CERN-ACC-2016-0008

HiLumi LHC

FP7 High Luminosity Large Hadron Collider Design Study

Deliverable Report

3rd Periodic HiLumi LHC Report

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14 January 2016

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 **1: Project Management & Technical Coordination**.

CERN-ACC-2016-0008

Grant Agreement No: 284404

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FP7 High Luminosity Large Hadron Collider Design Study

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

PROJECT PERIODIC REPORT

3RD PERIODIC HILUMI LHC REPORT

Document identifier:	HiLumi-P3-report_version_public
Year:	From Month 37 (Nov 2014) to Month 48 (Oct 2015)
Report release date:	14/01/2016
Work package:	WP1 Project Management and Communication
Lead beneficiary:	CERN
Project web site address:	http://cern.ch/hilumilhc
Document status:	Final

Abstract

The report of the work performed during the 3rd period, between 1 November 2014 (M37) to 31 October 2015 (M48) including the work progress and the use of resources.

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

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Reviewed by	L. Rossi	CERN	15/12/2015
Approved by	Steering Committee		10/01/2016

PROJECT PERIODIC REPORT

Grant Agreement number:	284404
Project acronym:	HiLumi LHC
Project title:	FP7 High Luminosity Large Hadron Collider Design Study
Funding Scheme:	Seventh Framework Programme, Capacities Specific Programme, Research Infrastructures, Collaborative Project
Date of latest version of Annex 1 against which assessment will be made:	14/03/2014
Periodic report:	1st ☐ 2nd ☐ **3rd** ✕
Period covered:	From Month 37 (November 2014) to Month 48 (October 2015)
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Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate):

  ☒ has fully achieved its objectives and technical goals for the period;

  ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations;

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.
- The public website, if applicable

  ☒ is up to date

  ☐ is not up to date
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: ....Lucio Rossi….....................

Date: 13/01/2016

The signature of this declaration is done directly via the IT reporting tool SESAM.

EXECUTIVE SUMMARY

The HiLumi LHC Design Study project consortium has 15 partners, including institutes from outside the European Research Area, such as Russia, Japan and 5 collaborating laboratories from the US, which enables the implementation of the construction phase as a global project. The HiLumi LHC Design Study is progressing well with the completion 18 out of 18 deliverables and the achievement of 10 out of 10 milestones in the third period.

WP1 focused on the coordination and preparation of the transition from the design phase to the construction phase of the HiLumi-LHC project, including the creation of a new governance model. Secondly, the project management team prepared the Cost & Schedule Review, which took place in March 2015. A new LHC and HL-LHC baseline was adopted subsequently, integrating modifications related to the Civil Engineering layout and works. Finally, the Quality Assurance plan was also finalized and presented.

WP2 issued a new version of the layout and optics of the IR1 and IR5 high luminosity interaction regions, updated with information on integration aspects and hardware and alignment tolerances. Magnet aperture requirements have been defined and finalized. The analysis and steering of the impedance of the components located in regions with high beta functions also deserved a special attention. WP2 continued the studies of the beam-beam effects, which confirmed the feasibility of the nominal scenario based on the β* levelling mechanism. Further studies on the optimization of the operational scenario and performance are required.

WP3 completed the engineering design of the baseline for the magnet lattice. Moreover, it started the hardware fabrication for short models of the triplet, of the separation dipole, and of the two-in-one large aperture quadrupole. Single coils in the mirror configuration have been successfully tested for the triplet. A second iteration on the layout has been carried out, with a refined estimates of the cold mass lengths, interconnection, and lowering the triplet gradient to provide additional margin.

WP4 teams registered significant progress in the design of the cryomodule for the SPS beam tests. Both cavity designs and their respective LHe vessel interfaces were finalized. The parts for both cavities were stamped. The high power and low level RF for the SPS test are progressing according to schedule. A new mobile cryogenic unit will mitigate the capacity limitations encountered in previous choices.

WP5 achieved a key milestone related to the verification of a new IR collimation solution. As a result, the teams presented a complete technical solution for the collimation in and around the experimental insertions for the baseline parameter sets of HL-LHC. The new solution solves the main problems that emerged during the previous period and provides a better performance and more flexibility against optics changes. Fitting new collimators adapted for the HL parameters in the tight transverse space around the experiments is a challenge that is still of particular concern.

WP6, in partnership with industry, finalized the development of the first MgB2 PIT high-performance round wire and the procurement launched of 80 km of wire, delivered in unit lengths of at least 500 m. To fully qualify the newly developed conductor, MgB2 material studies, stability studies, electro-magnetic and mechanical tests as well as modelling were performed. Moreover, quench propagation studies were completed, and quench measurements were made on long 10 kA range MgB2 cables operated in helium gas. This work provided essential input for the definition of the quench protection system of the MgB2 lines when operated in the LHC machine. FLUKA energy deposition studies on the components of the Superconducting Links were completed considering the most updated configuration of the superconducting lines.

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1. PUBLISHABLE SUMMARY

FP7 HIGH LUMINOSITY LARGE HADRON COLLIDER DESIGN STUDY

With the end of the European Union-funded initiatives, the High Luminosity Upgrade of the LHC (HL-LHC) is currently entering the construction phase. This transition has dominated the work of the Work Packages in this 3rd period. The HiLumi-LHC Design Study progressed well, with all 10 foreseen milestones and 18 deliverables completed. All WPs of HL-LHC, including those not covered in the FP7 Design Study, have successfully achieved their objectives.

WP1: Project Management and Technical Coordination

During the third and last period of the Design Study, WP1 has been involved in two major tasks: the coordination and preparation of the transition from the design phase to the construction phase and the organization and implementation of the Cost and Schedule Review. The first activity resulted in a new governance model which has been proposed and accepted by the collaboration and by CERN management. Secondly, the Cost & Schedule Review, implemented in March 2015, resulted in a set of recommendations for a phased production and installation of the Crab cavity system in order to minimize the impact of potential production problems on the project planning. A delay and extension of Long Shutdown 2 has also been foreseen to adjust the civil engineering works to the LHC operational cycle. A new LHC and HL-LHC baseline, featuring a few variations with respect to the previous one, was therefore discussed with experiments and received endorsement by the CERN Management. Besides this, WP1 presented a quality assurance management plan defining the way the HL-LHC project will implement its Quality Management System, including best practices in project and quality management. The radiological impact team presented a summary of best practices in radiation protection to the ITHACA working group.

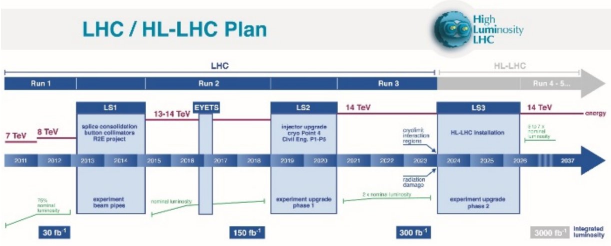


Figure 1The new LHC and HL-LHC timeline as endorsed by CERN management (last update 21.07.2015)

WP2 Accelerator Physics and Performance

During Period 3, WP2 studied the consequences of the decrease of the nominal gradient of the triplet quadrupoles and released new version of the layout and optics of the high luminosity interaction regions IR1 and IR5, including the latest information on integration aspects and hardware and alignment tolerances. The experience of LHC Run I (2010-2012) has provided critical input to define the magnet aperture requirements and finalize it. While the operational cycles for all the magnetic elements of the machine have been devised and optimized, the corresponding powering schemes have also been reviewed to allow the specification of the characteristics of the power converters for the new magnetic elements – including noise levels, reproducibility and accuracy. Magnet designers have progressed in their work towards field quality specifications, focusing on realistic operational scenarios. An operational scenario has been defined and limits on the impedance on the new components to be installed have been specified. A special focus has been put on the analysis and steering of the impedance of the components located in regions with high beta functions (e.g. crab cavities). The work has been carried out in collaboration with the teams responsible for the design. As part of the study on the possible intensity limitations, the cryogenic teams have been provided with data on the heat load on the beam screen resulting from the electron cloud and with the image currents. The analysis will contribute to the specification of the new cryogenics installations and to the evaluation of the available margins for existing installations. The study of the beam-beam effects has confirmed the feasibility of the nominal scenario based on the β^* levelling mechanism providing sufficient operational margin for operation at the ultimate luminosity of 7.5×10^{34} $cm^{-2}s^{-1}$. In parallel, the analysis of the compensation of beam-beam long-range effects through wires or electron beams is being pursued. Work is still ongoing regarding the definition of the beam conditions and measurements that need to be done with wires embedded in tertiary collimators to be installed in the LHC during the Year End Technical Stop 2016-17.

