Special Joint HiLumi WP2/WP5 Meeting

Tuesday 27th June 2023, 09:30 – 12:00

Chairs: Nicolas Mounet, Stefano Redaelli

Speakers: Carlotta Accettura, Leonardo Sito, Lorenzo Giacomel, Björn Lindström.

Participants (26): Oliver Aberle, Carlotta Accettura, Yannis Angelis, Xavier Buffat, Kay Dewhurst, Riccardo De Maria, Colas Droin, Lorenzo Giacomel, Massimo Giovannozzi, Björn Lindström, Lotta Mether, Nicolas Mounet, Francois-Xavier Nuiry, Thomas Pugnat, Konstantinos Paraschou, Antonio Perillo Marcone, Luisa Puddu, Stefano Redaelli, Giovanni Rumolo, Leonardo Sito, Guido Sterbini, Natalia Triantafyllou, Frederik Van Der Veken, Wilhelmus Vollenberg, Carlo Zannini, Markus Zerlauth

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MEETING ACTIONS

Actions:

1: Stefano to look into what happened with the TCDQ coating that had disappeared

2: Impedance team & Wil to measure and report back on the effect of oxidation on Cu-coating conductivity.

3: Nicolas, Xavier, Stefano & impedance/collimation team to design one or several scenarios making a good compromise between impedance and cleaning.

(see action list on the WP2 webpage, for the complete list of current actions).

1. General Information (Nicolas Mounet / Stefano Redaelli)

Stefano reported on the recent news from WP5:

- The crystal collimator (B1H) that was removed before the startup due to issues has been repaired and installed during TS1. It was tested at injection and the channelling could be found. We now have the full system with all four crystal collimators working. This Friday a dedicated CollUSM is scheduled to discuss both the hardware controls and the beam measurements.

Nicolas reported on the recent news from WP2:

- **Markus** presented an updated schedule for Run4 in the HL coordination group (EDMS 2902691, in preparation). The current assumptions are: 15 weeks for YETS; 3 TS of 5+2 days each; beam commissioning 40 days year 1, 40 days year 2, then 25 days; 20-22 MD days (reduced to 5 along the runs); ions and special runs of 29 and 9 days respectively; conservative assumptions for scrubbing (10 days in year 1); and intensity ramp-up (# bunches) now separated from physics, which still includes bunch intensity ramp-up. 69 days of proton physics at the start of Run 4, 145 days of physics at the end of Run 4.
- Also at the HL coordination group, **Rogelio** presented WP2 ideas towards a new Run 4 baseline. The main point is that WP2 is assuming flat optics as the new baseline. The project is OK with this, pending approval in the TCC. LHCb also supports the studies on flat optics. Regarding the pile-up limitations, the detectors are designed for a PU of 200, but computing resources are not yet approved to be there in Run 4. For the moment, a PU of 140 should be assumed as nominal, and a luminosity not exceeding 5×10^{34} cm^{-2} s^{-1}.
- At the TCC on 22/06, **Thibaut Lefevre** presented a technical update on WP13 activities, concerning HL instrumentation, showing in particular the progress of the BPMs between Q1 and Q5, and the progress on the BGC, among many other highlights.
- In the annual meeting, there will be one more session involving WP2, organised by **Guido**, on Wednesday afternoon, concerning the beam-beam wire compensator. The satellite meeting will instead be a managerial meeting (TBC).
- The HB 2023 workshop will be organised at CERN, 9-13 October. Talks related to WP2:
    i. A linearized Vlasov method for the study of transverse e-cloud instabilities – Sofia J. et al.,
    ii. Emittance growth from electron clouds forming in the LHC arc quadrupoles – Kostas et al.,

iii. Mitigation strategies for the instabilities induced by the HL-LHC Crab Cavities fundamental mode – Lorenzo et al.,
iv. Slow vs fast Landau damping threshold measurement at the LHC and implications for the HL-LHC – Xavier et al.,
v. High intensity beam dynamics challenges for HL-LHC – Nicolas et al.
vi. Analysis tools for numerical simulations of dynamic aperture with Xsuite – Thomas et al.
vii. Study of the performance of the CERN proton synchrotron internal dump – Thomas et al.

Talks related to WP5:

viii. Run 3 collimation system as a first step to the HL upgrade – Stefano et al.
ix. Mitigating impedance and improving cleaning with new betatron collimation optics – Björn et al.
x. Collimation simulation tool – Frederik et al.

