WP2
Meeting #173
Tue 21 April 2020, 9:00 – 12:00

Chair:	Gianluigi Arduini
Speakers:	Nicolo Biancacci, Nicolas Mounet, Xavier Buffat, Carlo Zannini, Gianni Iadarola
Participants (vidyo):	Carlotta Accettura, Roderik Bruce, Rama Calaga, Federico Carra, Riccardo De Maria, Ilias Efthymiopoulos, Massimo Giovannozzi, Wolfgang Hofle, Ivan Karpov, Sofia Kostoglou, Adnan Kurtulus, Ewen Maclean, Alessio Mereghetti, Elias Métral, Konstantinos Paraschou, Yannis Papaphilippou, Tatiana Pieloni, Stefano Redaelli, Giovanni Rumolo, Benoît Salvant, Kyriacos Skoufaris, Galina Skripka, Guido Sterbini, Rogelio Tomás, Christine Vollinger

AGENDA

MEETING ACTIONS

Stefano	Measurement of the resistivity of collimators taken out from the tunnel
Carlotta	Obtain a curve for the CFC resistivity vs. DPA.
Stefano, Nicolas	Finalize the choice of collimators (design and material) for the TCLs in the IRs.

Gianluigi	Set up new tables with all operational parameters.
Xavier	Check that putting the separation in the crossing plane (before collision) is a valid option.
Gianni, Lotta Mether, Konstantinos	Report on the bunch-by-bunch tune shifts due to electron cloud.

GENERAL INFORMATION (GIANLUIGI ARDUINI)

Gianluigi briefly went over the minutes from the previous meeting, which have been circulated. The first talk by **Ezio Todesco**, about the enigma of b4 correction for IR5 in the LHC, concluded that a wrong orientation of the beam screen in IR5 is excluded, hence the enigma remains. Massimo had suggested that stray fields from the CMS solenoid could be the reason. One remaining action (**Ezio**) is to check the field quality with the HL-LHC octagonal beam screen. **Frederik Van der Veken** then presented the effects of feed-down from b3 from D1, D2, MCBRD and MCBXF, showing a substantial impact on beta-beating. The possibility to use feed-down cancellation to increase the DA, remains to be studied - a talk is foreseen on that subject on May 19th. **Riccardo** then provided updates on the D1 aperture optimization, as a follow-up of several previous discussions. Solutions involving beam screen rotation or modification of its shape were discussed. A solution involving a 2mm shift could be found for both round and (to a lesser extent) flat optics, which will be discussed in the working group on alignment, and proposed to the TCC. Finally, **Gianni** showed updates on the HL-LHC filling schemes, which will be introduced in the TDR. The HiLumi WP2 web page was updated accordingly, and an action is expected regarding the analysis of burn-off for the different classes of bunches in the various collision points (**Gianni, Rogelio**). The latest filling schemes will be presented at the TCC (for protons and also for ions, after the talk of **Roderik** on the ions operational scenarios at the WP2 meeting on May 5th).

1 MEASUREMENT OF COLLIMATOR BLOCK IRRADIATED SAMPLES - STATUS AND PLANS (NICOLO BIANCACCI)

The status and plans of the irradiation tests are presented for four batches of samples: BNL-2018 (proton irradiation already performed, microstructure observations still to be done), GSI-2019 (ion irradiation, DC & RF resistivity tests and microstructure observations all done), GSI-2020 (ion irradiation postponed to 2021, DC resistivity measurements foreseen) and BNL-2020 (samples in preparation, tests in more than 1 year because of radioactivity). For GSI-2019 samples, resistivity tests on HiPIMS (coating technique used for the HL-LHC collimators) samples show an increase in resistivity by a factor 2 to 3 for Mo coating on Mo-graphite after irradiation (and a factor 2 for Mo on graphite) but more statistics is needed, which will be achieved with GSI-2020 samples. SEM-FIB observations on GSI-2019 irradiated samples show no significant change in microstructure for a peak DPA in the coating equal to the one expected by the end of HL-LHC. Additional RF measurements are planned with a new, smaller RF H011 cavity, still to be fabricated at CERN. This will be tested on GSI-2019 and GSI-2020 samples, as well as (if radiation level allows it) BNL-2020 samples.

