Minutes of 96th Collimation Upgrade Specification Meeting

Participants: C. Accettura (CA), G. Arduini (GA), C. Bahamonde Castro (CB), L. Bianchi (LBi), A. Bertarelli (AB), F. Carra (FC), M. Calviani (MC), T. Furness (TF), N. Fuster (NF), H. Garcia Morales (HG) (scientific secretary), S. Gallordoni (SG), G. Gobbi (GG), J. Guardia Valenzuela (JGV), M. Guinchard (MG), I. Lamas (IL), A. Lechner (AL), A. Mereghetti (AM), E. Métal (EM), M. Pasquali (MP), S. Redaelli (SR) (chairman), O. Sacristán (OSa),

Indico event [here]

1 Actions

Actions from this meeting:

• Temperature of coating with steady loss scenarios at most exposed collimators - Action for A. Mereghetti to prepare inputs for follow up by FLUKA team and MME.

• Simulations of cleaning (and hierarchy) for TCS deformation as predicted for CFC and MoGr - Action for ABP (N. Fuster) with inputs from MME (F. Carra).

• Review of TCS deformation in case of steady losses for all the TCS slots.
  – Check of present system with CFC (F. Carra with inputs from energy deposition)
  – Repeat FLUKA with final Run III layouts (simulations by A. Mereghetti)

• Improved collimator design for reduced dynamics deformation - Action for MME.

• Understand possible implications of UFO in IR7 - Action for STI (A. Lechner)

• From HiRadMat tests, determine the properties (dimensions, composition, ...) of possible material debris after beam impact on the coating - Action on MME/STI after inspection of respective HiRadMat experiments (F. Carra, I. Lamas)

• Validate coated samples of MoGr from new producer, from vacuum point of view – Action for MME and VSC

• Estimate correctly the amount of CFC needed for the TCSPM production (“Plan B”) in case of issue with MoGr – Action for IL.
2 Introduction and scope

- SR opens the meeting pointing out that this one is the follow up of previous special ColUSM on materials, held on May. We now have to close the relevant actions and review the status of the collimator material readiness for the LS2 productions. In particular, we now have new elements from (1) qualification of materials; (2) important tests performed at HiRadMat by STI and MME; (3) a clearer time line for the critical decision points and milestones for the production.

- SR also recalled the detailed scope of the LS2 production for HL-LHC and CONS that aims at producing:
  - 4 low impedance primary collimators with BPMs (TCPPM), + 1 spare. The active part is made of uncoated MoGr.
  - 8 low impedance secondary collimators with BPMs (TCSPM), + 2 spares. The active part is made of Mo-coated MoGr.
  - 4 dispersion suppressor collimators with BPMs (TCLD), + 1 spare. The active part is made of Inermet.

3 TCSPM beam tests at the LHC and ideas for IR7 low-impedance upgrade for LS2 (A. Mereghetti)

3.1 Summary of the presentation

- AM presents the results of the tests with the low-impedance collimator (TCSPM) at the LHC and the ideas for a low-impedance upgrade for LS2. He remains the audience that IR7 collimators account for a significant fraction of the total LHC impedance which has an impact on the beam stability. Since for the HL-LHC the beam intensity is foreseen to be twice the LHC intensity and the normalized emittance reduced, the impact on impedance and load on collimators is increased.

- AM recalled that there has been an extensive R&D program which converged to using MoGr as jaw material and Mo as coating material for TCSGs.

- AM presents the measurements performed at the LHC of the TCSPM collimator. He shows the design of the prototype with three coating stripes that one can exposed to the circulating beam by means of the so called fifth axis (transverse tank movements up to +/-10 mm). During 2017 an extensive MD campaign of impedance measurements was carried out in order to demonstrate the improvement of the upgrade baseline choice and to benchmark the impedance models. These MDs were very successful.

- AM shows some highlight results of the MDs. The aim is to measure the impedance contribution from each TCSPM stripe and compare results against
the TCSG nearby. Depending on the material, a different tune shift is induced as a function of the collimator gap. In general, there is a good agreement between measurements and expectations although there is some discrepancy with Mo coating.