WP3 Magnet Design

The activities of WP3 focused on the main tasks relates to the inner triplet, the separation dipoles, Q4 and cooling. Triplet QXF (LARP and CERN): After the completion of the conceptual design, the engineering design has been finalized and the first coils have been wound. A single coil has been successfully tested in a mirror configuration, reaching 76% of short sample after two quenches, and 90% after 20 quenches. A fine tuning of the operational conditions has also been completed. The operational current has been lowered from 82% to 77% of short sample conditions, increasing the magnet length of 5%. This has provided additional margin also for quench protection. The specification on the QXF strand have also been reviewed, keeping the copper content constant and reducing the critical current. The first model of QXF containing two CERN and two LARP coils has been assembled in US in summer 2015, and will be tested in fall 2015. Separation dipole D1 (KEK and CERN): After the manufacturing of the first test coil, the assembly procedure has been tested on a magnet slice of 200 mm thickness. The test has shown a rotation of the coil during the assembly in the yoke, and an iteration of the yoke design has been done to improve the alignment. A set of coils to be used for the first model is being manufactured in summer 2015, with a test foreseen in early 2016. Two-in-one aperture quadrupole Q4 (CEA and CERN): The engineering design of the Q4 based on a single layer has been finalized, and the first winding test have been completed. The analyses of the baseline, carried out together with other WP, suggested that the magnet inductance is too low for stable operation. Therefore, a new design with a two-layer coil will be adopted. The aperture requirement is also being reviewed in collaboration with the beam dynamics team (WP2). Cooling: The estimate of the temperature inside the triplet has been updated taking into account the reduced current and minor changes in the magnet cross-section. The cooling scheme is robust, but a further margin could be gained with the optimization of the geometry of the tungsten shielding in the beam screen. This will be carried out in the fall 2015, with the second iteration of the layout. Besides these results, a conceptual design has been completed and engineering is in progress for both the nested orbit correctors (in collaboration with CIEMAT) and the Separation dipole D2 (with INFN-Genova). The coils in the high order orbit connector have been assembled in summer 2015 and the

Figure 2: QXF mirror entering the FNAL test station

assembly of the corrector sextupole will be completed in fall 2015. A magnetic design of the D2 Q4 orbit connectors has also been completed. A cost and schedule review was done in March 2015 and the recommendations have been implemented in the planning.

WP4 Crab Cavities

Figure 3Stamped parts for the DQW (top) and RFD (bottom at Niowave.

After successfully completing the RF cavity prototyping in the second period, both cavities ("RFD" and "DQW") and interfaces were finalized including their LHe vessel and manufacture under progress. All the cavity parts were stamped at Niowave Inc. – thanks to the collaboration with US Labs that are associate to FP7-HilLumi (USLARP) – and will be assembled and surface processed in the US, in addition to electron-beam welding and testing. The second main focus of this period was the mechanical design of the dressed cavity including all couplers, tuner, internal magnetic shielding and the helium vessel, which is the heart of the FP7-Design Study of this last period. Full designs including thermal and mechanical analysis were performed for all both cavities with prototyping of certain parts being performed to validate the design concepts. The engineering design of the cryomodule and its interfaces to SPS environment including RF power, cryogenics and other services are in an advanced stage with several improvements over the previous setup. The cavity support system was optimized and two schemes for cavity alignment were proposed and the design is in the final stages. In the last few months of the project the team will focus on the thermal shield and outer vacuum vessel and vacuum interfaces. A new baseline location for the SPS in the LSS6 region is approved with the integration effort being ramped up. A detailed planning for installation of the various systems will be finalized soon.

WP5 IR Collimation

In the third period, the WP5 teams elaborated an improved collimation solution in order to address integration conflicts on the longitudinal space and changes of the optics layouts, for which the final validation is still ongoing. The detailed 3D design of new collimators for the IR is also being studied. The event that present collimators do not fit the tight transverse space around the experiments – where beams are brought in collision – has been considered. To address this, the teams studied various alternative scenarios to the baseline solution. Iterations on the collimator layout have also been done on the baseline solutions for the ALICE upgrade in IR2 and for the betatron cleaning insertion IR7. For IR 2, the alternative solutions are based on the insertion of a collimator in the "connection cryostat". For IR7, the team studied the benefits of a partial implementation of DS collimation, with one collimator per beam. The team focused the IR7 research on protons and ions. In addition to the main activities within the HiLumi programme, the FP7-WP5 teams also contributed significantly to other important collimation upgrade studies for HL-LHC, including development of new collimators for higher robustness and lower impedance and simulations for hollow e-lens enhancement of collimation performance and crystal collimation. In 2015, the team participated in the LHC beam commissioning and in the beam studies, which were crucial to understand the collimation system performance with the HL-LHC upgraded beam parameters.

WP6 Cold Powering

During the third period, Work Package 6 finalized the development of the first MgB2 PIT round wire suitable for cabling in a reacted form. The wire is the result of a collaborative effort between CERN and industry. The procurement of 80km of wire has already been launched and CERN will receive it by the end of 2015. This is an important achievement that will enable the start of a large cabling activity in industry – as required for the production of prototype Cold Powering Systems for the High Luminosity LHC. Regarding the MgB2 wire qualification, in depth material studies and measurements were performed, including 3-D nano-tomography analysis to quantify the void fraction in the superconducting filaments; analysis and measurement of the Young's modulus of the MgB2 wire constituents and of the composite; measurement of tensile and bending strengths; measurement of critical current of wires; measurement of critical current degradation in strands cabled with different twist pitches and modelling of AC losses in wires with superconducting filaments having different twist pitches. Concerning the MgB2 cable qualification, several MgB2 20-kA cables were measured in the Superconducting Link test station at CERN. The cables were operated in the same cryogenic condition as proposed for the LHC (helium gas cooling). In depth studies and measurements of the stability and quench protection of the superconducting lines were implemented on high-current MgB2 cables aiming at deriving the input required for the definition of the quench protection system of the associated instrumentation. In addition, the Work Package elaborated a new concept of Distribution Feedbox connecting the current leads to the Superconducting Link. The new system design separates the current leads from the cryogenic envelope housing the electrical joints between the leads and the Superconducting Link. This design was specifically developed for the Cold Powering Systems proposed for integration at LHC P7 – where transport and integration issues were very challenging. The concept will be considered also for the Cold Powering Systems that will be integrated at LHC P1and P5. Finally, energy deposition studies were carried out on the components of the Superconducting Link closest to the beam pipes. Results from FLUKA simulation obtained with a statistics of 33000 events and all normalized to 3000 fb-1 report a maximum dose and Displacement per Atom (DPA) in the superconducting material of respectively 0.1 MGy and 10-6. These values are not expected to be critical for the operation of the Superconducting Links during the LHC lifetime.

