CERN-ACC-2014-0293

HiLumi LHC

FP7 High Luminosity Large Hadron Collider Design Study

Deliverable Report

Conceptual Design of IR Collimation

Bruce, Roderick (CERN) *et al*

28 November 2014

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

This work is part of HiLumi LHC Work Package **5: Collimation**.

The electronic version of this HiLumi LHC Publication is available via the HiLumi LHC web site `<http://hilumilhc.web.cern.ch>` or on the CERN Document Server at the following URL: `<http://cds.cern.ch/search?p=CERN-ACC-2014-0293>`

CERN-ACC-2014-0293

Grant Agreement No: 284404

HILUMI LHC

FP7 High Luminosity Large Hadron Collider Design Study

Seventh Framework Programme, Capacities Specific Programme, Research Infrastructures, Collaborative Project, Design Study

DELIVERABLE REPORT

CONCEPTUAL DESIGN OF IR COLLIMATION

DELIVERABLE: D5.5

Document identifier:	HILUMILHC-Del-D5-5-v1.0
Due date of deliverable:	End of Month 36 (October 2014)
Report release date:	28/11/2014
Work package:	WP5 Collimation
Lead beneficiary:	CERN
Document status:	Final

Abstract:

Conceptual designs for upgraded IR collimation systems in IR1 and IR5 are worked out, based on the results obtained by simulated halo losses and energy deposition. The status of simulations of performance of the different layouts is also presented.

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404. HiLumi LHC began in November 2011 and will run for 4 years.

Delivery Slip

	Name	Partner	Date
Authored by	R. Bruce, A. Lechner, S. Redaelli	CERN	07/11/2014
Edited by	S. Redaelli, C. Noels	CERN	07/11/2014
Reviewed by	R. Appleby, WP5 deputy coordinator L. Rossi, Project Coordinator	UNIMAN CERN	16/11/2014
Approved by	Steering Committee		17/11/2014

TABLE OF CONTENTS

Executive summary

The WP5 teams have achieved the goal to define conceptual design layouts for HL-LHC collimation solutions in IR1 and IR5. Collimator layouts are included in the present working version of optics and layout, i.e. the baseline for round beams. The proposed layouts foresee collimation of the incoming beam, for beam cleaning and machine protection, as well as adequate cleaning of physics debris products. The studies covered both proton and heavy-ion operation. The present on-going simulation effort combined with first detailed integration studies has allow to detect some potential integration issues in the area between TAXN and D2. This is under investigation and will be addressed once the proposed solutions will be solidly confirmed for the final layouts.

1. INTRODUCTION

The layout definition for collimation solutions in the experiential regions is the main focus of the FP7 HiLumi-WP5 study teams. This requires finding solutions for the HL-LHC target parameters for stored beam energy and luminosity performance, which impose new challenges for the incoming and the outgoing beam collimation around the experiments, both for proton and ion operation. In addition, layouts must be re-designed to follow the magnet layout changes planned for LS3.

Following the recommendation of the collimation project external review in May 2013 [1], in 2013 the WP5 activities were focused on the collimation solutions in IR7 (proton and ion operation) and IR2 (ion operation). These upgrades require actions already in LS2 and were thus addressed with priority following the recommendations by the external review panel. These results are extensively reported in the HiLumi-WP5 document D5.4 [2]. This work is in full synergy with other IR collimation studies because the work on the 11T dipole/TCLD (lattice, layouts, integration, optics etc.) can be re-used in a modular way for all the dispersion suppressors around the ring. In the last year, the WP5 teams have put back the focus on the design of collimation solutions for the high-luminosity points IR1 and IR5.

In this document, the present baseline solution in IR1 and IR5 is presented. The collimation layouts are described in detail and the results of preliminary performance reach estimated in simulations are presented. Iteration on these results will provide the material for the detailed technical design of IR collimation which is the main goal for the next year.

It is noted that the WP5 teams have also worked on the preparation of the first version of the HL-LHC conceptual functional specification [3] and on the preliminary design report documents, covering all collimation upgrade scenarios also beyond the EU program.

2. INCOMING BEAM COLLIMATION IN IR1 AND IR5

The main roles of the incoming beam collimation are: (1) keeping all heat deposition into magnets well below their quench limits in standard operation; (2) protecting the relevant aperture restrictions in case of fast beam failures; (3) optimising the halo-driven background to experiments. For the present LHC layout, these roles are provided satisfactorily by a pair of tertiary collimators located in cell 4, at positions at nearly zero betatron phase difference upstream from the triplet magnets (i.e. located between the D2 and the TAN).

2.1. TERTIARY COLLIMATOR LAYOUT

For the HL-LHC, standard aperture calculations using the “n_1 method” [4] show that potentially critical aperture bottlenecks could be introduced upstream of the triplet. Therefore, we foresee to install a pair of horizontal and vertical tertiary collimators in cell 5 in front of Q5, which we call TCT5. This installation is further motivated by detailed simulation studies of the collimation performance that are presented in Section 2.2.

The present triplet protection collimators in cell 4, called TCT4, are kept at the same functional locations as they also provide a crucial protection role in case of orbit errors affecting the triplet region only. It should, however, be noted that the TCT4 have a shifted longitudinal position compared to the present LHC, in order to be compatible with the overall layout changes of the magnetic elements. The TCT4 will, for HL-LHC, be installed between the D2 and the TAXN. With squeezed optics, the betatron phase difference between TCT4 and triplet is close to zero.

This layout, including TCT5 and using the latest version of the HL-LHC lattice at the time of writing (HL-LHC v1.1) is shown in Fig. 1. For comparison, we show also the layout in the nominal LHC.