- AM shows the results of a second MD where a HL-LHC type of bunch was used, with intensities close to $2\times10^{11}$ p. The results are still consistent with expectations but the discrepancy with Mo coating is still observed.

- AM introduces different options for a low-impedance upgrade for LS2, showing four alternative layouts where different sets of TCSGs are replaced by the new TCSPMs. AM reminds the audience that, depending on the scenario, the collimation impedance can be reduced by up to 30% of the total LHC impedance.

- AM shows the results on the load on the coating layer that he performed with a new simulations setup, with FLUKA-SixTrack coupling. The four scenarios were considered. He shows the energy deposition in the coating layer for B1 in the horizontal and the vertical plane. In general, vertical plane is more affected than the horizontal plane. These results are rough because they do not include the contributions from electromagnetic cascades and from secondary particles generated deposition in upstream collimators. However AM believes that these can be used to comparatively assess the different layouts.

3.2 Discussion

- SR asks about the need to repeat more impedance measurements in 2018. EM replies that there is no need to do more measurements.

- The statement that the discrepancies from the impedance models might be caused by non uniform thickness of the coating (EM) triggered a discussion on how thick it is and on possible additional measurements. AB pointed out that measurements of thickness and roughness cannot easily be done in the lab. It was agreed that the coating procedures should be kept under good control. GA commented that a factor 2 on tune shift, if confirmed, should not be critical for stability, but the issue with the measurements should be understood.

- EM commented that the standard way to compare the different impedance contributions is now to express, for different layouts, the required octupole current to stabilize the beams. Updated version of the plots shown by AM can be made available. EM recalled that the results will be presented in detail at the upcoming Annual HiLumi Meeting in Madrid by S. Antipov.

- SG asked what is the configuration for the calculation of the octupoles current. This is the worst case at top energy with beams separated.

- SR asked if MME or STI can comment on whether the steady losses are an issue for coated collimators. AB commented that we should not be too to
sensitive on the details of the thickness at these scales. AL commented that the full propagation of secondary particle cascades is an important ingredient for the proper assessment in simulations of the robustness of coating in standard operations. He believed that AM’s models are too optimistic as they include only ionization. AM agrees and maintains that he presented a first study that, although clearly not conclusive, can be used for comparative assessments. SR agrees that in the given time constraints, AM’s work provides an important first step. SR suggests that complete energy deposition studies with coated collimator should be pursued, as this has not been studied yet in detail for the case of circulating beam losses (which is relevant for IR7).

**ACTION:** ABP+FLUKA teams to provide inputs to MME for the study on energy deposition on coating for the worst case of 0.2 h lifetime, with HL-LHC beam parameters.

## 4 Deformation of TCSP and TCSPM for HL-LHC slow loss scenarios (F. Carra)

### 4.1 Summary of the presentation

- FC presents simulation of secondary collimator deformation for the HL-LHC slow loss scenarios, comparing CFC and MoGr jaws. The two scenarios considered are the operation with 1 h and 0.2 h beam lifetime (BLT) values with a maximum stored beam energy of about 700 MJ.

- FC shows some details of the simulation results. He explains that the most exposed collimator is a skew TCSPM in the position TCSG.A6L7.B1 with an energy deposition of 12.6 kW for CFC and 20.7 kW for MoGr (1 h BLT).

- For the CFC case, the stresses are negligible and the temperature remains under 63 degree. The deflection, which is towards the beam, is slightly higher than the specification but can be solved with a simple design modification. For 0.2h BLT, the stresses are ok and the maximum temperature is about 140 degrees.

- For the MoGr case, the stresses are ok and the temperature remains under 127 degree for 1h BLF. For 0.2h BLT, the stresses are ok and the maximum temperature is about 241 degree.

- FC concludes that for a 0.2h BLT, the sagitta is relevant and a factor 3 above specification of 100 µm for CFC and a factor 5 for MoGr.