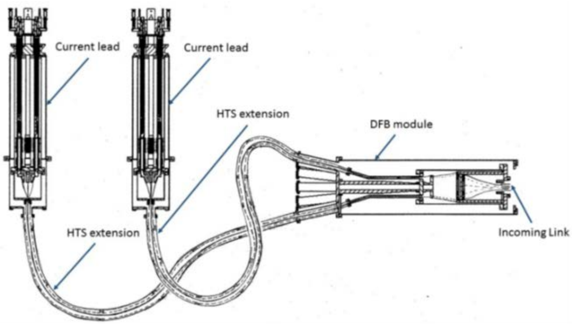


Figure 4: New concept of Distribution Feedbox. The current leads are connected to the cables in the Superconducting Link inside the Distribution Feedbox (DFB) module.

Coordinator: CERN

Partners: see http://hilumilhc.web.cern.ch/about/participants

Website: http://cern.ch/HiLumiLHC

2. CORE OF THE REPORT FOR THE PERIOD: PROJECT OBJECTIVES, WORK PROGRESS AND ACHIEVEMENTS, PROJECT MANAGEMENT

2.1. PROJECT OBJECTIVES FOR THE PERIOD

WP1

- Preparation of the Cost & Schedule review; proposed by the project management and then called by the CERN management, this has been a major step to have the baseline scrutinized.
- Re-definition of the baseline. Small changes have been introduced for technical reasons (a few examples: the length of the low-β quadrupoles (IT, inner triplet), suppression of superconducting link in P7, change in baseline location for the crab cavity SPS test), or for cost reduction reasons (change in magnet protection and operating current, reduction of low impedance collimators, etc.). However, much deeper modifications have been introduced due to the choice of Civil Engineering lay-out and due to the non-compatibility of the Civil Engineering works with the LHC operation during Run2 and Run3. The baseline has been completed with the definition of all the tools and framework for the project, like the QA plan, the chart for Industry etc…
- A better definition of scope, performance and hardware of the possible option and variants has also been an important goal of this last year of Design Study, with a definition of a plan B and of the steps to follow it (for example implementations of electron beams for long range compensation).
- Furthermore this last year has been dedicated to the preparation of the next phase of the project, beyond the FP7-Design Study. In particular the new governance model, the optimization of the budget and its profile, the revision of the common LHC/HL-LHC timeline with the experiments upgrade and with LIU (LHC Injector Project).

WP2

The main objectives for the period were:

- Review of the optics and layout taking into account the update of the design parameters of the Inner Triplet quadrupoles and of the results of the integration studies.
- Update of the specification of the field quality of the new magnets taking into account the progress in their design, of the new optics and layout and of the beam-beam effects.
- Critical review of the impedance of new components (in particular those in regions with large beta functions) in order to evaluate beam induced heating and beam stability limits.
- Follow-up of possible impedance reduction measures in collaboration with the equipment designers.
- Update of the estimate of contributions to the heat load expected on cryogenics resulting from electron clouds and impedance.
- Definition of the machine settings and beam parameters in the various phases of the HL-LHC cycle for the nominal and ultimate luminosity scenarios taking into account potential intensity limitations resulting from single and two-beams stability, impedance,

beam-beam and electron cloud effects and evaluating the effect of feedbacks and other mitigation measures (e.g. Landau damping, RF harmonic systems, etc.).

- Evaluation of the impact of vibrations induced by the HL-LHC civil engineering work on LHC operation and performance during Run III.

WP3

The objectives for this period were (i) have a first iteration of the baseline and make design changes or fine tuning of operational conditions if necessary, (ii) complete the engineering design for the triplet, D1, Q4 and start the coil construction, (iii) estimate the costs, provide a tentative schedule, and if possible define design changes compatible with the project targets to reduce the costs.

WP4

The main objectives for **WP4** for this period have been to finalise the dressed cavity designs, and start manufacture of the dressed cavities and to progress the cryomodule design. This period also included the LHC cost & schedule review.

WP5

The **WP5** team has completed the design of the **IR collimation** baseline for HL-LHC layout, addressing the challenges of incoming and outgoing beam cleaning for the HL-LHC parameter set. A detailed integration study of the conceptual design elaborated for the previous optics indicated potential conflicts of longitudinal space in the region between the TAXN and D2. This required an iteration on the design and adjustments of the collimation layout: a fixed mask in front of the D2 was replaced by a new collimator design – TCLX – that protects better downstream magnets, thanks to a transversally thicker jaw. The design of new collimators for this region has been launched for the complete technical solution. Improved solutions were also studied for other HL-LHC insertions, for example addressing in simulations the gains in IR7 cleaning from one single dispersion suppressor (DS) collimator instead than two, for ions and protons, and considering alternative solutions around IR2 to the baseline implementation of DS collimators with 11 T dipoles.

The work has proceeded well and the expected deliverables were achieved. The upgrade scenarios have been finalized to a level that is considered sufficient for the technical design report of HL, due at the end of the FP7-HiLumi's fourth year.

WP6

The main objectives for the reference period were:

- The completion of the development/production of a high-current MgB_2 round wire with mechanical characteristics enabling cabling after reaction;
- The qualification and test of high-current (20 kA range) MgB_2 cables operated in the same cryogenic conditions as in the LHC;
- The modelling and measurement of the stability and quench behavior of high-current MgB_2 cables operated in helium gas;
- The conceptual design of a Cold Powering System incorporating a Superconducting Link;
- The study of the energy deposition on the components of the Superconducting Link most near to beam pipes.

2.2. WORK PROGRESS AND ACHIEVEMENTS DURING THE PERIOD

2.2.1. WP1: Project management and Technical Coordination

This WP manages the project, monitors progress and communicates information within and outside the consortium. It includes 6 tasks:

- Task 1.1: Management
- Task 1.2: Parameter and Lay-out Committee
- Task 1.3: Quality assurance plan
- Task 1.4: Radiological impact
- Task 1.5: Liaison with Detector and Injector Upgrades
- Task 1.6: Dissemination of Information and Industry outreach

For details of Task1.1 and Task 1.6 please refer to section "Project management during the period".

2.2.1.1. Task 1.2: Parameter and Lay-out Committee

Progress towards objectives and significant results

The main goal of the HL-LHC Parameter and Layout Committee (HL-LHC PLC) in 2015 was the establishment of a baseline layout and definition of baseline beam and operational parameters. The work of the HL-LHC PLC has directly accompanied the preparation of the Preliminary Design Report (PDR) of the HL-LHC project. The HL-LHC PLC focuses on the approval and documentation of key decisions and parameters and does not directly address detailed technical discussions. These are conducted in the accompanying HL-LHC Technical Committee (HL-LHC TC). The period from November 2014 to August 2015 featured in total 4 HL-LHC PLC and 12 HL-LHC TC meetings. The main focus of these meetings evolved around:

- Preparation of the LHC Preliminary Design Report PDR (published in January 2015).
- Preparation of the LIU & HL-LHC Cost and Schedule Review (HL-LHC CSR) in March 2015.
- Specification of the underground civil engineering work and establishment of a feasible schedule for the civil engineering work during LS2 that does not require excavation work to take place during the LHC Run III.
- Review of the powering schemes for the new HL-LHC insertions following the decision of a complete underground installation of the HL-LHC power converters.
- Review of the ion beam parameters, the potential performance reach and operational scenarios up to and during the HL-LHC era.
- Establishment of the baseline triplet layout including L^* (distance of the first magnet from the Interaction Point [IP]) and TAXS integration following the SC cable and MQX reviews in November and December 2014. These reviews confirmed the choice of a 150mm coil aperture while recommending an operating point of 75% of the load line, implying a reduction in the magnet gradient and a corresponding increase of the magnet length.
- Review of the collimation baseline following the operational experience of the LHC in Run I, including the results from material tests for new collimator jaw materials and the results from vibration studies that revealed a potentially harmful effect of cultural noise on the machine efficiency during the HL-LHC era.