- **Gianluigi** asked if there will be reference measurements on the samples to be irradiated in 2020, BEFORE irradiation. **Nicolo** answered that there will be DC resistivity measurements for the GSI-2020 samples (these are very thin so do not allow RF measurements), and DC & RF measurements for the BNL-2020 ones; then the same measurements will be done by the company.
- **Gianluigi** asked about the meaning of DCMS and HiPIMS. **Nicolo** said that DCMS (direct current magnetron sputtering) is the standard sputtering technique used for coating, while HiPIMS (high power impulse magnetron sputtering) is a more recent technique that provides a coating very similar to the bulk material.
- Regarding the resistivity analysis of the GSI-2019 samples (slide 4), **Stefano** wondered if the full area of the sample was irradiated, or rather if the factor 2-3 on the global resistivity means actually higher values were reached locally. **Carlotta** answered that the sample area was fully irradiated (but over a varying depth) and that the value measured is the uniform resistivity.
- **Gianluigi** asked if the design of the new cavity is ready, if it is fabricated, and if not how many people are needed to do it. **Nicolo** answered that it was about to be fabricated when CERN closed, and that one person from EN-STI is needed. **Stefano** mentioned that it is not people from EN-STI who will actually fabricate the cavity; this has to be checked with **Inigo Lamas**. He added that it is probably not urgent anymore – one has to check how the planning of BNL changed recently. However, **Gianluigi** mentioned the need of the cavity also for the GSI samples, and the fact that it's better to be ready before the start-up, so we should check if the samples can be sent to the company, because after start-up this activity will become very low priority with respect to many other activities, so one should avoid being blocked by fabrication time. **Stefano** agreed. As a follow-up to the meeting, **Nicolo** discussed with **Ricardo Fiastre** who said the cavity could be fabricated between 2 to 4 weeks after CERN re-opens. **Carlotta** added that the GSI samples are radioactive, so they need to be checked by radio-protection before being shipped, which requires manpower as well. Other samples need to be shipped by a company to us, then they will be shipped to GSI or BNL.
- **Stefano** mentioned that despite the effect of irradiation, the resistivity of Mo remains much lower than that of CFC. For the LHC there are only a few collimators concerned so a factor 2-3 is ok. **Carlotta** added the factor 2-3 is still much less than for other coatings, and there is no dramatic effect on the microstructure. A factor of 2 is accepted from the impedance point of view. On top of this, **Nicolas** and **Carlotta** mentioned that irradiated CFC is also undergoing a significant resistivity increase albeit in a limited area of a few cms as seen in FLUKA simulations (up to a factor 30 on resistivity according to **Carlotta**, for the DPA accumulated during the full HL-LHC lifetime - it is much less for the LHC according to **Stefano** - this can be checked with **Anton Lechner**). **Gianluigi** then wondered if we could get a resistivity measurement from the actual collimators of the machine. **Stefano** said that two primaries are out, so measurements could take place as soon as the level of radiation allows it. **Gianluigi** asked also about the possibility of measurements on the secondaries, but **Stefano** said the DPA is much smaller in secondaries (by a factor of 5 according to **Carlotta**). **Federico** also mentioned that the DPA is very localized in CFC collimators.

- **Gianluigi** wondered if irradiation could be related to the discrepancy between model and impedance measurements, in particular those of 2018 which are much further away from the model as those of 2017 (see 161st WP2 meeting). **Stefano** argued that collimators have very different doses so an irradiation cannot explain a global difference for all collimators. **Elias** and **Gianluigi** insisted that it would be good to get measurements of collimator jaw resistivity, Action: **Stefano**) and to be able to predict all the resistivities for each collimator depending on the dose received on each of them - even if it might be different in the machine (Action: **Carlotta** - obtain a curve of resistivity vs. DPA).

2 SHORT UPDATE ON THE DIFFERENCE BETWEEN OLD AND NEW IMPEDANCE MODEL (NICOLAS MOUNET)

The impedance model of HL-LHC received two additional updates compared to the one presented during the 170th WP2 meeting. First, the impedance factors due to the shape and weld of the octagonal beam screens in the triplet region were updated thanks to new computations by **Carlo**. The updated factors are lower than the previous estimates, but the impact on the impedance model is confined to low frequencies and hence no effect is foreseen for any operational configurations with the transverse damper on. Second, the beta* was updated from 15cm to 40cm as this is the most critical configuration before collision. The latter has a clear impact in impedance because of the corresponding change in TCT and TCL settings in the interaction region.