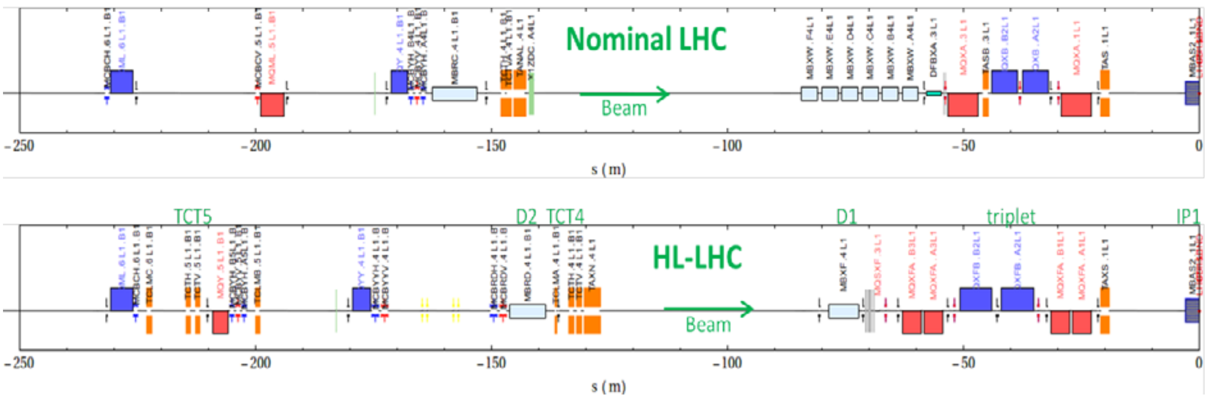

Figure 1: Layout of the elements seen by the incoming beam in IR1 for the nominal LHC (top) and HL-LHC (bottom). The IR5 layout is equivalent.

2.2. STATUS OF CLEANING AND MACHINE PROTECTION STUDIES

In order to validate the collimation performance with the new layout, an extensive simulation campaign has been launched. At the time of writing, some of these studies are still on-going and we discuss here the present status of the validation.

First, we quantify the general need for local protection collimators in the experimental IRs through tracking simulations. We study the need for TCTs both for cleaning in standard operation, as well as for the case of passive machine protection during an abnormal fast failure (asynchronous beam dump). We present also the overall cleaning in the LHC with the new HL-LHC layout.

During an erratic beam dump, one or several beam extraction kickers fire at the wrong moment and several bunches risk being kicked up to amplitudes where they might directly impact on the aperture. The most critical case, called single-module pre-fire, is the triggering of only one module. Direct beam impacts during such failures could potentially damage magnets, as well as certain sensitive collimators made of tungsten. During Run I, the protection of sensitive equipment during erratic dumps has been one of the main driving terms for the margin between TCTs and the dump protection devices (TCDQ and TCSG) in IR6 [5]. It is very important that this protection is satisfactory also for HL-LHC.

We simulate the distribution of beam impacts around the ring during a single-module pre-fire using SixTrack [6], which combines a fast and accurate optical tracking through the magnetic lattice with a Monte Carlo simulation (K2) [7, 8]. For this study, we use a special SixTrack version that includes the effect of the mal-functioning dump kickers [9, 10]. An initial study for the case of a perfect machine, where the triplet aperture is at its nominal value and there is no error on the positioning of the dump protection but all TCTs removed, significant losses of the order of 10^8-10^9 protons are found on the triplet aperture in IR5 in B2. These losses can be fully suppressed by the TCT4, which demonstrates the need of local protection devices.

Furthermore, in the same case of a perfect machine, losses of up to 10^8 protons appear in the Q4 and Q5 magnets, upstream of the TCT4. If the apertures in Q4 and Q5 would be made smaller, the losses increase rapidly. This is illustrated in Fig. 2, which shows the result of a series of SixTrack simulations, where the apertures in the Q4 and Q5 were varied, as well as the effective setting of the dump protection devices.

As it has been under consideration whether the apertures in Q4 and Q5 could be reduced to levels similar as the triplet [4], which potentially could be as low as 12 σ, it is clear that local protection from a TCT in cell 5 is very important in order to intercept these losses. Protection levels achieved for the case of asynchronous dump failures are under study but are also expected to be significantly mitigated by the TCT5.

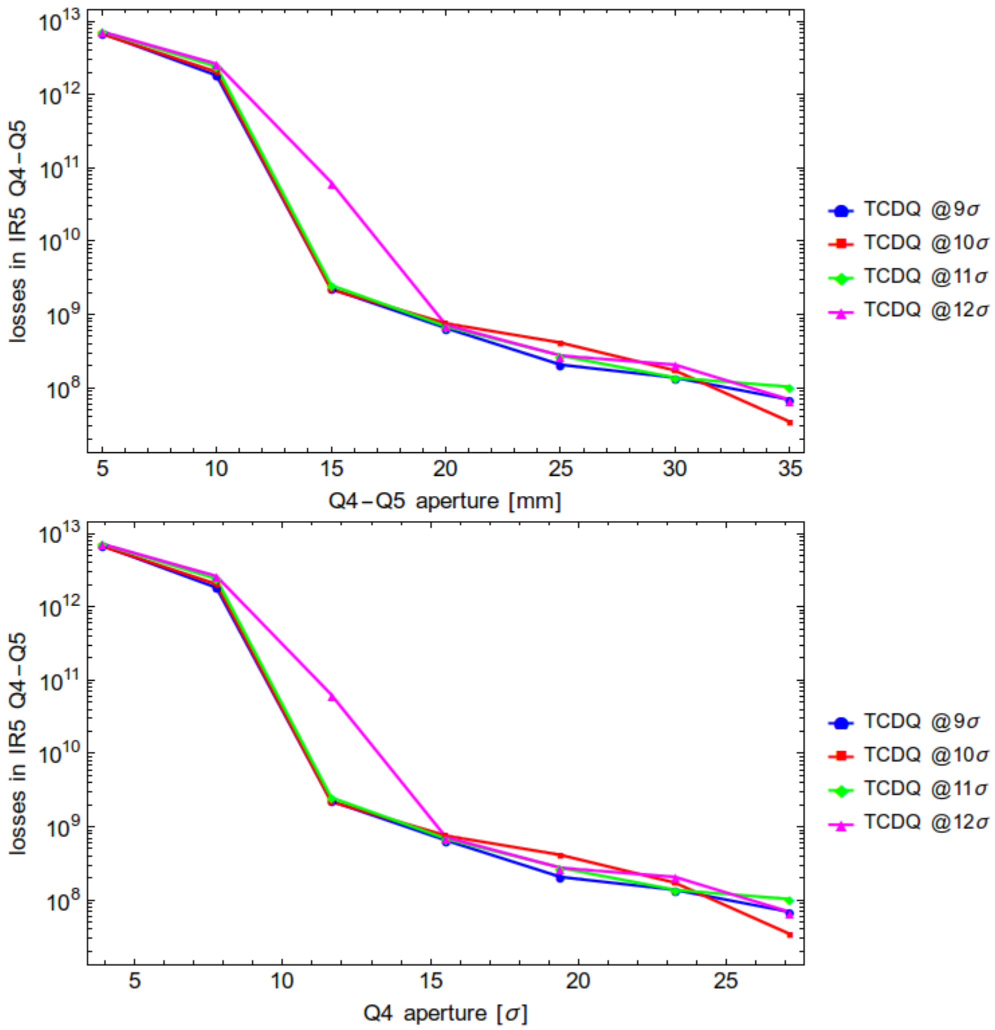

Figure 2: Total simulated losses from SixTrack during an erratic beam dump (single-module pre-fire), normalized to a bunch population of 2.2e11 protons, that are impacting in the Q4 and Q5 in IR5 B2, for different magnet apertures and settings of the TCDQ (dump protection). All other collimators were kept at their design setting, with the primary collimator at 5.7 σ and a 2 σ retraction in IR7. Optics version HL-LHC v1.0 was used. Courtesy of E. Quaranta, CERN.