- Review of new (e.g. the crab cavity test installation in the SPS) and existing (e.g. SM18) hardware test facilities and their upgrade plans in view of the project transition from a design study towards a production project with hardware prototyping and testing.
- Review of the HL-LHC baseline configuration and preparation of the HL-LHC Technical Design Report (TDR) for publication by the end of 2015.
- Review of technical non-conformities in the existing LHC that impact on the performance reach of the HL-LHC.

The HL-LHC Cost and Schedule Review recommended a phased production and installation of the Crab Cavity system in order to minimize the impact of potential production problems on the project planning. The new plan foresees a distributed installation over Long Shutdown 3 (LS3) and Long Shutdown 4 (LS4). Furthermore, the discussions at the Cost & Schedule Review highlighted the tight schedule for planning and conducting the underground civil engineering work for the HL-LHC. This lead to a change of the LHC schedule such that the HL-LHC civil engineering work can be launched in time and completed during LS2. The latter was motivated by the observation that civil engineering work cannot be conducted in parallel to LHC operation as it would result in intolerable beam losses and impact on the overall LHC machine availability. The result was a delay and extension of Long Shutdown 2 (LS2) by 6 month, now starting at the end of 2018 and extending up to the end of 2020, accompanied by an equal displacement of LS3 along with the specification of a novel underground installation. The so-called double decker solution, where the new HL-LHC installations are located above the existing LHC tunnel, minimizes the civil engineering work required for connecting the new and old tunnel installations and provides naturally shielding of the new installations from the beam operation in the existing LHC tunnel. A crash program was launched for initiating the required civil engineering studies and for agreeing with all HL-LHC work package leaders on the overall volume for the new underground installations.

A comparison of the different underground installation options (installation of all new equipment in the new underground areas versus a partial underground installation with additional installation on the surface) revealed only small budget and schedule differences between these options. A complete underground installation was therefore adopted as the new baseline, as it minimizes the need for surface installations and minimizes the distance of the new equipment to the existing LHC tunnel. The decision implied therefore a revision of the overall powering strategy for the new insertions (e.g. superconducting links of much reduced length and the possibility of serial powering for some of the different insertion elements, the latter of which is still subject of ongoing discussion).

The HL-LHC Cost & Schedule Review also highlighted inconsistent assumptions on the ion operation schedule during the HL-LHC era, leading to a review of the operation options and required beam parameters for reaching the ALICE upgrade goals along with a clear specification of the required ion beam parameters at the exit of the SPS injector. These specifications will be evaluated and followed by the LHC Injector Upgrade (LIU) project with a revision of the estimated performance reach with ion beam operation.

The SC cable and MQX reviews in November and December 2014 lead to a reduction of the operating gradient of the new triplet magnets for the HL-LHC, which required in turn a further iteration on the magnet length and overall installation integration in the LHC (namely in terms of space requirements for the whole triplet assembly, optimized positioning of the Beam Position Monitors (BPMs), vacuum valves and distance of the triplet assembly from the IP). The entailing technical discussions and optimization extended well into the second half of 2015.

Planning for a backup beam configuration with flat beams in case Crab Cavity operation gets delayed or interrupted due to technical problems, required a review of the TAXS and TAXN absorber design for the experimental regions and lead to the implementation of additional collimators next to the new TAXN absorber. This development was accompanied by a general review of the HL-LHC absorbers (e.g. the injection protection devices TDI) and the overall collimation scheme. The studies resulted in a new baseline schedule for the production of dispersion suppressor collimator units using 11T dipole magnets and the proposal of a new dispersion suppressor collimation scheme using new collimators in the empty cryostats of the LHC dispersion suppressors in IR1 and IR5. The discussions also highlighted the need of dedicated magnet quench tests in the LHC during ion beam operation in Run II and further motivated the adoption of hollow electron lenses for halo control and the mitigation of resulting loss spikes due to cultural vibration noise.

Technical problems with the COLDEX test installation in the SPS at the beginning of Run II triggered a re-evaluation of the optimum location for a crab cavity test installation in the SPS. The problems of the COLDEX facility and continued worries about the effects of e-cloud on LHC operation implied a probable extension of the COLDEX operation beyond the original planning. This could cause conflict with the schedule for the Crab Cavity test stand installation that was supposed to be installed at the same location following the termination of the COLDEX experiments. Discussions at the HL-LHC TC and PLC resulted in the proposal of a new location (LSS6) for the Crab Cavity test facility in the SPS that allows a parallel operation with the COLDEX installation and avoids conflicts with other upgrade plans in the SPS (e.g. the construction of a new beam dump in LSS5). Discussion of the SM18 upgrade plans highlighted the criticality of implementing the SM18 upgrades in time for measuring the second MQXF magnet from the US and indicated potential problems related to the cryostat upgrade for FRESCA. The discussions also put forward the proposal of a two-phase string test of the triplet assembly: a first phase implemented by mid-2019 using the triplet prototype magnets and a second phase using series production magnets that cannot start before 2021.

Contractual milestones and deliverables

In the third reporting period, task 1.2 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.1.2. Task 1.3: Quality assurance plan

Progress towards objectives and significant results

The main objectives of this period were:

- the preparation of the quality assurance management plan with its associated procedures, guidelines and templates,
- the consolidation of the documentation management plan and
- the preparation of the first Manufacturing Folder for an HL-LHC component

The HL-LHC quality assurance management plan defines the way in which the HL-LHC project will implement its Quality Management System (QMS). It includes project management best practices as well as guidelines on the areas not covered by the LHC Quality Assurance Plan. Among other items it contains:

- the processes applicable to the project that have been determined in the HL-LHC Life Cycle, as well as their interaction and their future monitoring and development;
- the six areas required by the ISO 9001:2008, namely Control of Documents, Control of Records, Internal Audits, Control of Nonconformance, Corrective Action and Preventive Action; and
- a list of procedures, templates, plans and guidelines that have been elaborated to enable the implementation of such processes.

Among the more than 50 supporting documents we can underline the Contract Management Procedure [EDMS 1503762], the Scheduling Procedure [EDMS 1498909], the Options Management Procedure [EDMS 1500192, the Documentation Management and Control Procedure [EDMS 1398333] or the Safety Organisation for HL-LHC [EDMS 1313247]

The documentation management plan has been implemented during this year. Presently there are nearly 1000 nodes in our EDMS following the Governance and Project structure and more than 3200 long-term documents stored. In what concerns the short-term documentation storage, support has been provided to harmonize and complement the SharePoint and Indico sites for the different WPs. The plan has also been applied to the recently implemented WP17.

To complete the process of standardization it has been released the first Manufacturing and inspection plan (MIP) for an HL-LHC component Crab cavity High Order Mode (HOM) Coupler. Based on an HL-LHC MIP template it contains the more than 130 activities to be done for the fabrication of the DQW HOM coupler (HCACFHC001). Linked to each task the re the references to the documentation, the standards and procedures to be followed, the inspections and the inspection reports.