The full model is compared to a previous one from Sergey Antipov (2019, with beta*=48cm). In the vertical plane, the new model is higher by 20 to 40% (slightly less in horizontal). The main contributions to the difference were identified as the two secondary collimators that are not anymore Mo-coated in the baseline configuration, and to a lesser extend the TCLs in Q6 of IR1 and 5 (which are, in the updated model, closer to the beam, with higher beta functions and higher resistivity) and the pumping holes (higher impedance due to higher beta functions in half the arcs, with ATS optics). The impact on octupole thresholds of the update of the model with respect to the 2019 one is only of 13%, because the most critical plane (horizontal) is less affected than the other one. The crab cavities have a strong impact on imaginary tune shifts, but a much lower one on the real tune shifts, hence the overall stability threshold increases by only 5% more with the crab cavities.

- **Gianluigi** asked if the resistive-wall impedance is the main reason for the higher impedance of the TCLs in Q6. **Nicolas** answered in the positive.
- **Riccardo** commented that the settings in the TCLs in Q6 could be actually smaller than 22.4 sigmas for beta*=40cm. **Stefano** said that this is the baseline scenario but indeed they could change.
- **Stefano** commented that there is an ongoing discussion about the kind of collimator (material and design) to be put for the TCLs in Q6. **Gianluigi** confirmed that this has to be discussed (Action: **Stefano**, **Nicolas**).
- As a follow-up of the meeting, **Elias** mentioned that the model with two uncoated collimators was already presented by **Sergey Antipov** in 2019 (at that time several options were possible for the uncoated collimators) – see e.g. his talk at the COLUSM #120**.**

3 Short update on the HL-LHC octupole and TeleIndex requirement with the new impedance model (Xavier Buffat)

New transverse stability thresholds for HL-LHC are presented, which take into account the latest developments of the impedance model (see previous talk) and update the ones shown during the [170th WP2 meeting](). The results include long-range effects and both the crab cavity angle and beta* are scanned to find the best configuration for both octupole polarity and synchronous/asynchronous collapse. For the positive polarity the threshold becomes 550A in octupole current (vs. 450A with the old model) with a teleindex of 1, but the required teleindex becomes 1.6 when residual lattice errors (coupling and lattice non-linearities) are included. With negative polarity, a teleindex of 2.95 is required without errors (vs. 2.6 with the old model), but this becomes 3.1 with residual lattice errors. Both the positive and negative polarities are invalidated by dynamic aperture (DA) considerations. Possible alternatives are: 1) to reconsider the coating of the two uncoated secondary collimators; 2) to introduce an additional 1 sigma retraction in the collimators (to be confirmed with the new model); 3) to check the DA with positive polarity, higher beta* and lower crab cavity angle; or 4) to mitigate the "Shaqiri effect" by putting a separation in the crossing plane before entering into collision.

- **Gianluigi** pointed out that the third alternative to gain margin (collide at higher beta* / asynchronous collapse / crab cavities still a little on) is also good for the cryogenics which require to lower the initial luminosity. **Xavier** confirmed and said the crab angle is not optimal, but we could free this area better with a separation in the crossing plane.
- **Yannis** asked why we choose beta*=41cm. **Xavier** answered this is the ultimate scenario. If we relax this, there remains still part of the 4% additional octupole current due to residual coupling, but not the margin needed to accommodate the lattice (mainly triplet) non-linearities, so one could gain stability margins. **Gianluigi** pointed out the need to set up new tables with all operational parameters (Action: **Gianluigi**). **Riccardo** confirmed this is indeed needed.
- **Riccardo** asked if one could get some margin from the crossing angle, i.e. not going up to 250 mu.rad, in order to mitigate the DA. **Yannis** confirmed this could be an option. **Xavier** said that a large crossing angle with a separation is very critical for stability, so it is better to have a crab angle, or equivalently to reduce the crossing angle. **Gianluigi** mentioned that if we increase beta*, we can decrease the crossing angle. **Xavier** said that stability wise, it is the Piwinsky angle that matters (one wants a small one for stability, which is in conflict with what is good for DA). If one could put the separation in the crossing plane, then all of these constraints will disappear; one needs to check in MADnPySSD. **Riccardo** mentioned that the bumps in the crossing plane are already there, and the optics is ready. **Gianluigi** confirmed this would be useful to confirm, and **Xavier** said he can check this (Action: **Xavier**).
- **Rama** mentioned that in the context of the lower luminosity required by cryogenics at the beginning of the fill, there were discussions with **Rogelio** to use the crab angle in the opposite way. **Xavier** pointed out that actually, here a crab angle with a minus sign is the usual one (i.e. it compensates the crossing angle). So according to the plots, with a positive crab angle (i.e. the crab cavities working in the opposite way as usual), one gets a very severe loss of Landau damping.