Furthermore, to assess the need of local protection for cleaning, simulations with the standard collimation version of SixTrack [6] were performed. This simulation starts with a proton halo impacting on the primary collimators in IR7 and the output is the distribution of residual out-scattered losses around the ring, both on the collimators and on the aperture. The simulation method is identical to the one described in Ref. [11], where also a detailed benchmark with LHC measurements from Run 1 has been performed.

In order to estimate cleaning losses without TCTs, simulations were first carried out with the TCTs open, and the aperture in the triplets, Q4, and Q5 decreased in steps. The round optics with β^*=15 cm was used and nominal collimator settings. Preliminary results show that cleaning losses appear both in the triplets and in Q4/Q5 at normalized apertures above 12 σ, which is the minimum allowed aperture [12]. Therefore, even if the aperture alignment, orbit and optics correction would fulfil the requirements, cleaning losses could be expected. This is illustrated in Fig. 3, which shows the losses in various magnets in the experimental IRs as a function of normalized aperture.

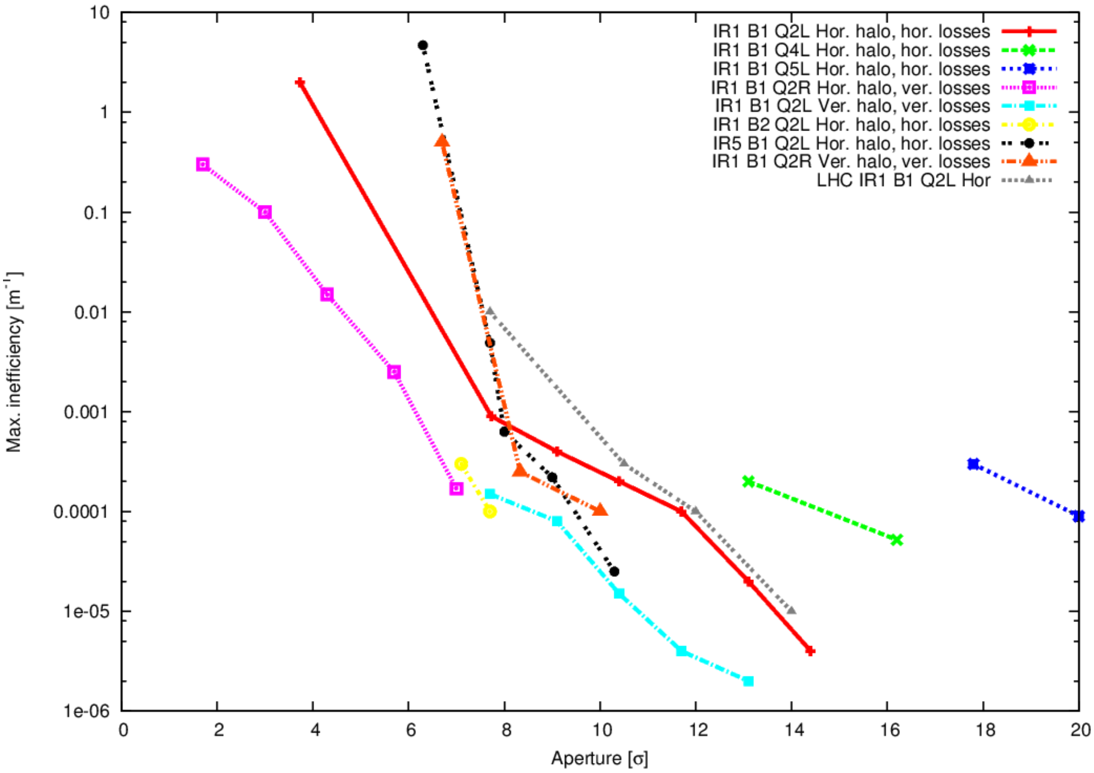

Figure 3: Simulated cleaning losses from SixTrack on different IR magnet apertures, when these apertures were varied. No TCTs are included in the simulation. Nominal collimator settings were used and optics version HL-LHC v1.0. Courtesy of H. Garcia, Royal Holloway University of London.

In order to alleviate these losses, which occur at locations with the limiting apertures of the ring, local protection is needed. Further simulations show that the introduction of TCTs efficiently suppresses the local losses in the downstream elements, as long as the normalized aperture of these elements is larger than the TCT setting. This can be understood from the fact that, at squeezed optics, the phase advance between cell 5 and the triplets is very small due to the very large β-functions.

The simulated cleaning losses around the ring and zoomed in IR5, for the layout including the TCT5, are shown in Fig. 4. As expected, the losses in the IR7 DS (limiting location in the ring) are equivalent to previous studies [13] and independent of the TCT installation. It should be noted that the IR7 TCLDs are not included in the results in Fig. 4.