To these objectives and to the normal quality tasks, it has been added as objective the preparation of the training material for the different policies, procedures, guidelines and templates.

Contractual milestones and deliverables

In the third reporting period, task 1.3 had one deliverable D1.9 to submit.

- D1.9 Final QA Management plan: ACHIEVED on June 2014. The HL-LHC project is committed to be a project of excellence respecting the best practises in project and quality management. It is the policy of HL-LHC to develop and maintain a quality program complying with regulatory requirements and considering best industry practices. This document defines the way in which the HL-LHC project will implement its Quality Management System (QMS) and provides an overview of the quality procedures and other quality related documentation that are part of the HL-LHC quality management system

Planning, deviations and corrective actions

Task on schedule		Ahead of schedule	√	Minor delay		Significant delay	

2.2.1.3. Task 1.4: Radiological impact

Progress towards objectives and significant results

The work during the reporting period focused on following the progress of the project and on providing radiological risk assessments. This included active participation of a member of the Radiation Protection group in TC, PLC, WP8, WP15, WP17 and ITHACA working group meetings on a regular basis in order to ensure prompt replies to any request. For example, a summary of best practises in radiation protection during design and operation was presented during the first ITHACA working group meeting.

FLUKA Monte Carlo calculations of activation and residual dose rates were carried out with the most up-to-date geometry layout (developed for energy deposition studies by the FLUKA team) based on the beam line model HLLHC v1.0. The results were used to obtain preliminary work-and-dose planning estimates for critical interventions in the most radioactive areas of the accelerator (e.g., the TAS and inner triplet areas).

The methodology for such estimations as well as first results were discussed at the "4th HiLumi LHC/LARP Annual Meeting". The three presentations on radiation protection studies included residual dose rate maps for the inner triplet area, job dose estimates for interventions in this area as well as radiological risk assessments for the installation of the DFBX in IR1 and IR5 and the DFBA in IR1, IR5 and IR7. In particular, the discussed examples underlined the importance of performing radiological assessments already during the design phase in order to detect and implement options leading to a dose reduction during the operational and dismantling phases.

Furthermore, first radiological risk assessments were performed for the new service galleries in Point 1 and Point 5. Among others, the radiological implications of an emergency escape via the present LHC tunnel as well as different shielding options for RF and cryogenics connections to the LHC tunnel were studied. The latter focused on optimizing the shielding such that access to equipment is maximized. For these studies a new geometry model for the Monte Carlo calculation was developed and shared with the Radiation to Electronic (R2E) team in order to perform also risk assessments for radiation-induced electronics damage. As an example, Figure 5 (left panel) shows the effective dose map in case of an accidental loss of one full beam on a bulky object just in front of a connection core between the LHC tunnel and the new service galleries for a scenario without any additional shielding. On the right panel the figure shows the effective dose values averaged on the full height and on the full width in the 40 m long UA gallery. Results for a scenario with two 80cm thick concrete shielding walls are shown in Figure 6. In addition to the shielding, the position of the connection core between the service gallery and the LHC tunnel was optimized such that it is not in line-of-sight of the UA gallery, contributing to an additional dose reduction in this gallery.

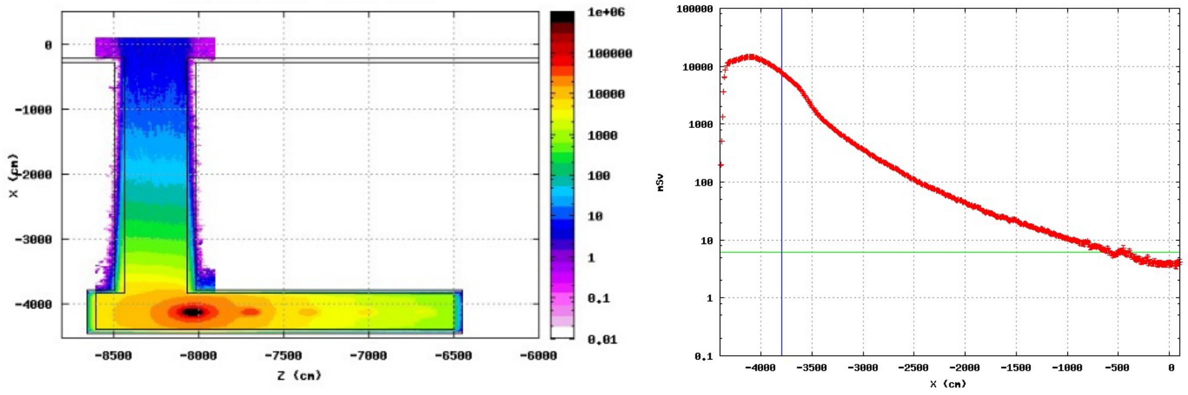


Figure 5. Left panel: effective dose map in the UA gallery in case of an accidental loss of a full beam just in front of the connection core; the colour scale is in mSv, the contour plot is shown for a horizontal section. Right panel: effective dose profile along the UA gallery averaged over the full height and on the full width of the gallery.

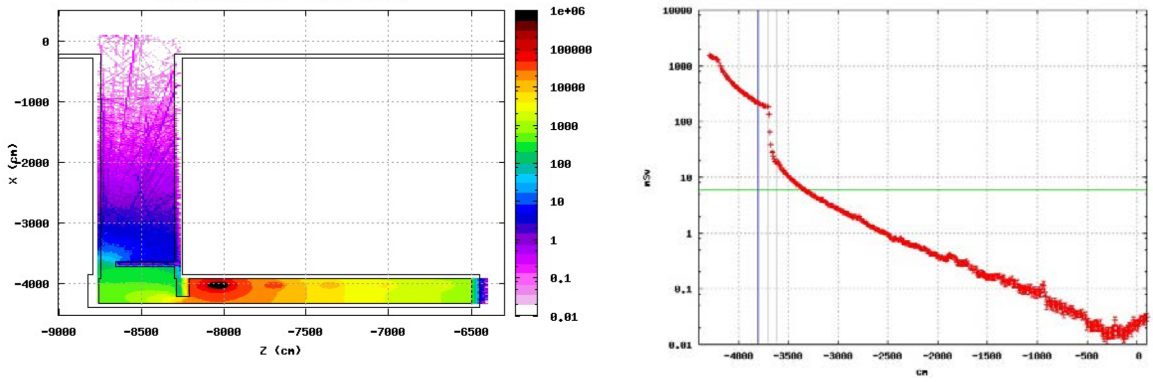


Figure 6. Left panel: effective dose map in the UA gallery with two shielding walls (80 cm concrete each) in case of an accidental loss of a full beam just in front of the connection core; the colour scale is in mSv, the contour plot is shown for a horizontal section. Right panel: effective dose profile along the UA gallery averaged over the full height and on the full width of the gallery.

Contractual milestones and deliverables

In the third reporting period, task 1.4 had no deliverables and milestones to submit

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.1.4. Task 1.5: Liaison with Detector and Injector Upgrades

Progress towards objectives and significant results

Detector Liaison

The liaison with detector has been managed though the HL-LHC coordination Group (https://indico.cern.ch/category/4192/), that sees the participation of the Experiment management, of the HL-LHC management, of LIU project Leader, the CERN Director for Research and the CERN Director for Accelerators. This is a strategic overview groups and a forum to approve technical solutions or define the criteria for optimization the performance.

The work at more technical level is organized and executed by WP8-Collider-Experiment Interface (see Figure 7).