4 Beam-beam induced crabbing (Xavier Buffat)

A two-particle model is used to evaluate the maximum beam-beam induced crabbing angle. This quite pessimistic model is refined using Hirata's 6D approach, in order to include the non-linearity of the force and the Gaussian distribution of the bunch (still, in a non self-consistent manner). The beam-beam induced crabbing is then evaluated for a crossing angle spanning -0.3 to 0.3 mrad, and for both 60cm and 15cm beta* (start and end of the collisions), showing at maximum a 5mu.rad crabbing angle (which is further reduced by the crab cavities induced crabbing). The non-closure contributions from beam-beam and crab cavities are out-of-phase, so they could be disentangled by well-placed head-tail monitors.

- **Gianluigi** asked if "out of phase" means out-of-phase with respect to the kick from the crab cavities. **Xavier** answered in the positive. **Gianluigi** asked then if we need two head-tail monitors at 90 deg from each other. **Rogelio** mentioned that this is what was agreed (not exactly 90 deg but close enough, in IR4).
- **Gianni** asked whether there is no effect if we look at non-colliding bunches. **Xavier** answered that indeed there is no effect since all this originates from head-on collisions.
- **Gianni** commented about a similar possible effect from electron cloud: there is no crabbing kick from e-cloud on the unperturbed distribution, so the effect should be zero except if there is a non-closure. He wondered if it would be small. **Xavier** expected that it is indeed small, as beam-beam is the strongest. **Gianni** wondered what would be the scenario to study. **Rogelio** said even though a non-closure is expected from the crab cavities, it's difficult to know or control it. The question is still if the electron cloud will interfere with this, and if it can amplify it. **Gianni** expected the effect is fully negligible; with some hypothesis on the crabbing angle one could try to show it's negligible with a simplified model. **Rogelio** said that if the effect is thought to be negligible, this is not high priority. **Xavier** mentioned that one option could be to assume that one crab cavity is not working, and check if it's indeed negligible.
- **Yannis** pointed out that one also has to understand the impact of non-closure on DA with beam-beam (both in nominal and ultimate configurations), scanning possible non-closure scenarios.
- **Gianluigi** commented that it is good to have the estimates of beam-beam induced crabbing. He wondered if it is enhancing the non-closure, or if it is in quadrature. **Gianni** said it adds with the other experiment. **Gianluigi** asked if it is then in 90 deg with respect to the non-closure. **Xavier** answered in the positive.
- **Riccardo** mentioned that it would be useful to test a scenario where only one side of the crab cavities works, as a failure scenario. He wondered whether we want to operate like this, if there is no strong issue. This is interesting also for optimization.
- **Ilias** mentioned that the numbers have to be compared considering the jitter on the bunch length, and on the position within the bucket. **Xavier** said that even including these, it remains small. **Gianluigi** said it could also be compared to the varying arrival times at the IPs: in IP1 and 5 most bunches will arrive at the same time, **Gianni** added that they arrive at the same time but not at the right time. **Xavier** said that if the bunches are displaced longitudinally, the induced crabbing can only be reduced. **Gianluigi** said that the change of the longitudinal position in IP2 and 8 should be larger.

5 TUNE SEPARATION ALONG THE BUNCH TRAIN (CARLO ZANNINI)

This is a follow-up of the presentation done during the 170th WP2 meeting on the expected tune shift along the bunch train of HL-LHC (baseline filling scheme, with 2760 bunches) from PyHEADTAIL simulations. The impedance model used is the resistive-wall part of the impedance (2019 model). The tune separation along the bunch train is specifically investigated here, which requires first to understand if the bunch-by-bunch tunes simulated are accurate in absolute value. The rather large (~1e-3) tune shift of the first bunch of the train, with respect to the unperturbed tune, is found to be caused by the detuning impedance and to be a multibunch/multiturn effect. This reduces the initial tune separation of 1e-2 from optics, to around 8e-3. On top of this, the tune separation is found to vary all along the bunch train, with a total excursion of 2e-4.