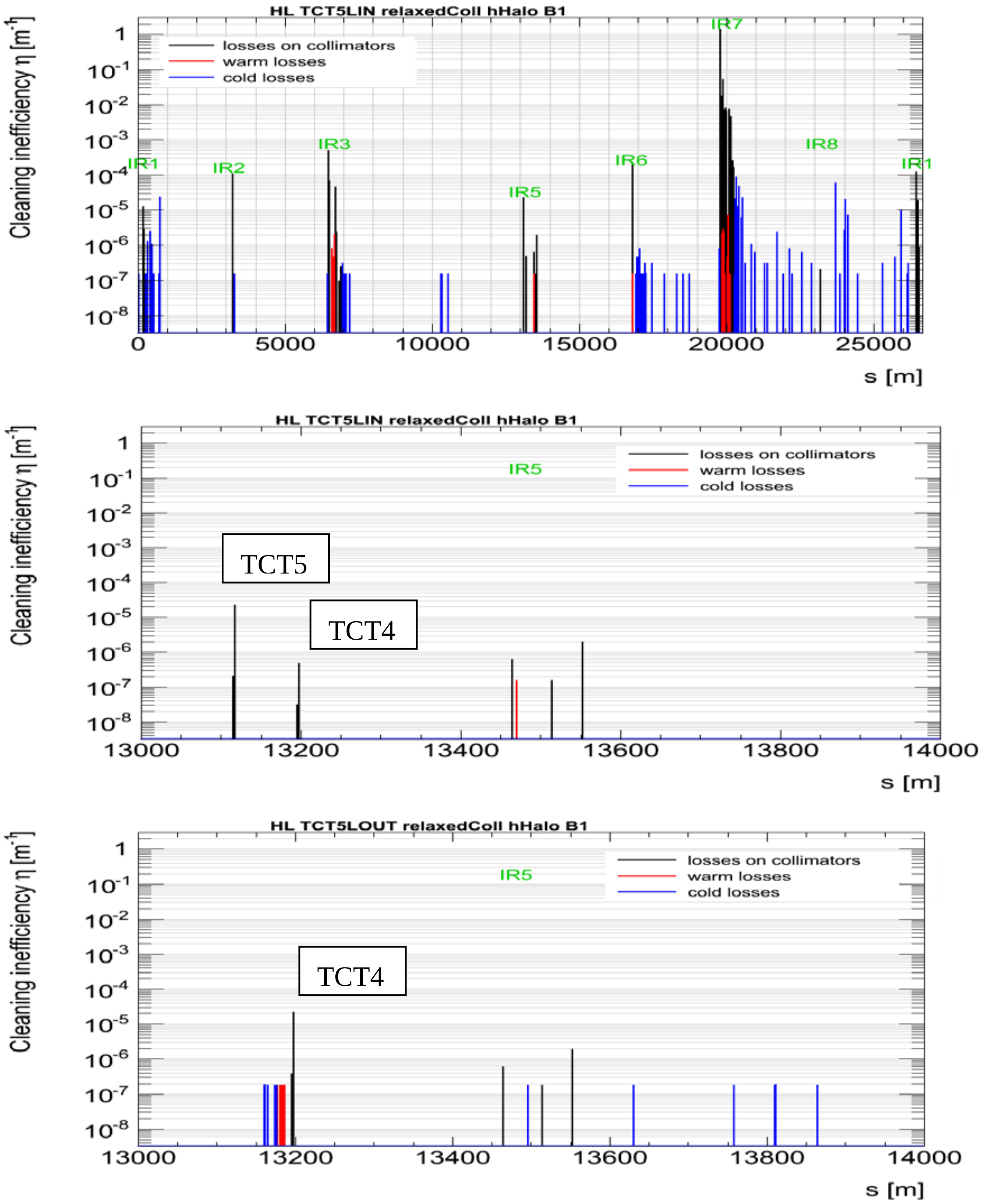

Figure 4: Losses from a horizontal halo in B1, simulated with Sixtrack around the LHC ring (top) and zoomed in IR5 (middle) using the collimation layout for HL with the TCT5 installed. A round β=15 cm optics (HL-LHCv1.0) was assumed and collimator settings with 2σ retraction. The bottom plot shows the losses in IR5 for the same case but without TCT5. Courtesy of R. Kwee-Hinzmann, Royal Holloway University of London.*

We show in Fig. 4 also the IR5 losses for the case without TCT5. It can be seen that introducing the TCT5 re-partitions a very significant fraction of the losses from the TCT4 to the TCT5 – the TCT4 losses decrease by about a factor 40. This reduction is caused by the fact that the phase advance from cell 5 to cell 4 is very small, and therefore TCT5 shadows the TCT4 to a large extent. The TCT5 alleviates also the small aperture losses in Q4 and Q5 that can be seen in the simulation without TCT5. On the other hand, the presence of the TCT5 does not help protect the triplet in case of local orbit errors.

The cleaning performance has now also been validated with pre-squeeze optics for the first time [14]. This validation was carried out using the MERLIN code [15], which is a C++ accelerator physics library that has recently been updated to include improved scattering physics in the collimators. The result is shown in Fig. 5, which demonstrates that no cleaning issues are expected in this configuration.

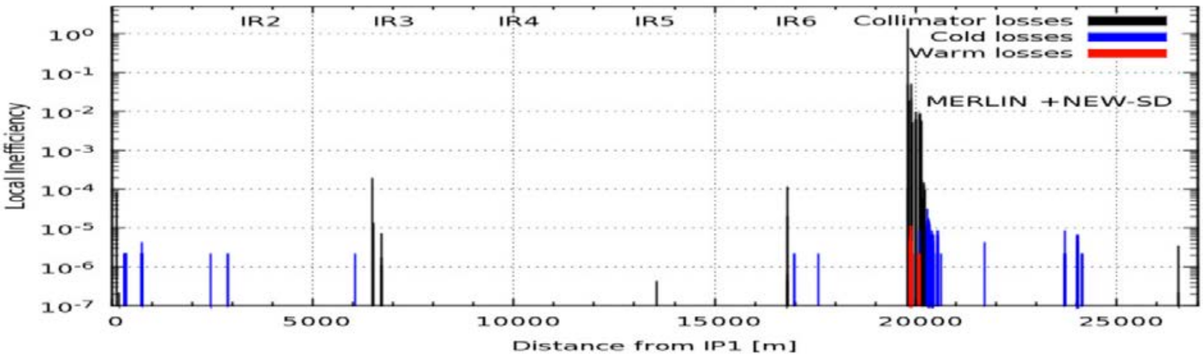

Figure 5: Losses around the ring, as simulated with MERLIN, for horizontal halo losses in the pre-squeeze optics configuration and using nominal collimator settings. The simulation includes a recently improved version of the scattering physics in the collimators. Figure from Ref. [14].

In conclusion, it is clear that the TCTs in cells 4 and 5 are needed to intercept losses during asynchronous beam dumps, which could be critical in case of machine errors. Furthermore, they can suppress potential cleaning losses. However, it is still under investigation whether this is strictly necessary to avoid quenches during regular operation, although it is clearly beneficial. Because of integration constraints, it is also under study whether it is sufficient to have the TCT5 only and remove the TCT4.