### 4.2 Discussion

- SR commented that, for any design, it will be critical to respect the specified deformation with the peak losses at levels of 0.2 h BLT. In particular, he pointed out that the MoGr jaw moved towards the beam and this scenario can lead to a further increase of losses. SR suggested that for the first installation,
we might avoid installing the new collimators in the most exposed slots. SR asked FC to assess the deformation for other slots, by checking the energy loads simulated in the past (Action).

- SR asked if the deformations shown are plastic. FC confirmed that this indeed the case and no permanent deformation is lefts after loads are reduced.

- SR also pointed out that the present collimators were already exposed to the 1 MJ loss cases during the quench tests in 2015. Did we see any indication of problems?

- GA asks what are the consequences of deformations towards the beam. SR believed that this can cause increasing losses, on the other hand he points out that the most exposed collimators are the skew ones so there is more margin in the settings as the retraction from the TCPs in the horizontal and vertical case are actually larger.

- it was also agreed that one should look at what happens in case of deformation of the primary collimators. Can they move further into the beam? Action FC.

5 Results of HRMT-35 experiment on “TDI jaw coating” (I. Lamas) [slides]

5.1 Summary of the presentation

- IL shows the results of the HRMT-35 experiment on coated TDI jaws. He explains that after dismantling the TDI in 2016, severe damage on the Ti coated surface on the hBN absorbing blocs was found and this motivated dedicated tests in HiRadMat. It was possible to add also some samples of MoGr to the set of jaw mockups of this setup, with different coatings.

- IL shows the experimental configuration for the four different absorbing materials and coating configurations: graphite with Cu coating, graphite with Mo coating, CFC with Mo coating and MoGr with Mo and Cu coating.

- Different impacts were performed on each sample, with varying impact parameters to ensure that the grazing scenario could be achieved in all cases. In general, preliminary results indicate quite good coating adhesion with no apparent surface rupture for Cu coated graphite. Mo-coated graphite and Mo coated CFC appears to be resistant however some damage was observed for the Mo-coated MoGr. IL concludes that further PIE will be performed when residual dose rate is low enough.

- IL took also the opportunity to give some news on the status of the collimator production. Two companies have been finally qualified for the LS2 production. A possible splitting strategy is under negotiation and should be finalized for December Finance Committee. IL explains that it is crucial to match the
absorbing material with the collimator industrial production plan. The pre-
series jaws (TCSPM and TCLD) will arrive at CERN the 1st of August 2018
and the absorbing material is needed by the 1st of May 2018. 2 series of
collimator units per month need to be fed.

- IL gives the details of the CFC material characterization for one of the selected
  companies. This was studies as a alternative scenario in case of problems with
  the MoGr (note that a new company will be in charge of its production). Some
details of the characterization can be found in the slides. It was pointed out
that the new CFC from the Japanese produce who provided the one for the
present collimator, presently meet essentially all the specs except the electrical
resistivity that is still more than 60 % higher.

- IL also pointed out that he is following up irradiation tests the BLIP facility at
  BNL, with the aim to test coated samples in presence of high radiation doses.
  This is done in collaboration with the Radiate experiment.

Follow up after the meeting: [Slides LMC on 29th of November]

5.2 Discussion

- In response to SR who asked a clarification on the scope of the tests, IL stressed
  that this is for the run II operation of the TDI. The present limitations to
  operations are of about 144 b so the conclusion by IL is that there is o risk for
  the operation in 2018.

- SR asked if the very good performance of the Cu coating on graphite and CFC,
  which basically show no effect at all, is expected. This looks extremely good.
  SGi replied that according to simulations, there was no damage expected as
  the temperature, even if above melting, might be reduced very fast because of
  heat transmission.

- SGi asked if UFOs can be a concern after impact, is the behaviour observed
  at HiRadMat happens in IR7. SR replied that no systematic study was made,
  however IR7 is certainly one of the most UFO-tolerant insertions. SR com-
  mented that this is not the case for the TDI that are closer to cold magnets.

- In the discussion that followed, is was clarified that the MoGr samples used
  in the test were recuperated from previous beam tests areas. Therefore, the
  vacuum team could not perform the standard cleaning procedure on these samples before coating them. SR commented that therefore
  the results should not be considered as exhaustive and stated that this should
  have been clarified before the performing the tests and announcing the results
  the MoGr behaved less well than CFC.