The main results from November 2014 for this task have been:

1. An agreement on the ultimate performance definition. Without changing the characteristics and the cost of the equipment, by using the engineering margin, the maximum performance that could be reached without margin (i.e. this performance are not the baseline lie the nominal performance) are now defined to be:
   a. $L_{lev\ ult.}$ = 7.5 $10^{34}cm^{-2}s^{-1}$; this implies an average pile up of μ ~ 200 in the detectors and an increased level of heat deposition in the IR magnets and other elements, like the TAS and TAN. Note that this value is 50% beyond the nominal design HL-LHC performance (defined as L_{lev} = 5 $10^{34}cm^{-2}s^{-1}$ with μ ~ 140)
   b. $L_{total\ integral} \geq 4000\ fb^{-1}$; this limit, which more than 30% above the nominal design limit of 3000 fb^{-1}, has much to do with radiation resistance components in the magnets (and detectors).
2. A new LHC and HL-LHC baseline featuring a few variations with respect to the previous one described in the Deliverable D1.7. The changes have bene triggered by the need of extending the LS2 and shifting of its start to allow excavation for HL-LHC new underground facilities during LS2 (and also on request of the Experiments Alice and LHCb and to give proper time to the LIU installation). They changes, illustrated in the new plan of Fig. 3, are here summarized:
   a. Shift of six months (from July to December 2018) of the start of LS2.
   b. Extension of six months of the duration of LS2, now two-year long
   c. Shift of one year of the start of LS3, from end of 2024 to end of 2025.
3. The launch of the ITACA Working Group to discuss intervention in highly activated zone. This WG, chaired by the HL-LHC representative and co-chaired by an experiment representative, has the mandate to improve best practice and issue recommendations both for design and construction of equipment as well as to implement measures to easy intervention in "hot zone" according to ALARA principle.
4. The decision of the having access to the VCX area (the real interface between the machine equipment and Detector equipment). The new baseline is that access to VCX will be from experiment side, rather than machine side. This allow to keep L* = 23 m or even to have a marginal gain of 0.3 m to better optimize beam position monitors.

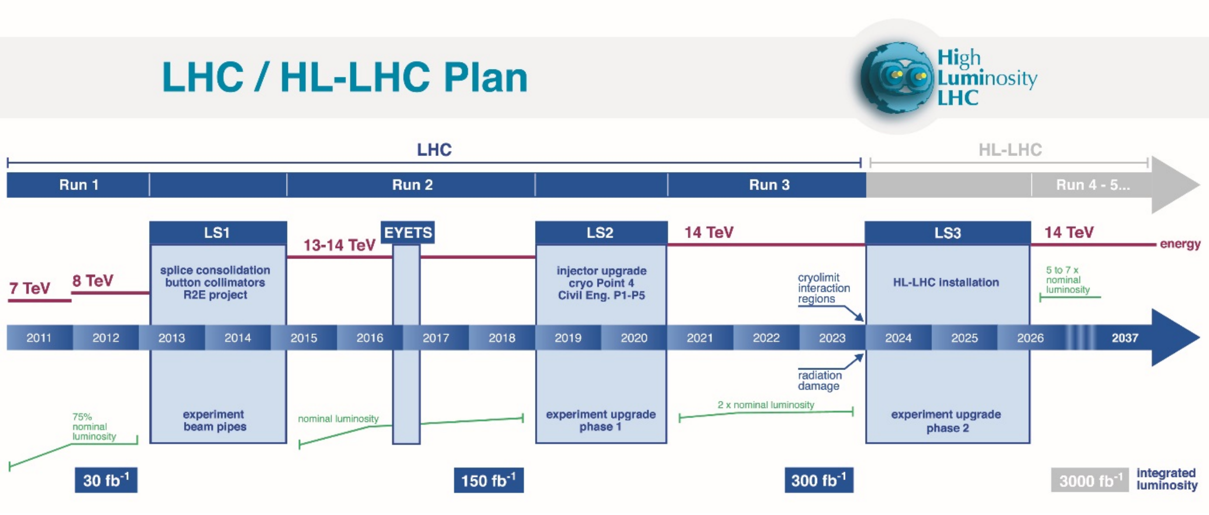


Figure 7. The LHC and HL-LHC timeline as discussed with experiments and endorsed by the CERN Management. (last updated 21.07.2015)

Injector liaison

The outcome and recommendations of the LIU and HL-LHC Cost & Schedule Review in March 2015 highlighted existing differences in the assumptions of the ion and proton beam operation scenarios during the HL-LHC era. This implied modifications of the baseline project implementation planning of the LIU and HL-LHC projects that could affect the overall performance reach and beam requirements during the initial operation period of the HL-LHC. For example, the planning of ion beam operation during Run V and consecutive running periods would reduce the time available for proton physics. Additionally, ion beam operation during Run4 and Run5 implies demanding ion beam parameters that might lie outside the reach of the current LIU upgrade plans. Finally, a phased installation of the Crab Cavity system in the LHC might have impacts on the beam requirements from the injector complex during the early operation period of the HL-LHC, while the actual performance reach of the injector complex for ion beam operation might have implications on the collimation requirements in the LHC.

It was therefore decided to launch a third joint workshop between the LIU and the HL-LHC projects in the second half of 2015 so that first impressions and lessons learned from Run II operation of the LHC can be considered during the workshop discussions and combined with recommendations and conclusions from the LIU and HL-LHC Cost & Schedule Review. The results from this workshop are expected to be available in time for the next meeting of the CERN Machine Advisory Meeting in January 2016.

The joint workshop is planned in the second week of October, two weeks before the 5th general HL-LHC meeting. The workshop is planned as a one-day event with 5 separate sessions:

- Discussion of the Cost & Schedule Review outcome and potential consequences on the beam parameters.
- Operational experience from the LHC and injector complex operation after LS1.
- Shutdown planning for LS2 and the Extended Year End Technical Stop (EYETS) in 2016.
- Beam tests in the injectors and the LHC needed for the LIU and HL-LHC projects.
- Possible non-baseline improvements towards reaching target goals (beam parameters and luminosity) for the LIU and HL-LHC projects and their implications.

In order to fit all 5 sessions into a one-day workshop program it is necessary that most of the technical discussions will actually take place before the workshop so that the actual workshop meeting can focus on summaries of the different discussions. The speakers of the various sessions have therefore not only the task of presenting the main points and outcome at the workshop, but also, of organizing the required preparatory discussion meeting before the workshop. The program and the speakers have therefore been identified already in June, well in advance of the actual workshop, such that the different speakers have sufficient time over summer for the organization of the required preparatory meetings and discussions.

Main conclusions and recommendations from the workshop will be drafted by the end of 2015 in time to be considered and potentially included in the preparation of the HL-LHC TDR.

Contractual milestones and deliverables

In the third reporting period, task 1.5 had no deliverables and milestones to submit

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.2. WP2: Accelerator Physics and Performance

This WP manages the project, monitors progress and communicates information within and outside the consortium. It includes 6 tasks:

- Task 2.1: Coordination and Communication
- Task 2.2: Optics and Layout
- Task 2.3: Particle Simulations
- Task 2.4: Intensity Limitations
- Task 2.5: Beam-Beam Effects
- Task 2.6: Beam Parameter and Luminosity Optimization

2.2.2.1. Task 2.1: Coordination and Communication

Progress towards objectives and significant results

Main activities of the last period were:

- Participate to the organization of the Joint LARP HiLumi Meeting (May 2015), the HL-LHC and LIU Cost and Schedule Review and of the Fifth HiLumi Annual Meeting planned for October 2015.
- Organization of Task leader meetings (see details below) in order to discuss progress in the various Tasks and to review the information to be transmitted to other WPs or required from other WPs.
- Maintain the good links with other WPs in order to progress with the definition of the layout and of the hardware specifications. This implies the participation to meetings organized by or in conjunction with other WPs.
- Participation and/or reporting to the Restricted and Extended Steering Committee Meetings, to the HL-LHC Coordination Group and to the HL-LHC Technical and Parameter and Layout Committees.