2.3. STATUS OF BACKGROUND CONTRIBUTION FROM HALO LOSSES

The status of background studies, taking as input the halo losses on the IR tertiary collimators, was estimated for the 2013 HiLumi Annual meeting and reported in the D5.4 document. The case of halo impact only on the tertiary collimators closest to the experiments (TCT4) was considered as a pessimistic case study (loss sources closest to the experiments). The final shower simulations with tertiary collimators also at the Q5, expected to be less critical, could not be performed yet due to the unavailability of the full IR geometries for energy deposition studies. However, as seen in Fig. 4, with the TCT5 installed, the IR losses move from the TCT4 to the TCT5, which is farther away from the experimental detectors. With the TCT5 we could thus expect a decrease in halo-induced background, however, the quantitative decrease factor can only be assessed following future shower simulations.

3. OUTGOING BEAM COLLIMATION IN IR1 AND IR5

Collimation on the outgoing beams of the high-luminosity experiments is designed to keep the heat deposition into superconducting magnets of the matching sections and of the dispersion suppressors safely below their quench limits, protecting them from the products of physics debris. Concentrating losses on the collimators might also be beneficial to reduce the effect of total radiation doses to critical components (like insulating materials in the magnets). Previous WP5 reports were focused on the simulations of physics debris collimation until LS3. This work has been very useful because the HL-LHC layouts were indeed derived from the solution deployed for the LHC in LS1.

3.1. PRESENT OUTGOING COLLIMATION LAYOUT

This HL-LHC layout, inherited from the present LHC, is based on 3 horizontal physics debris absorbers placed in cells 4, 5 and 6 (3 movable collimators per beam per side of IR1 and IR5). The HL-LHC challenges require in addition up to 4 fixed masks on the IP-side of D2, Q4, Q5 and Q6. The layout for the outgoing beam in IR1 (assuming the sequence for HL-LHC v1.1) is shown in Fig. 6 and compared to the layout in the nominal LHC. As can be seen, the TCLs in cells 4 and 5 have been shifted longitudinally in the HL-LHC layout as a consequence of the general layout changes.

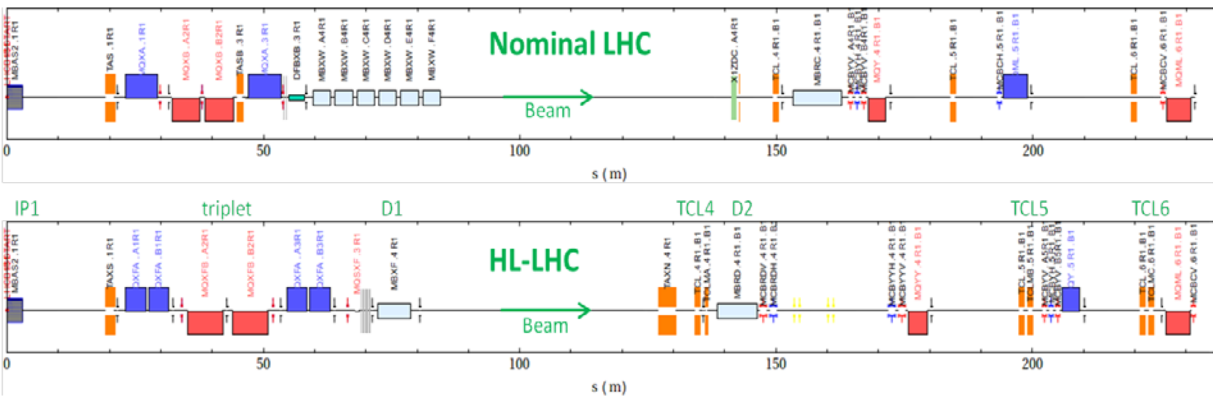

Figure 6: Layout of the elements seen by the outgoing beam in IR1 for the nominal LHC (top) and HL-LHC (bottom). The IR5 layout is equivalent. The longitudinal position of the interaction point is located at the zero of the x axis.

3.2. STATUS OF ACHIEVABLE PERFORMANCE

As shown in the previous section, the present protection system for magnets in the IR1 and IR5 matching sections comprises three TCLs located upstream of the D2/Q4, Q5 and Q6. A detailed account of the protection provided by these devices for nominal operation after LS1 has been presented in the Deliverable Reports 5.3 and 5.4. In particular, it has been shown that for a nominal luminosity of $10^{34}cm^{-2}s^{-1}$ the TCL4 alone yields a sufficient global protection against the collision debris-induced heating. Even with a large half-gap of 15 σ, it allows to keep the peak power density in the D2 and in all matching section quadrupoles below ~0.1-0.3 mW/cm^3, i.e. well below the quench level by a factor of at least ten. The presence of the TCL-6 on the other hand is beneficial for other special operational scenarios (Roman Pots inserted) and, in addition, it allows reducing the head load in the DS.

The situation becomes however more challenging after the HL upgrade, owing to optics changes (e.g. larger crossing angles) and hardware modifications [16]. The latter for example imply larger apertures upstream of the matching section (in the triplet, D1 and TAXN) and a shorter distance between separation dipoles (see Fig. 6). These changes entail an increase of the collision debris reaching the matching section, which adds on top of the increase implied by the new design luminosity (ultimate levelled luminosity of 7.5x10^{34}cm^{-2}s^{-1}) [16]. Energy deposition studies suggest that sufficient protection can still be achieved by the system of three TCLs in combination with fixed masks which have a similar aperture as the neighbouring magnet beam screens [17, 18].

In particular, the role of the TCL5 and TCL6 becomes more important compared to the present machine [16]. The present status of energy deposition studies (courtesy by L.S. Esposito and WP10 [17, 18]) is briefly summarized in the following. Only results for IR5 are shown since power loads to matching section magnets are generally higher than in IR1 owing to the horizontal crossing scheme. The results presented here can still be subject of change, in particular since they depend on pending design choices.

