimator damage limit. Finally, spurious dumps can be caused for given thresholds of beam loss monitors. The proposal for mitigation is a hollow e-lens in IR4. An international HL project review will take place next week to address needs for hollow e-lenses. O.Brüning stresses that this review concentrates on the needs for such a device rather than its technical requirements and that analysis of lifetime at the LHC should be discussed at the TCC meeting before this review.

S.Redaeli recalls very briefly the losses observed during Run I. During 2011, the minimum lifetime recorded as a function of fill number was very good, i.e. typically well above 1 h. On

the other hand, as the machine performance was pushed in 2012, the beam lifetime dropped systematically to below 1 h. The losses occurred throughout the cycle. The number of dumps caused by beam losses was 40-45. Even basic extrapolations of these numbers to the operation at higher energy would pose limitations for HL-LHC.

In 2015, the machine operated with higher stored energy, with a total number of 2240 bunches. The beam lifetime though was very good. During the squeeze, the total transmission was good and the minimum achieved lifetime is generally above 1h, with some isolated drops. During adjust again the lifetime is above 1 h, which is much above the 0.2 h lifetime considered for the collimator design. The peak power loss in squeeze and adjust is around 100 kW as opposed to a design value of 500 kW. O.Brüning notes that although this number seems high, it does not correspond to only one collimator. S.Redaeli confirmed that these figures refer to the total power lost from the beam. Peak losses on individual collimators are much lower, reaching a maximum of about 30 kW at the most exposed secondary collimators. F.Cerutti points out that less than 10 % of this power is indeed deposited in just one collimator. Scaling to HL-LHC energy and total intensity, there is a factor of 2 to 3 to be multiplied with the actual situation.

During 2016, the beam intensity was around  $2.5 \times 10^{14}$ , as the total number of bunches was limited. The beam transmission and lifetime in the squeeze is quite good. The total power loss is 100 kW as intensity is not very high. O.Brüning stresses that even with the factor of 3 scaling, i.e. 300kW, the power loss is still within the collimator budget. Clearly, these extrapolations are very optimistic as they assume that the lifetime remains the same independently of the bunch intensity.

S.Redaeli ends his presentation with a to do list in order for it to be ready for the review. R.Tomas questions if all the fills used for luminosity production were used for this statistics. S.Redaeli answers that there is a filter on total intensity, to avoid setup fills and part of the intensity ramp ups. O.Brüning asks if there are no losses during the transition to lower beta\*. E.Metral points out that there were some issues with the orbit in the squeeze. In addition, J.Wenninger mentioned that when coupling was corrected, the dip in lifetime disappeared. S.Redaeli agrees and adds that, clearly, lifetime is very good in Run II but it is difficult to conclude that there will be no issue for HL-LHC. In his opinion it is dangerous to rely on the present performance, as was already observed during 2011 vs 2012. In any case it is not obvious to scale losses to HL-LHC. For the review, an outline of the different beam parameters will be presented for the operation runs in 2011, 2012, 2015 and 2016. Other dedicated talks will address specific aspects such as halo population, beam-beam, orbit, etc. It should be also taken into account that the beam lifetime depends on the collimator settings that will be deployed in HL-LHC, e.g. a tighter hierarchy may be considered to recover beta\* after the June re-baselining which could impact in turn on the expected beam lifetime.

E.Metral mentions that during 2012 there were a lot of instabilities. R.Tomas adds that there were issues with the orbit and the BPM readings. S.Fartoukh adds that a lot of improvement was observed after smoothening the MCBX function. He adds that the 40 dumps mentioned correspond only to the period of a few months and then disappeared. S. Redaeli points out that the lifetimes became quite low throughout the year.

O.Brüning concludes that it is important to try to quantify the net impact on the machine performance. One important aspect is how many of the fills will be lost before going to stable physics. Is it 1% or e.g. 20%? S.Redaeli answers that an estimate will be indeed presented. E.Metral asks if there is any estimate about the halo population of the tails at different stages in the fill. S.Redaeli answers that G.Valentino will present the results of dedicated MDs covering tail populations in different phases of the operational cycle, but experience is limited. Note that we lack a halo monitor at the LHC. R.Tomas suggests to try in MD 50 ns with high brightness as in 2012.

O.Brüning closes the subject by inviting all to participate to the review, which is indeed open and will take place during Thursday and Friday 6-7 of October (see <https://indico.cern.ch/event/567839/>).

## Update on Mini TAN and D2 protection for IP8, F. Sanchez Galan - [slides](#)

F.Sanchez Galan presented the progress with the protection devices in point 8. Support of many WPs was provided but mainly from WP10 and WP12. He reviews the scope, iterations and work progress. During HL-LHC, an increase of the LHCb luminosity is foreseen but there is currently no TAS or TAN foreseen in point 8. Thus, there is a need of protection with minor impact on layout in particular for D2, which without protection would have a rather high load. The first idea was to install a miniTAN inside the Y chamber. This is not possible because of space constraints as there is also the BRAN inside and only a bit less than 600 mm are available. After evaluating the space constraints, the concept of a short TAN with an integrated BRAN came up. But still another device was needed for protection. The concept of an additional mask introduced again a problem for integration. The solution presented in Chamonix 2016 included a mask, a miniTAN and the BRAN inside the miniTAN. Again, at that location there is really no space at all. F.Cerutti evaluated different options for protection and analysed two possibilities: a displaced miniTAN alone, or a cold mask. The single mini-TAN option is preferred with 500 mm absorber length. Integration studies revealed however, that the integration was not possible unless collimators were moved. A practical limit exists in the position of collimators not from optics but again from an integration point of view. The TCTPH is too close to the vacuum pipe and cannot be displaced without colliding with the vacuum chamber.