- Provide feedback on the conceptual specifications of equipment.
- Contribution to the writing and finalization of the HL-LHC Preliminary Design Report, HL-LHC Technical Design Report and of the High Luminosity LHC book.

Work Package and Task Leader meetings

Dates	*Type of meeting*	*Venue*	*Attendance*	*Indico link*
07/11/2014	**37th HiLumi WP2 Task Leader Meeting**	**CERN**	**5**	http://indico.cern.ch/event/343574/
05/12/2014	**38th HiLumi WP2 Task Leader Meeting**	**CERN**	**10**	http://indico.cern.ch/event/354507/
30/01/2015	**39th HiLumi WP2 Task Leader Meeting**	**CERN**	**6**	http://indico.cern.ch/event/367759/
20/02/2015	**40th HiLumi WP2 Task Leader Meeting**	**CERN**	**7**	http://indico.cern.ch/event/371766/
27/02/2015	**41st HiLumi WP2 Task Leader Meeting**	**CERN**	**10**	http://indico.cern.ch/event/371767/
06/03/2015	**42nd HiLumi WP2 Task Leader Meeting**	**CERN**	**7**	http://indico.cern.ch/event/371768/
13/03/2015	**43rd HiLumi WP2 Task Leader Meeting**	**CERN**	**9**	http://indico.cern.ch/event/376191/
20/03/2015	**44th HiLumi WP2 Task Leader Meeting**	**CERN**	**8**	http://indico.cern.ch/event/376192/
27/03/2015	**45th HiLumi WP2 Task Leader Meeting**	**CERN**	**7**	http://indico.cern.ch/event/376193/
10/04/2015	**46th HiLumi WP2 Task Leader Meeting**	**CERN**	**7**	http://indico.cern.ch/event/376194/
17/04/2015	**47th HiLumi WP2 Task Leader Meeting**	**CERN**	**14**	http://indico.cern.ch/event/376195/
24/04/2015	**48th HiLumi WP2 Task Leader Meeting**	**CERN**	**5**	http://indico.cern.ch/event/376196/

05/06/2015	**49th HiLumi WP2 Task Leader Meeting**	**CERN**	**6**	http://indico.cern.ch/event/394920/
12/06/2015	**50th HiLumi WP2 Task Leader Meeting**	**CERN**	**6**	http://indico.cern.ch/event/394921/
19/06/2015	**51st HiLumi WP2 Task Leader Meeting**	**CERN**	**10**	http://indico.cern.ch/event/394922/
03/07/2015	**52nd HiLumi WP2 Task Leader Meeting**	**CERN**	**3**	http://indico.cern.ch/event/394924/
24/07/2015	**53rd HiLumi WP2 Task Leader Meeting**	**CERN**	**5**	http://indico.cern.ch/event/394927/
31/07/2015	**HiLumi WP2 Task Leader Meeting**	**CERN**		http://indico.cern.ch/event/394928/
19/02/2015	**Task 2.2 meeting: Powering specification for HL-LHC**	**CERN**	**5**	http://indico.cern.ch/event/369635/
19/05/2015	**Task 2.2 meeting: Powering specification for HL-LHC**	**CERN**	**7**	http://indico.cern.ch/event/392952/
10/12/2014	**18th HiLumi WP2 Task 2.4 meeting**	**CERN**	**9**	http://indico.cern.ch/event/354942/
04/03/2015	**19th HiLumi WP2 Task 2.4 meeting**	**CERN**	**11**	http://indico.cern.ch/event/377643/
18/03/2015	**20th HiLumi WP2 Task 2.4 (and 2.7) meeting**	**CERN**	**6**	http://indico.cern.ch/event/381250/
25/03/2015	**21th HiLumi WP2 Task 2.4 (and 2.7) meeting**	**CERN**	**7**	http://indico.cern.ch/event/383042/
29/04/2015	**22nd HiLumi WP2 Task 2.4 (and 2.7) meeting**	**CERN**	**9**	http://indico.cern.ch/event/390084/
17/06/2015	**23rd HiLumi WP2 Task 2.4 (and 2.7) meeting**	**CERN**	**7**	https://indico.cern.ch/event/399555/
01/07/2015	**24th HiLumi WP2 Task 2.4 (and 2.7) meeting**	**CERN**	**3**	https://indico.cern.ch/event/403464/

08/07/2015	**25th HiLumi WP2 Task 2.4 (and 2.7) meeting**	**CERN**	**6**	https://indico.cern.ch/event/406037/
15/07/2015	**26th HiLumi WP2 Task 2.4 (and 2.7) meeting**	**CERN**	**6**	https://indico.cern.ch/event/406051/
11/12/14	**Beam-Beam Meeting**	**CERN**	**~10**	https://indico.cern.ch/event/357186/
09/03/15	**Beam-Beam Meeting**	**CERN**	**~10**	https://indico.cern.ch/event/379336/
16/03/15	**Beam-Beam Meeting**	**CERN**	**~10**	https://indico.cern.ch/event/381660/
30/03/15	**Beam-Beam Meeting**	**CERN**	**~10**	https://indico.cern.ch/event/384403/
13/04/15	**Beam-Beam Meeting**	**CERN**	**~10**	https://indico.cern.ch/event/387294/
20/04/15	**Beam-beam and luminosity studies meeting**	**CERN**	**~10**	https://indico.cern.ch/event/388760/
18/05/15	**Beam-beam and luminosity studies meeting**	**CERN**	**~10**	https://indico.cern.ch/event/394407/
01/06/15	**Beam-beam and luminosity studies meeting**	**CERN**	**~10**	https://indico.cern.ch/event/395568/
15/06/15	**Beam-beam and luminosity studies meeting**	**CERN**	**~10**	https://indico.cern.ch/event/397870/
22/06/15	**Beam-beam and luminosity studies meeting**	**CERN**	**~10**	https://indico.cern.ch/event/402410/
29/06/15	**Beam-beam and luminosity studies meeting**	**CERN**	**~10**	https://indico.cern.ch/event/402412/
20/07/15	**Beam-beam and luminosity studies meeting**	**CERN**	**~10**	https://indico.cern.ch/event/402414/
27/07/15	**Beam-beam and luminosity studies meeting**	**CERN**	**~10**	https://indico.cern.ch/event/402415/

Contractual milestones and deliverables

In the third reporting period, task 2.1 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.2.2. Task 2.2: Optics and Layout

Progress towards objectives and significant results

During period 3, the powering scheme for the new triplet has been thoroughly reviewed. This task entailed not only the analysis of several layouts for powering the triplets, but also the specification of the ripple amplitudes, and of frequency spectra.

In terms of layout, two alternatives have been proposed. They address both the minimisation of the total number of power converters used, as well as the minimisation of the current ripple on the machine tune. The detail of the three possible layouts is given in Figure 8.