Fig. 7 shows the collision debris-induced peak power density in D2 and Q4 coils (including corrector magnets) for round beams and an instantaneous luminosity of 7.5x10^{34}cm^{-2}s^{-1}. Two alternative options are shown, one where the TCL4 (10 σ half gap) is complemented by a 50 cm long mask (TCLMA, as in layout version HL-LHC v1.1 shown in Fig. 6) and a second option where only the TCL4 is present, but is located closer to the D2. In both cases, the TCL4 absorber blocks are assumed to be made of Inermet (tungsten alloy), which yields an improved shielding performance compared to the present TCL4 (made of copper). The maximum energy density predicted by the simulations allow for an adequate safety margin with respect to the assumed quench level of ~13 mW/cm^3. Another option presently under study is a TCL4 with a larger lateral absorber cross section, which would also provide sufficient protection in case of other optics configurations (e.g. flat beams), where an increased leakage is expected if the present jaw design is retained. This option would imply that no mask is required in front of the D2 for all operational scenarios presently under consideration. The simulations also suggest that the peak dose in the D2/Q4 coils, accumulated over 4000 fb^{-1}, can be kept below 20-25 MGy [17].

In contrast to the present machine, the TCL5 and TCL6 are necessary to reduce the heat load to the Q5 and Q6, respectively. In addition, masks between the TCLs and the magnets are required to allow for a sufficient margin with respect to the assumed quench level. This is illustrated in Fig. 8, which shows the peak power density in Q5 and Q6 coils with and without masks (50 cm long). In either case, the TCL half gap was assumed to be 10 σ. The masks also allow keeping the peak dose, accumulated over a luminosity of 4000 fb^{-1}, below 20 MGy.

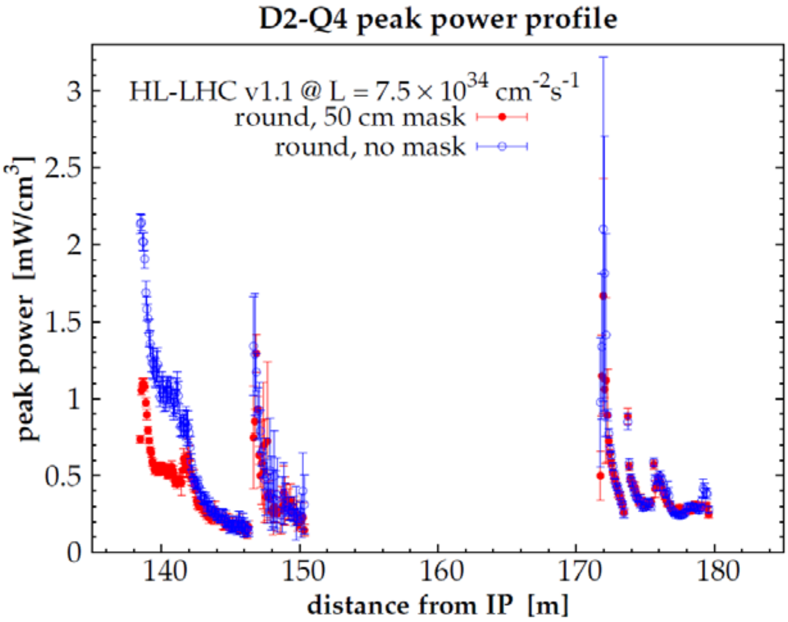

Figure 7: Peak power density induced by the collision debris in D2 and Q4 coils, assuming an instantaneous luminosity of 7.5x10^{34}cm^{-2}s^{-1}. The figure compares two alternative options: one with TCL-4 and TCLMA and the second only with TCL-4 (in both cases the TCL half gap is 10σ). Figure courtesy of L.S. Esposito et al. [35].

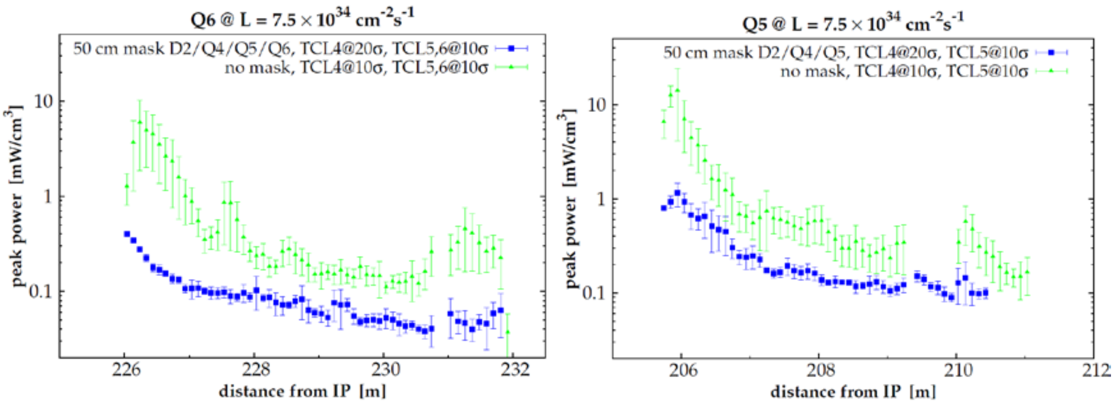

Figure 8: Peak power density induced by the collision debris in Q5 (left) and Q6 coils (right), assuming an instantaneous luminosity of 7.5x10^{34}cm^{-2}s^{-1}. The figure compares two alternative options: one with TCLs and masks and the second only with the TCLs (in all cases the TCL half gap is 10σ). Results apply to layout version HL-LHC v1.0 with round beams. Figure courtesy of L.S. Esposito et al. (from Ref. [17]).

3.3. PRELIMINARY CONCEPTUAL LAYOUTS FOR HEAVY-ION CLEANING

Operation with heavy-ion beams introduce particular demands on collimation, since new beam-loss mechanisms appear that are not present with protons [19, 20]. Secondary ion beams with a changed magnetic rigidity are created in the collision points when ions undergo ultra-peripheral interactions at the collisions. The dominating processes are bound-free pair production (BFPP), where electron-positron pairs are created and an electron is caught in a bound state, thus changing the ion charge, and 1- or 2-neutron electromagnetic dissociation (EMD1 and EMD2) where one of the colliding ions emits one or 2 neutrons, respectively, thus changing mass.

These secondary beams are lost in localized spots in the DS, where the dispersion starts to rise, and estimated heat loads in the IR2 DS during operation at the ultimate ALICE luminosity of 6e27 cm^{-2} s^{-1} are above the quench level [21]. In order to alleviate these losses, it has been proposed to install a collimator, called TCLD, in the IR2 dispersion suppressor [22]. In order to make space for the collimator, a standard 8.3T dipole is replaced by two shorter 11T dipoles. This layout has been discussed in detail in a previous WP5 deliverable report [23].