Discussion:

- **Stefano** asks what the main motivation for using flat optics is, if we anyway are limiting the pileup. What is the added value of the flat optics, assuming baseline pileup? **Nicolas** replied that it is a few percent. Regardless of the scenario, we gain with flat optics, even though it is smaller with a lower pileup. There is no reason not to use flat optics. **Markus** commented that we are not yet ready to make flat optics the baseline, and currently it is not even an official alternative in the baseline. By the end of the year, we should decide on a consistent parameter set for the flat optics and make it an official option, while also removing some other options that are no longer relevant. This could be presented during a longer TCC this year (before annual meeting if possible), where we would possibly discuss the different optics alternatives, including what we gain and lose, and what changes would be required. **Stefano** replies that if this becomes baseline, we should identify the resources for additional studies. **Markus** agrees.
- **Riccardo** comments on the pileup, that it is not clear whether or not we could do more than 140 in Run 4, but it is clear that in Run 5, the experiments should be ready to handle 200. Concerning the baseline, it is useful to distinguish between Run 4 and Run 5, and 200 should be considered baseline for Run 5. Putting this into perspective, the goal of Run 4 is also to approach the Run 5 configuration. Do we still consider 140 the baseline for Run 5? **Markus** replies that this question was asked to the experiments, and they were reluctant to commit to that for Run 4, because of computing power, but for Run 5 they would do it. There is hope that they could handle 150 or 160 in Run 4, but the machine needs to ramp up slowly. Also, costwise they prefer to wait as long as possible before purchasing computer power.
- **Stefano** comments on the TCC, that another aspect of **Thibaut**'s presentation was the good result of the BGC tested in the electron beam stand. We will try to organise a report on this with **Adriana**. One outstanding issue on the e-lens simulations are the profile measurements at high current, needed to have a realistic performance estimate. In **Thibaut**'s presentation, he showed nice and reliable measurements of the hollow electron beam.

- **Nicolas** mentioned that one outcome of the last WP2 meeting was that recent DA simulations indicate a DA below 6σ, with current assumptions of octupole current at FT. Tightening the collimators in Run 4 will thus be difficult. **Stefano** comments that it appears that the request to reduce the impedance contribution by IR7 has become worse in recent years. It would be useful to identify the differences compared to past simulations, because in the long term, we should rather consider closing the collimators to add flexibility of the machine and the performance in other aspects, such as the wire and the forward physics experiments. It is a requirement from WP5 to keep the possibility to have nominal collimator settings deployed in the future, and try to find other mitigations, in particular in case of any intensity limitation. **Nicolas** replies that for the impedance simulations, as you make them more realistic you tend to add details and new devices, which in turn tends to degrade the impedance. Also the impedance model has been developed further. What is also more refined now are the DA studies, limiting the octupole current, whereas in the past we would typically assume max octupole current. **Lorenzo** adds that for presentations in previous WP meetings, he assumed the best parameters that we could have in HL, i.e. lowest emittance, max intensity etc. The 380 A we had in the past for standard beams looked okay, but with the new DA studies this is no longer the case. **Stefano** stresses that it is important to keep a bit of flexibility in the systems. **Nicolas** comments that this is also one of the motivations for the flat optics, as it reduces the impedance in the plane of the crab cavities.

Minutes of the last meeting were circulated, and they were approved.

2. Cu-coated graphite TCSPMs – overview of tests and planning (Carlotta Accettura)

Carlotta presents the status of the characterization and initial production and testing of Cu-coated graphite collimators, as well as plans for the production series. 10 TCSPMs + 2 spares will be produced with this new material choice. The Cu-coating is more stable than Mo against beam impacts as shown in HiRadMat tests, graphite blocks are cheaper than MoGr ones, and it is also a good solution for impedance. There are also plans to coat the tapering of the collimators, which was not considered before as they were made in MoGr. In a first stage, a small batch of six pre-series blocks and 20 plates are procured to optimise the tests and procedures for the Cu-coating. The UHV tests of the blocks carried out before coating were all ok, with a degassing of 1.1×10^{-8} mbar.l/s, a factor of five below the requirements. As for the coating method, HIPIMS was shown to be superior to DCMS, providing a conductivity of 34 MS/m, although there is some variation between the plates, ranging from 17 to 55 MS/m. The coating was shown to vary in thickness between samples due to position, correlating with the conductivity. Repeating the coating improved the conductivity results, and it is concluded that the position in the oven should be optimised to get a coating of proper thickness (3 microns). The blocks also showed a variation of the conductivity along the length of the blocks.