- SR commented on the order of CFC. This is an important “plan B” that has
  to be addressed in cases of issues with the last vacuum results for coated MoGr
  (see also presentation by AC). SR also pointed out that the order should be
made for the exact quantity of material, including only TCSPM and note TCPPM. Note also that in any case the transitions are made of MoGr son this should not be part of the CFC order. Action IL.

6 Results of MultiMat (A. Bertarelli)

6.1 Summary of the presentation

- AB presents the preliminary results on the HRMT-36 (MultiMat) experiment. AB presents the objectives of the experiment. The goal is to assess/validate materials for the HiLumi upgrade using a single and flexible platform to test specimens of a large palette of materials used in collimators under high brightness beam. He gives an general overview of the experiment and an overview of the of the design.

- AB explains that the experiment was installed the 2nd of October and got experimental runs from the 3rd to the 17th of October. One of the tests included impacts without any offset. AB shows the waves induced by the impact of the beam which agree with the simulations. AB shows the material state after the impact of the beam presenting some breakage.

- AB presents the results of the test including a beam offset which induces lateral oscillations. This results on a permanent deformation on high-Z materials.

- AB presents the results of the tests with grazing impacts to probe the strength of the different coatings. He shows the resulting impact on the different coatings tested (Mo, Cu, TiN) where some damage was observed.

- To conclude, AB presents the preliminary results on the Multimat Adaptive Collimator System (MACS). It remained operational after high intensity impact.

- Tests on coating of Mo and Cu on CFC and MoGr indicate that each coating behaves in a similar way for the two underline bulk materials and that, as expected, Mo is less damaged than Cu.

- AB thanks all the people involved in the experiment.

6.2 Discussion

- SR wonders if there are any plans on still silicon carbide. AB replies that there are no plans for the moment for collimators, but it is being studies for dumps.

- GA asks about the mark observed in the Mo coating. AB replies that this is due to the tin alloy melting and had nothing to do with the material itself.
7 MoGr procurement and status of the characterization (F. Carra) \([\text{slides}]\)

7.1 Summary of the presentation

- FC presents a summary of the MoGr procurement and status of characterization. First, he gives some details about the procurement.

- FC shows the MoGr samples provided by the company that won as best bidder, and its characterization. FC explains that, according to the formulation of the contract, the quantities to be produced are to be confirmed by the company and after that the first pre-series will be received. Already the penultimate grad shows figures of merit above specification (compared to the properties obtained by the company who developed it). Last grade received shows good electrical conductivity and RF index.

- The last remain point is about the vacuum performance (see next talk). FC also commented that results of vacuum tests on coated samples are due by mid-December.

- In conclusions, no show stopper has been identified so far and we are confident that the MoGr can be used for collimator production from the vacuum point of view.

7.2 Discussion

- In response to a question by SR, FC said that the price per unit increases in case of production of lesser items therefore the price has to be re-negotiated once the number of units is confirmed. For the moment, the order include all the TCPPMs, all the TCSPMs and the transitions. It is not know how the unit price was.

- SR stressed the importance of getting samples with coating from the final producer in time for the new BNL tests. Jorge commented that this seems feasible.

8 Outgassing tests summary of Nanoker MoGr (C. Accettura) \([\text{slides}]\)

8.1 Summary of the presentation

- CA presents the results of the tests on the Nanoker MoGr. She first explains the vacuum requirements.

- CA shows that the MoGr outgassing rates as recevied was about $9.9 \times 10^{-8}$ which is above requirement. After firing the MG at 950 degree for 48 h, the total outgassing of the jaws dropped to $1.2 \times 10^{-8}$ which is within the requirements.
CA explains that there will be a future test for surface preparation effect, vacuum firing and Mo coating.

- CA also pointed out that an internal leak is under investigation.

### 8.2 Discussion

- AB comments that now for all materials we seem to have to require 48h firing. That was not done for the present collimators so what is now installed in the LHC is not compliant by the present standard. CA commented that 2h only are required for stainless steel. For some other materials, 48h are indeed now a requirement.