If ATLAS and CMS require the same ion luminosity as ALICE, a similar TCLD installation has to also be foreseen there. As the nominal collision optics in IR1 and IR5 differs from IR2, new layout studies are on-going. A preliminary result is illustrated in Fig. 9 for IR1. The results are based on the nominal LHC optics and the study would have to be repeated once an ion collision optics is available for the HL-LHC sequence. However, it is not expected that this will change the conclusion on the optimal dipole to exchange.

In the example in Fig. 9 it is proposed to exchange the dipole MB.B9R1.B1 for two shorter 11 T units. The installation would be completely symmetric on the other side of P1 for beam 2 as well as in P5. In total, 4 assemblies with 11 T dipoles and TCLDs would be required for IR1 and IR5 in addition to the two units foreseen for IR2.

Although detailed shower simulations of the quantitative reduction of losses in cold magnets are still pending for IR1 and IR5, the gain is expected to be similar to what was found for IR2 [22].

Even though it is estimated that TCLDs in IR1 and IR5 are not strictly needed for high-luminosity proton operation, they could nevertheless have a beneficial effect in reducing the radiation dose in the DS and downstream magnets. Although detailed simulation studies on this are still pending, a qualitative assessment can be made based on the proton loss distributions presented in Ref. [24]. As an example, simulation losses in the IR1 DS from both FLUKA and SixTrack are shown in Fig. 10. These losses are mainly caused by dispersive effects and are therefore likely to be mitigated by an upstream TCLD installation. The assessment of the quantitative gain has to come based on future dedicated simulations.

A TCLD installation could also allow operating with a more open setting of the TCL6, which might be beneficial for the total machine impedance. However, it is clear from Fig. 8 that the

TCLD has the potential to cure only the losses in the cluster starting around s=400m and that the upstream losses would not be affected.

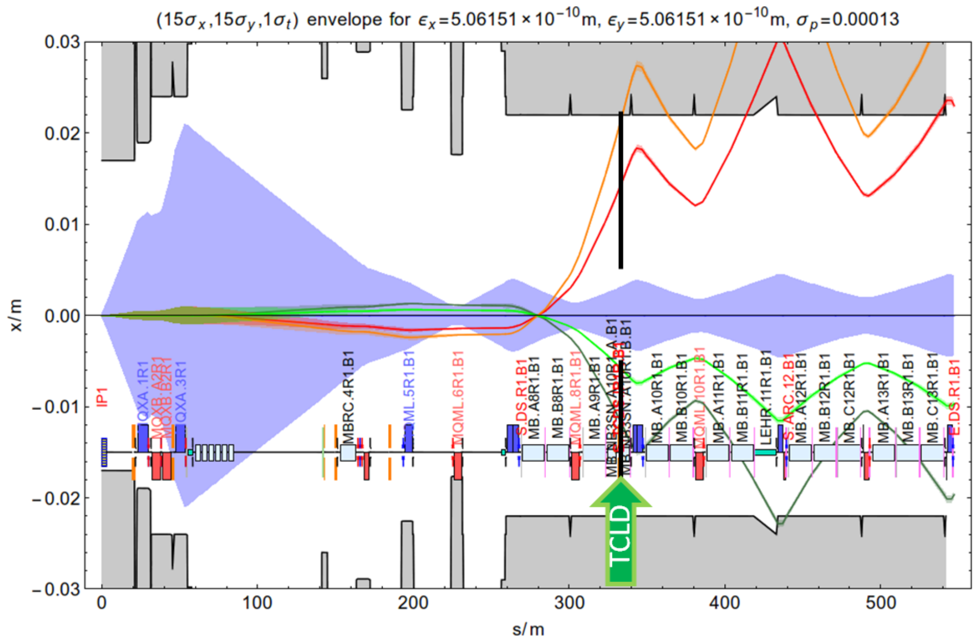

Figure 9: Secondary beams created in Pb ion collisions, shown in the horizontal plane, emerging from IP1 and potentially quenching dispersion suppressor magnets. A collimator installed in the position indicated can intercept the most intense (red) beam. Courtesy of J. Jowett and M. Schaumann.

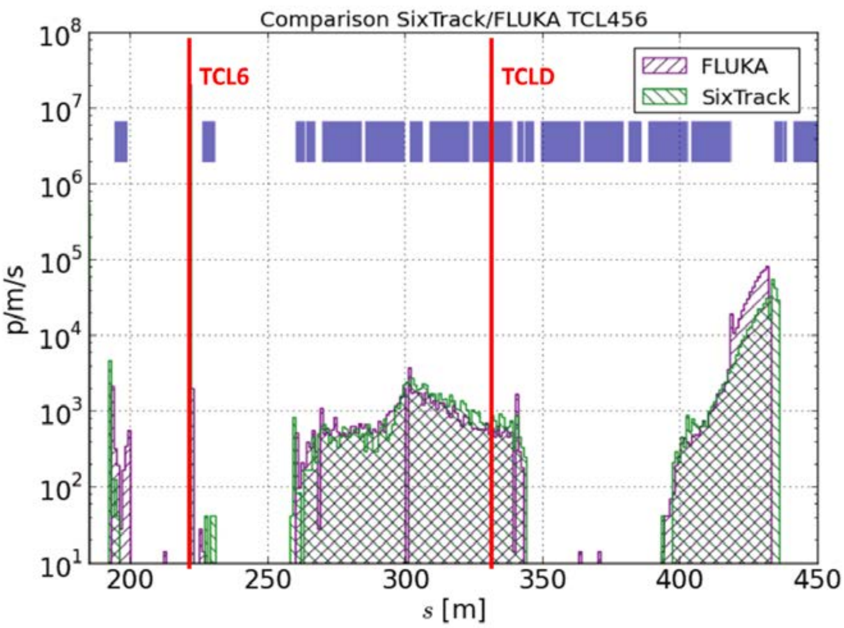

Figure 10: Collisional proton losses around the IR1 DS versus longitudinal position, for FLUKA (purple) and SixTrack (green) simulations, with TCL4, 5 and 6 set at 15, 35 and 10 σ. The losses are expressed in protons/m/s, for the design luminosity. The locations of the TCL6 (included) and the possible TCLD (not included in the simulation) are indicated by red lines. Figure adapted from Ref. [24].