Discussion:

- **Stefano** asks about the length of the blocks. **Carlotta** replies that 2x500 mm blocks will be used for the jaws, and separate blocks for the tapering. The coating is easier to do on blocks of this length, rather than 1000 mm long blocks.
- **Stefano** asks about the conductivity of Cu vs bulk Cu, and recalled that for Mo, the results for the coating was similar to bulk Mo. **Carlotta** replies that 55 MS/m is the theoretical conductivity of

copper, but they found 34 MS/m on average. This is consistent with what was found for Mo on graphite, and the difficulty with coating on graphite lies in the porosity and roughness of the bulk material.

- **Stefano** recalls that it was ineffective to add the coating to CFC and wonders whether the roughness of the surface of the graphite blocks is treated by the company before shipment to help with this. **Carlotta** replies that aside from the mechanical tolerance, CERN also specifies a value of average 1.6 µm for the roughness, which is manageable by the company. With the MoGr collimators, it was noticed that the average roughness is not a good measure for estimating the quality of the coating, since it rather depends on the maximum roughness, which however cannot be controlled. Regarding CFC, it was so rough, one order of magnitude worse than graphite, that the conductivity with and without coating was the same. There can still be a large local roughness on the surface, which could be an explanation for the variation of the measured conductivity. **Nicolas** comments that the impedance is not a very local effect, so unless there are insulating points, there should not be an issue as long as the average conductivity is good.

- **Nicolas** asks if there is data on the effect of radiation dose on the Cu coating in general, i.e. not necessarily on graphite, and whether or not we are confident that it will last without any issues. **Carlotta** replies that we cannot do long term studies of radiation on Cu-coated graphite, although there are devices (the TCDQs) already installed in the machine with Cu-coated graphite that did not experience any issue. **Stefano** interjects that these are not good examples, because when they were opened up, the coating was no longer there. We can not say quantitatively that it was fine. **Francois-Xavier** replies that indeed we do not have such measurements. **Carlotta** comments that from a theoretical point of view, the fact that Cu has a lower melting temperature means that in terms of annealing of Cu due to radiation, it starts at a lower temperature than Mo. **Nicolas** further comments that the dose is quite local, and that we can move the fifth axis if there is an issue. **Carlotta** agrees and mentions that it is localised along a width of ~ 1 cm. **Stefano** agrees that this is the planned mitigation. (**Action:** **Stefano** will look into what happened with the TCDQ coating that had disappeared.)

- **Wil** comments that a wide variety of witness samples made out of glass can be added, to do thickness measurements, DC resistivity etc. to ensure that the process is okay. The initial surface of the graphite cannot be controlled here, but for the coating process we can decide what to monitor, if we should check all blocks in detail or just the first two blocks. **Carlotta** suggests setting up a series of controls together, and that we should probably check the first samples in detail and once we see that the process is reliable we can trust it for the remaining blocks. **Wil** adds that the bakeout for the TCDQ and TDI in the past went a bit too fast and that there was a bit of oxidation on the copper. It is important to measure the conductivity of the new samples after the bakeout. **Carlotta** mentions that in the past, 15 degrees per hour was used and she does not think that this has changed as it is a standard process.

- **Stefano** suggests that we could replace the currently installed MoGr TCSPMs with the new collimators, since these are the locations that are most critical in terms of impedance, and re-locate the MoGr at locations with lower contribution to the impedance. **Nicolas** agrees that it is a good point, although there is not a lot that can be gained from this, unless the tapering has a large impact which we do not yet know. He thinks that it is probably not justified.

3. CU COATING CONDUCTIVITY MEASUREMENTS (LEONARDO SITO)

Leonardo presents the details on the conductivity measurements that were done on the pre-production series samples, comparing the two sputtering techniques (DCMS and HiPIMS), cleaning, positioning and the coating thickness. The measurement is done using a H011 mode cavity, with a resonance frequency of 16.5 GHz which gives a sufficiently small skin depth (0.5 µm in Cu, < coating thickness). However, this is sensitive to the surface roughness. Calibration is done using known conductivity samples. Coating methods were tested on both glass and graphite, with HiPIMS giving a factor of ~2 higher conductivity. The coating thickness depends on the positioning of the samples in the oven. Three cleaning methods were compared, and Firbimatic + US cleaning in demineralized water was chosen. The measurements on the blocks are difficult, since they risk damaging them. Each block was measured at five locations along the length of the block, with a peak-to-peak variation of about 7.1 MS/m. It is planned to also measure the blocks following UHV treatment and to further understand the effect of positioning in the oven and surface roughness.