- **Rogelio** commented that this is a 5% effect on the tune separation, which does not seem to be a significant problem. **Rogelio** also asked if all the impedance is included. **Carlo** answered that only the resistive-wall part is there. **Nicolas** confirmed that only the geometric impedance is missing but this does not provide any detuning impedance. **Rogelio** asked about the possible coupling terms from the skew collimators. **Nicolas** answered that they are quite small. **Rogelio** asked about the effect of the offset due to the orbit. **Nicolas** answered the effect is most probably small.
- **Gianni** pointed out that we already correct the average of the tune shift. Also, by chance we correct on the first bunch. **Gianluigi** said that anyhow it seems the excursion is small at the end, between 1e-4 to 1.5e-4.
- **Yannis** wondered how large is the tune shift from electron cloud on top of this one. **Gianni** answered it is of same order of magnitude and probably not important; as electron cloud kicks go down with energy (contrary to the impedance). There is ongoing work by **Lotta Mether** and **Konstantinos** on this subject. **Gianluigi** pointed out the need to see this information as soon as we get an idea of the result. **Gianni** confirmed there is a plan to study this during this year (in particular the single-bunch tune shift from mode 0) (Action: **Gianni**, **Lotta, Konstantinos**).

6 BEAM STABILITY WITH E-CLOUD FOR BUNCH INTENSITIES BELOW 2.3E11 (GIANNI IADAROLA)

This is a follow-up of the presentation made by Luca Sabato at the 165th WP2 meeting. The purpose is to investigate instabilities from electron cloud for intensities lower than 2.3e11 protons per bunch. In the dipoles, it is shown that the critical intensity range is 0.5 to 1e11 protons per bunch for which single-bunch instabilities occur (as observed during Run 2 at injection and for the 2016 scrubbing run). At any higher intensity, in the dipoles the electron cloud density is strongly reduced at the beam location, which is a clear mitigation of single-bunch instabilities. Coupled-bunch instabilities could occur but are in turn suppressed by the transverse damper (ADT). In the arc quadrupoles, simulations show that the electron density is also decreasing with intensities higher than 1.2e11 protons per bunch. The beneficial effect of high intensities was confirmed by a test in 2018 with trains of 12 bunches spaced by 25ns, which showed no instability even at zero octupole current for 1.8e11 protons per bunch, while a beam with the same filling scheme but an intensity of 0.7e11, underwent instabilities even with 56A in the octupoles.

With small emittances (1.2 mu.m), high intensities have the same beneficial effect according to simulations, but the octupole current will have to be increased to compensate for the reduced tune spread.

In conclusion, the increase in single-bunch intensity has only a positive impact on the beam stability from electron cloud, for the full range 1.2e11 to 2.3e11. Still, for the HL-LHC operational scenarios the proposal is to keep the injection settings as in Run 2 (Q' from 15 to 20 units, octupole current 50 A, and ADT damping time less than 20 turns) as this will be needed during reconditioning phases at the beginning of each run, keeping in mind that later optimization might be possible. During scrubbing runs and intensity ramp-up, Q' and octupole currents might have to be increased to control instabilities, hence one prescription is that the optics choices of HL-LHC should not degrade the DA with respect to the one of Run 2.

- **Wolfgang** asked if we need the high-bandwidth settings for the transverse feedback only at the injection plateau or also at flat top and/or for colliding beams. **Gianni** answered that for simplicity we can keep it during the ramp, and put it off when colliding (for noise reasons) as done in Run 2.

7 ROUND TABLE (GIANLUIGI ARDUINI)

The date of the next meeting is May 5th. **Sophia** will also present her work regarding the noise from the power converter, as a preparation to her talk at the TCC. Therefore, the agenda will be:

- HL-LHC ion operational scenario (**Roderik Bruce**),
- Performance aspects with LHCb leveled luminosity at 1.5×10^{34} $cm^{-2}s^{-1}$ (**Rogelio Tomás**),
- Table with the expected sources of noise: characteristics, origin and mitigation measures (**Guido Sterbini**),
- Summary of power supply ripple observations in the LHC and impact on the HL-LHC (**Sofia Kostoglou**).

Reported by N. Mounet