Photos of the area clearly demonstrate that the first collimator is too close (~1mm) to the vacuum chamber and a displacement is not possible unless the collimator is modified. To integrate a 500 mm absorber would need the displacement of the collimators towards the Y chamber, which is only possible with a redesign of the TCTPH to avoid interference with the vacuum chamber. Work started on different configurations and the integration work revealed the need to displace the BPMs from their current position in front of D2 to the vicinity of the Y-chamber (towards D2 side). The collimators are not displaced, and the space released allows for the installation of an absorber with 456 mm longitudinal shielding. F.Cerutti needs to do further calculations, but it seems to be an acceptable solution at first glance. There are also a lot of implied modifications for the vacuum, but they do not affect critical components like

collimators. The proposed absorber with reduced shielding, necessitates the displacement of the BPM to the Y-chamber.

In conclusion, there will be a single absorber in front of D2. The layout exercise has just finished. There are no displacements of collimators or the Y-chamber, no BRAN displacement or displacement of scintillators. The next steps to be followed are the detailed design work, evaluation of the survey and alignment with the bake out equipment in place, finalization of the RP confirmation and Fluka team calculation's. The ECR is being prepared. P.Fessia would like to underline that there is already an existing problem with the bake-out equipment in point 8, related to the LHC (baking of the TCTPH), that has to be worked out with consolidation. R. De Maria asks why there is a discrepancy between the model and the reality found in the tunnel. P.Fessia says the discrepancy found in the tunnel was already revealed in CATIA. F.Sanchez Galan stresses that the model showed a theoretical transversal clash displacing the collimators by 400mm, and that it remains with less 1 mm tolerance in transverse dimensions (baking non-conformity). S.Fartoukh points out that the crossing angle assumed in the simulations is very large, and comments that small crossing angle should be worse for protection. F.Cerutti answers that indeed the simulations consider the most aggressive configuration. The currently proposed lay-out with one absorber situated in front of D2 gives a better protection than the previous baseline configuration (one absorber + one mask).

## Updated Parameter Table – R.Tomas Garcia

R.Tomas Garcia presented an update of the HL-LHC parameters after the re-baselining, with the minimum beta\* of 20cm, two CCs per beam and IP side, and a crossing angle reduced to  $12.5 \sigma$ . The peak pileup is smaller than 1.3 events/mm. In this table, the RF needs in bunch length to ensure stability is included, leading to 1.2ns (i.e.  $\sigma$  of 9 mm). A presentation of E.Shaposhnikova showed that, the bunch value was below the stability limit already from intermediate bunch length (a bit larger than the 7.5 mm baseline). Assuming that pile up is kept at 140 events / mm, leveling times are reduced. O.Brüning asks to include a footnote the CC voltage, mentioning that the cavities are assumed to run at nominal voltage in the new configuration which corresponds to approximately 70% of the required total voltage. The effect of the bunch length in the integrated luminosity during the fill is a loss of around 1.3%. This is assuming the same voltage and 3 eVs longitudinal emittance. R.Calaga stresses that 3 eVs looks too big. O.Brüning asks that this value is confirmed off-line. R.De Maria suggests that also the voltage of the main RF system is mentioned. S.Fartoukh mentions that the bunch longitudinal distribution is not a Gaussian, but a cosine square. O.Brüning suggests to implement also a footnote on both of these comments. M.Zerlauth asks whether the BCMS option should be scaled. Rogelio agrees and comments that this can be done quite easily. O.Brüning suggests to finalize this by tomorrow (30/09) and update it on Monday (3/10), leave it for comments up to Wednesday (5/10) and have it ready for the TDR and the C&S review. G.Arduini suggests to leave the bunch length untouched and have another iteration later, as a lot of studies have been done with the old value (in addition to the TDR being based on the intermediate bunch length). R.Calaga agrees and suggests to use the correct longitudinal distribution for estimating the IBS impact correctly. S.Fartoukh points out that even the old

value of 8.1 mm was not corresponding to a Gaussian. O.Brüning agrees to leave the old bunch length with a footnote that the bunch length is been re-discussed. G.Arduini asks if the maximum voltage of 16 MV is the correct number. R.Calaga replies that this is correct, but ones should mention in a footnote that full-detuning is assumed.

Lucio Rossi comments off line after the meeting that the update of the parameter table should not introduce variations of the nominal HL-LHC luminosity performance goals: nominal levelled luminosity of  $5 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ . Rather, the table should vary the implied maximum average event pileup for the different configurations.