Discussion:

- **Carlotta** comments that the point about air exposure is good and its effect on the measurements should be studied. During the production, the air exposure time is however minimised, and the blocks are put in vacuum plastic bags to protect the coating. **Nicolas** asks if the next samples to measure are under inert gas and how fast the oxidation occurs. **Wil** replies that they can be put under vacuum if needed, and that the oxidation is very fast (<< days), and should be measured at least once. **Francois-Xavier** points out that during assembly, the blocks are unpacked from the plastic bags and are exposed to air for several days before being put into the vacuum vessel. It would be good if **Wil** can confirm that the oxidation does not affect surface conductivity significantly. (**Action** **Impedance team & Wil** to measure and report back on the effect of oxidation on Cu-coating conductivity.)
- **Nicolas** mentions that it is important for the simulation models to also measure the graphite side, due to its impact on the low frequencies. **Leonardo** replies that it is difficult to measure the conductivity of graphite due to the porosity, since it gives a variation of more than 30 %. **Carlotta** agrees and adds that they did measure the average conductivity with DC in the past.
- **Stefano** asks if the coating on the tapering will also be measured. It is important to verify the quality of the coating also there. **Nicolas** agrees and comments that it is not important to investigate it in too much detail, but it should at least be measured a few times to know what to put in the model. **Leonardo** replies that the angle of the tapering is small, 15 degrees, so it should be possible. **Carlotta** adds that there is only space to do one or two measurements on the tapering due to the space, not more.
- **Francois-Xavier** asks if the graphite can be measured on the side of the long blocks, since those faces are not coated. **Nicolas** agrees.
- **Francois-Xavier** comments that they are in the process of ordering all the blocks from the German producer and that given the nice measurements he does not see any showstopper. He asks if the others agree. **Nicolas** asks to first see the talk by Lorenzo.

4. IMPACT OF CU COATING RESISTIVITY ON HL STABILITY; IMPEDANCE MITIGATION SCENARIOS (LORENZO GIACOMEL)

Lorenzo presents a comparison of the impedance due to Cu-coating instead of Mo-coating, as well as a couple of other scenarios for further reducing the impedance. For beam considerations, the main issue is the impedance around 1 GHz. The impact on the octupole current, compared to Mo-coating, depends on the conductivity of the Cu-coating; an average conductivity of about 30 MS/m leads to the same, whereas better conductivity leads to better results. Even if the conductivity is only 20 MS/m, the influence on octupole current is however small, with an increase of a few A. 30 MS/m can thus be considered a soft limit. The rematched IR7 optics currently being tested in the LHC can further reduce the impedance in HL-LHC, and a preliminary study shows potential gains of 10 to 40 percent on the imaginary and real parts, respectively. To understand what the maximum theoretical gain might be, by optimising the secondary collimators, a study was done with all secondaries, except for two, retracted fully. This shows an improvement of the impedance and octupole threshold by about 20 %.

Discussion:

- **Nicolas** clarifies that it is just an idea to, during FT, when the impedance is the most critical, take some TCS out while ensuring that the cleaning is not degraded. **Stefano** comments that this is also the part that is most critical for cleaning as the bunch current is maximum (this scenario was considered, for example, for quench tests). If one can be sure that there are no drops of lifetime in this phase, one could study this. This was however the motivation for the relaxed settings, where the same retraction between primary and secondary collimators is kept in order to not significantly degrade the cleaning. Previous simulations indicated a strong impact if this is not respected, which will be more tricky to sustain without 11T dipoles. **Xavier** suggests that we could try to find a compromise, where we balance a small degradation of the cleaning performance for a gain in impedance. **Stefano** clarifies that when the relaxed settings were proposed, the 11T dipole, with TCLD collimator, was still in the baseline and we were thus less sensitive to the IR7 settings. Now that the 11T dipoles have been descoped we have had to focus on optimising the cleaning performance.
- **Xavier** asks if the main worry is when we put the beam in collision, rather than at FT. **Stefano** replies that we perhaps could consider entering collision in the combined ramp and squeeze, if it would be beneficial.
- **Xavier** asks for clarification on the available margin in cleaning. **Stefano** replies that based on the quench test, there is a limited margin for the operation at 7 TeV for the scenario without 11T dipoles, which was quantified at Chamonix2022.
- **Stefano** asks for clarification on the scenario considered. Concretely one is requesting a scenario where we only move the collimators to the configuration giving max impedance when we are already in collision. One scenario could have been to move the primary, but for that we would need the HEL. **Xavier** replies that we can keep the tight settings for when we are in collision, but before that we keep just a few secondaries in, with the nominal retraction. The question is how many would be needed to keep the cleaning performance good enough. **Stefano** replies that this has to be studied, but even just changing the material of collimators, as well as the relaxed settings themselves, have a not negligible impact in other areas, such as the experiments.
- **Stefano** also suggested repeating a similar study with nominal settings and without crab cavities to see how the two scenarios compare.