4. FUTURE PLANS / CONCLUSION / RELATION TO HL-LHC WORK

The progress of the WP5 activities in the last year has been very satisfactory. The main goal of providing a conceptual design of IR collimation in the LHC high luminosity experiments was achieved: baseline layouts are available for proton and ion beams in IR1 and IR5. Note that the baseline scenario for the ion in IR2 was worked out and reported already for the D5.4 document due in Oct. 2013.

The IR collimation in IR1 and IR5 covers two functionalities: cleaning and protection against incoming beam losses and cleaning of the collision products. Two pairs of horizontal and vertical tertiary collimators downstream of D2 and in front of the Q5 magnets are foreseen for the incoming beam. Three horizontal movable physics debris absorbers are foreseen for the outgoing beam. Up to 4 fixed masks are also foreseen for physics debris cleaning, to be mounted on the IP side of the magnets (covering both apertures). The present simulations indicate that these layouts provide sufficient protection and cleaning for proton runs, without the need of additional local collimation in the dispersion suppressors around IR1 and IR5.

On the other hand, as pointed out for the case of IR2, operation with ion beams poses concerns also in IR1 and IR5 so the addition of dispersion suppressor collimators is also needed in these IRs if ATLAS and CMS wish to run at the same peak luminosities as ALICE. Conceptual IR1/5 designs for the ion case have also been worked out. Detailed simulations need to be performed with energy deposition tools however no differences in performance compared to the IR2 case are expected.

It is important to realize that these conceptual IR collimation designs are worked out for the baseline HL-LHCV1.1 optics with round beams. The presented results and the conclusions drawn at this stage must be confirmed by simulation repeated for future versions of the optics. It is also noted that the conceptual designs presented here feature some integration issues in the region between the TAXN and the D2 that are presently being addressed. If simulations confirm that the presented conceptual solutions are satisfactory, a complete design of the region (aiming at optimizing the design of collimators, vacuum components and cold-warm transitions) will be carried out.

Future studies will address aspect related to the operation with flat beams. The studies concerning the impact of collimators on impedance indicate that measures to reduce the collimator impedance might be required, in particular for the TCL-6 where beam sizes are very small. A feedback on the collimator design, including material choices for collimator jaws, will be required after having studies in detail failure scenarios for the incoming beam. In addition, we will study if the number of collimators can be reduced compared to this baseline. For example, detailed aperture analyses are on-going to see if the tertiary collimators at the Q5 could be reduced in number or even removed. The position of the tertiary collimators protecting the triplet might also be re-tuned in case of major integration issues. Final technical design of the IR collimation will also include details on the collimation design and on the jaw material, in light of results of simulations of slow and fast beam failures.

5. REFERENCES

[1] http://indico.cern.ch/event/251588

[2] http://cds.cern.ch/record/1644775/files/CERN-ACC-2014-0009.pdf

[3] http://lhc-collimation-upgrade-spec.web.cern.ch/lhc-collimation-upgrade-spec/Documents.php

[4] M. Fitterer et al. Optics Considerations for PIC and US1 scenarios for HL-LHC in the framework of the RLIUP review, CERN-ACC-NOTE-2014-0031 (2014)

[5] R. Bruce , R.W. Assmann. LHC beta*-reach in 2012, Proceedings of the LHC Beam Operation Workshop - Evian 2011 (2011)

[6] G. Robert-Demolaize, G. et al. (2005), Proc. of the Particle Accelerator Conf. 2005, Knoxville, 4084.

[7] [4] T. Trenkler and J. Jeanneret, CERN SL/94105(AP)(1994).

[8] C. Tambasco, An improved scattering routine for collimation tracking studies at LHC, Master's thesis, Universita di Roma, Italy (2014).

[9] L. Lari et al. Proceedings of IPAC12, New Orleans, Louisiana, USA, p 547 (2012).

[10] L. Lari, et al. Proceedings of IPAC13, Shanghai, China, p 996 (2013).

[11] R. Bruce et al. Simulations and measurements of beam loss patterns at the CERN Large Hadron Collider, Phys. Rev. ST Accel. Beams 17, 081004 (2014)

[12] R. Bruce et al. Parameters for HL-LHC aperture calculations and comparison with aperture measurements, CERN-ACC-2014-0044 (2014)

[13] A. Marsili et al., Simulation of the collimation cleaning performance with HL-LHC optics, Proceedings of IPAC13, Shanghai, China p987 (2013).

[14] M. Serluca et al., HI-LUMI LHC collimation studies with Merlin code, Proceedings of IPAC2014, Dresden, Germany, p784 (2014)

[15] http://sourceforge.net/projects/merlin-pt/

[16] Esposito L.S. and Cerutti F. (2013), "Energy deposition in the Matching Section with latest layout version", Presentation at the 3rd Joint HiLumi LHC-LARP Annual Meeting, Daresbury, England,

[17] Esposito, L.S. et al. (2014), "Energy deposition studies for physics debris (TAXN-D2 region)", Presentation at the Joint WP2-WP5 meeting & 46th ColUSM, https://indico.cern.ch/event/343840/.

[18] M. Brugger et al. (2014), "Energy deposition and radiation to electronics", Chapter 10 of the HL-LHC PDR, to be published.

[19] J.M. Jowett et al (2003) "Heavy Ion Beams in the LHC", Proc, 2003 Particle Accelerator Conference;

[20] Bruce, R. et al. (2009), "Beam losses from ultraperipheral nuclear collisions between Pb ions in the Large Hadron Collider and their alleviation", *PRSTAB*, **12** 071002.

[21] J. Jowett, M. Schaumann,: Dispersion Suppressor Collimators for Heavy-Ion Operation, Presentation at the LHC Collimation Review 2013, http://indico.cern.ch/event/251588

[22] Steele, G. et al. (2013), “Heat load scenarios and protection levels for ions”, Presentation at the LHC Collimation Review 2013, https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=251588.

[23] R. Bruce, A. Lechner, and S. Redaelli. Energy deposition simulations for upgraded collimation layouts, CERN-ACC-2014-0009 (2014).

[24] A. Marsili et al. Multi-turn tracking of collision products at the LHC, Proceedings of IPAC2014, Dresden, Germany, p166 (2014)

6. ANNEX: GLOSSARY

Acronym	**Definition**
DS	Dispersion Suppressor
IR	Interaction Region
IP	Interaction Point
LS1, LS2, LS3	Long-shutdown1, 2, 3
TCLD	Target Collimator Long for Dispersion suppressor
TCT	Target Collimator Tertiary (“tertiary collimators”)
TCL	Target Collimator Long (“physics debris collimator”)