## Background vibration measurements in Point 5– M.Guinchard

M. Guinchard starts his presentations presenting first the ground motion measurements, followed by a summary of the dynamic response of the MQXA cold mass and an overview of the seismic network installation.

Vibration measurements are taken since 2005. They first started in sector 1-2, in 2010, measurements were taken directly in CMS cavern (slab and top of detectors), in 2012 both side of CMS cavern were covered, in 2015 a vibration system was put in the inner detector of ATLAS, and last week one was put in ALICE.

Today some measurements are also done on the surface. The set-up in sector 1-2 allows synchronous measurements with a phase error smaller 0.01 deg. Measurements are taken while LHC systems are in operation and during night time. They are multi-directional over 1km. The Power Spectral Density (PSD) versus the frequency shows a clear transition at 1 Hz. Below this value the impact is micro-seismic, above 1 Hz, it is cultural noise. The PSD integration shows 0.5 nm to 30 nm. A coherence measurement was done for all 3 directions presents the more interesting behaviour. For a distance of 900 m, only micro-seismic is observed.

Regarding the CMS set-up, this is again a synchronous measurement from both sides, LHC systems are in operation and they are multi-directional. The measurements for different distances show coherence up to 1 Hz and then the signal decreases. O.Brüning asks why the curve corresponding to 98 m, does not have any signal. M.Guinchard answers that this is at the limit of the sensors. The valley in the middle of the plot is also an artefact of the measurements.

Other measurements in the world are shown, revealing that the LHC tunnel is very quiet. TT1 is very close to the LHC tunnel and it is equipped with a lot of sensors. O.Brüning is surprised that the ISR tunnel is as similar as the LHC. E.Mainaud Durand replies that ISR is already 10 m underground.

Cold mass vibration studies were undertaken for measuring the three transfer functions of the triplet magnets in SM18. Two eigenmodes with strong responses were observed at frequencies of 22 and 8 Hz. After an analysis of the MQXA cold mass, a lot of Eigen frequencies were observed and in particular 8.9 Hz close to 8.4 Hz. The mode shape is lateral. There are also the 23.5 Hz and 25.7 Hz lines, corresponding to bending modes in the cold mass (vertical

and lateral). In conclusion, the frequencies correspond to the cold mass not the vacuum vessel.

Regarding the seismic network, a proposal was approved in LMC, funding was identified, P1 and 5 will be installed in the 2016/2017 Year End Technical Stop. The network captured the earthquake from Italy, in TT1 where  $\pm 50\mu\text{m}$  displacements were measured.

In conclusion, a large number of ground motion measurements were performed at CERN over the last decade. The ground motion excitations are coherent over a short distance and on a very limited frequency band (0.1 to few Hz). After several metres, only the micro-seismic excitation is coherent. Experimental modal analysis of the MQXA cold mass has confirmed the dynamic response measured during previous studies. Improvement of the cryostat stiffness should not affect much the dynamic response of the cold-mass. Seismic network installation is in progress as planned.

P.Fessia confirms that as modes are linked to the cold mass, we cannot damp them with modifications to the cryostat. D.Duarte Ramos could come to report on the eventual blocking of support feet for minimising vibrations. He adds that if there is a problem in the triplet, there will be a damping of a local source from cultural noise, but not much else.

O.Brüning asks if the data from the sensor is centrally logged. M.Guinchard replies that this is not yet done. There is a plan to start the equipment in March for civil engineering activity, and then it will be available in TIMBER. O.Brüning stresses that a lot of groups are interested in the data. M.Guinchard mentions that for the TT1 station, he is collaborating already with J.Wenninger.

## **AOB: Summary of Wide band feedback review – G. Arduini**

G.Arduini summarises the Wide band feedback review. The final report is still being written. There were 4 main tasks: instability of SPS LIU beams, experience with the feedback demonstrator, evaluation of feasibility and performance, and outlook of a roadmap. The findings revealed that there has been clearly significant improvement for the SPS demonstrator feedback system, with the possibility to demonstrate damping of single bunch instabilities, and up to 64 for multi-bunch and concurrent operation with the existing damper. Damping of TMCI has not yet been demonstrated. Three years will be sufficient to build a full system but that implies continuity and conservation of the gained experience. An update concerning LHC and HL-LHC simulations was also given: a system for e-cloud instabilities with 4 GHz of bandwidth, where for the SPS it is only required to go up to 1 GHz, will be needed. A further upgrade for kickers and power amplifiers would also be necessary for application to the LHC or HL-LHC. This could be of interest for HL-LHC if signs of e-cloud instabilities are expected / observed even if the e-cloud build-up is suppressed in the dipoles. Tests after LS2 with beams with higher bunch intensity from the injectors are important for addressing this need. O.Brüning asks when the report will be out. Gianluigi answers that it is expected at the beginning of next week. O.Brüning mentions that an estimate of cost for the kicker upgrade is needed before LHC or HL-LHC can respond to the review recommendations. A link to the TCC page should be made when the report is ready.

The meeting is closed with a summary of the next agenda.

The next TCC meeting will take place on the 13<sup>th</sup> of October 2016.