- **Stefano** comments that the motivation for the relaxed settings was impedance and instability concerns with nominal parameters and adequate margins assigned to all systems (tune, coupling, octupoles, ….). **Xavier** clarifies that in the last operational scenario document, the relaxed settings were motivated by both halo concerns and for being able to put the octupole threshold at an acceptable value. The latter is driven by recent DA studies.
- **Xavier** asks if it is better to use retracted settings, or TDR settings with the trick of fully retracting some collimators only until collision. **Stefano** replies that the feasibility of retraction of collimators is to be demonstrated and that it is not good with a scenario where it is assumed that the beams will be stable when the beam intensity is the highest. **Nicolas** suggests to discuss offline and to put on the table exactly what needs to be done. (Action: **Nicolas, Xavier, Stefano** & impedance/collimation teams, to design one or several scenarios making a good compromise between impedance and cleaning.)
- **Nicolas** notes that we should try not to go below 30 MS/m, although this is a soft limit, and asks if everyone agrees that we can go with the Cu-coating. **Stefano** agrees.
- **Carlotta** asks if, when they have two different values for the conductivity in the two blocks, one can consider the average over the full one-meter length. **Nicolas** confirms that this is okay.
- **Nicolas** asks if the plan is to measure all blocks or just a subset. **Carlotta** replies that the measurements risk damaging the coatings, so the plan is to e.g. only measure the first six blocks to see that they are consistent, and to then rely on the witness samples. 20 plates were ordered to be used as witness samples.
- **Nicolas** asks if all Mo-coated blocks were measured. **Carlotta** replies that only the witness samples were measured in the coating batch of 18 blocks. **Stefano** adds that the full collimator was also measured, although this is a bit indirect.

5. Collimation cleaning performance with the latest materials (Björn Lindström)

Björn shows an update on collimation cleaning performance with the new materials, comparing both relaxed and tight settings. Graphite has a lower density than MoGr, leading to more leakage out of IR7, whereas Inermet180 has a higher density than Cu-diamond, leading to more energy deposition in the TCTs. v1.5 optics were used with four different beta* (15, 20, 64 and 100 cm) for horizontal and vertical betatron loss maps. Asynchronous beam dumps were also presented. The new materials lead to a 7 % increase of the DS losses, on top of the already 7 % increase due to the relaxed settings. The increase on the TCT losses is 75 % for b1 and 200 % for b2 due to the relaxed settings, with a further increase by up to 55 % due to the new material choice. B2V is the most critical due to a bad phase advance from the TCPs to the IP1 TCTs, and might need to be mitigated, based on the requirements of the experiments. The impact distribution on the TCTs with the new materials is similar and the previous FLUKA results on power deposition can probably be scaled up accordingly without further simulations. For asynchronous beam dumps, the TCTs see an increase of 6 % when considering the new materials, which should not be a concern.

Discussion:

- **Stefano** clarifies that even small changes on the collimators can be detrimental. The quench tests, not discussed here, indicate that we should nevertheless be okay, also without the 11T dipoles, but there is not a lot of margin. **Björn** adds that **Volodymyr** published the FLUKA power deposition studies with relaxed and tight collimator settings, assuming only MoGr secondaries, in the last IPAC. The value for the energy deposition was up to about 18 mJ/cm^3, indicating a very small margin at 7TeV.

- **Nicolas** underlines that the losses on the TCT look very large. **Björn** explains that in particular the 200 % increase for B2 looks worrying and should probably be mitigated. With these losses there are concerns for the BLM thresholds and possibly also the experiment background. **Stefano** adds that the LHC is still tolerant with respect to background and that the TCT losses may not be a showstopper however the experiments need to provide an official statement.
- **Carlotta** asks whether or not the information on the background and power loss previously reported by FLUKA needs to be updated. **Björn** replies that the FLUKA team is already simulating the IR7 DS with the new inputs, and that a discussion should be done regarding the TCT losses. **Carlotta** comments that the power deposition in the TCTs due to the halo is anyhow only on the order of 1 W, which is not worrying.

6. AOB

The next WP2 meeting will be a joint meeting with WP4, next week (on Tuesday July 4th).

There will also be a ColUSM meeting, dedicated to an update on crystal collimation, on Friday 30th (unusual time - 3 pm).

Reported by Björn Lindström