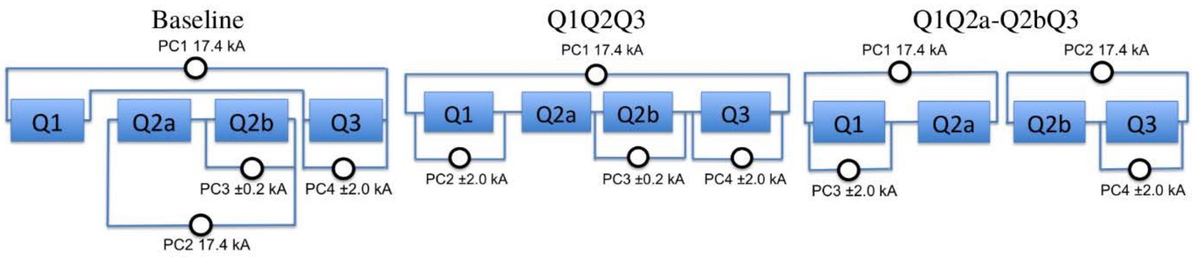


Figure 8: Possible layouts for the IT powering.

The analysis of the impact of the ripple on HL-LHC performance has been addressed by considering the impact on dynamic aperture. These studies are aimed at providing upper bounds to the acceptable amplitude of the ripple frequencies. Several configurations have been considered, which included several effects, such as beam-beam, crab cavities, and Landau octupoles. The results are shown in Figure 9, where the dynamic aperture as a function of the physical angle is shown for several ripple frequencies. For each configuration the minimum and maximum dynamic aperture over the sixty realisations of the magnetic errors is given. It is clearly seen that only 300 and 600 Hz ripple lines have a sizeable impact on the dynamic aperture.

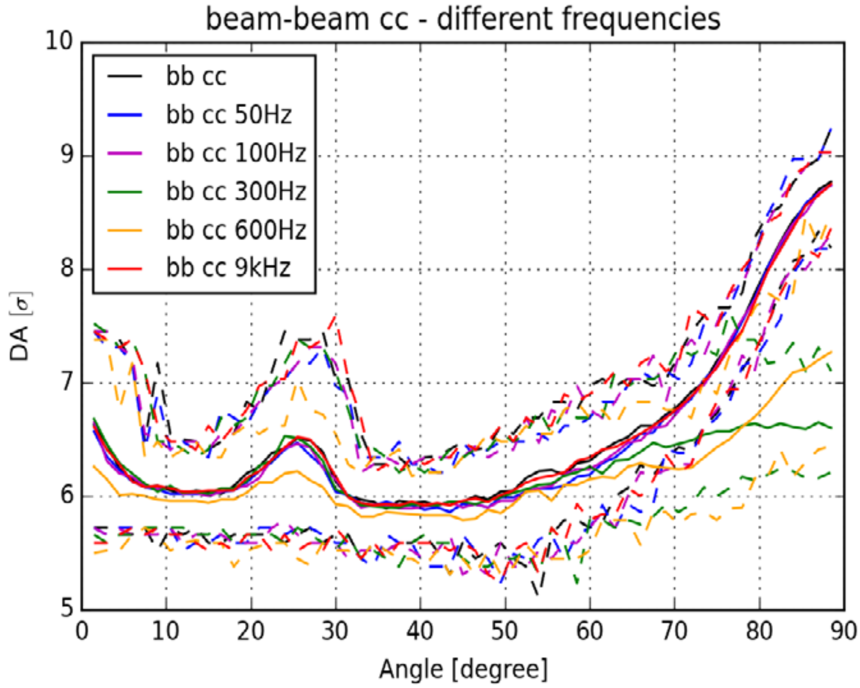


Figure 9: Dynamic aperture (in units of the r.m.s. beam size corresponding to a normalized emittance of 3.75 μm) as a function of the physical angle for several ripple frequencies and in the presence of magnetic field errors. The simulations have been performed for the collision optics (β=15 cm) with a nominal full crossing angle of 590 μrad and full compensation of the crossing angle by means of crab cavities at IP1 and 5 for the nominal bunch population (N_b=2.2×10^{11} p). The minimum and maximum dynamic aperture over the sixty realisations of the magnetic errors are represented by the dashed curves while the average dynamic aperture is indicated by the continuous curves. The only frequencies that introduce noticeable reduction in the dynamic aperture are 300 and 600 Hz.*

Analysis of the time requested to perform the pre-squeeze of the optics as well as of the squeeze has been carried out in view of providing specification for the characteristics of the circuits, mainly of Q4 and Q5. Finally, the ramp down time of the IT quadrupoles has been critically reviewed in order to avoid limiting the HL-LHC performance in terms of turn-around time. This piece of information will be essential in the final specification of the power converters.

The analysis of the powering scheme has then been oriented to the specification of the circuits of the separation dipoles, D1 and D2, and of the Q4 and Q5 quadrupoles. The option of powering the separation dipoles in series has been evaluated and found to bring some reduction in the tune ripple. The possible impact of this choice is being evaluated by WP6 and WP9.

As far as the Q4 is concerned, the option to power both apertures in series with a trim power converter to ensure the necessary optics flexibility is still considered viable. The baseline, however, is to assume the same type of powering layout that is implemented in the current LHC, namely with two power converters and a three-lead scheme, so that the current in one aperture has to be in the interval given by half and twice the current in the other aperture.

All main power converters for the new main IR magnets should be of Class 1, i.e., with 1 ppm accuracy, to ensure that the amplitude of the tune ripple is not exceeding 10^{-4}.

The tolerances on the roll angle for the IT quadrupoles as well as for Q4 and Q5 has been reviewed. The coupling correction procedure is being scrutinised following this study and this might induce a revision on the tolerances of the roll angle, but, provisionally, sub-millirad values should be aimed at.

Intense efforts have been devoted to the review of the layout of the high-luminosity IRs. This has been a necessary step following the request from WP3 to reduce the nominal gradient of the of the new Inner Triplet (IT) quadrupoles. New lengths have been specified, while the new layout and optics are being finalized in close collaboration with WP3, 4, 5, 8, 12 and 15 taking into account the constraints revealed by the integration studies.

In addition, the aperture requirements are being critically reviewed taking into account the new information on the tolerances of the equipment to be installed in the magnets' aperture.

Contractual milestones and deliverables

In the third reporting period, task 2.2 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.2.3. Task 2.3: Particle Simulations

Progress towards objectives and significant results

The simulations of the impact of the field quality at injection for the various classes of new magnets have been completed. The main result is that the expected field quality is compatible with the request of having a minimum dynamic aperture over the sixty realisations of the field errors around 10 σ (without beam-beam).

The situation in collision energy is radically different. The field quality of the new triplets has been scrutinised, by means of detailed dynamic aperture simulations, performed without the inclusion of beam-beam effects. The latest estimates of the field quality as provided by WP3 have been probed. The harmful impact of the increased multipole components b_{10} and b_{14} has been clearly observed, with the minimum dynamic aperture approaching 9 σ. The field quality of the latest cross section of the triplet magnets has partly addressed the above issues and new simulations will be performed with the most recent data. These will be completed by the analysis of the impact of the field quality in the presence of beam-beam effects in order to assess the needs of a revision of the field quality specifications.

The latest optimisation of the field quality of the D2 separation dipole has been very successful and its impact on the dynamic aperture in collision has been largely reduced and it is no more a source of concern.

With the detailed specification of the conditions for the collisions, it has been possible to launch the study of the evolution of the dynamic aperture during the squeeze and for various running conditions, mainly chromaticity and octupole settings. The dependence of the dynamic aperture on the value of β^* is shown in Figure 10. A linear behaviour is clearly observed. Flat optics configurations have been studied, too and the corresponding dynamic aperture value is very close to that of the round β^* configuration corresponding to $\sqrt{\beta^*_{\times}\,\beta^*_{\parallel}}$.

The dependence of the dynamic aperture on the linear chromaticity is shown in Figure 11. Also in this case a linear behaviour is found, showing that too high chromaticity values are detrimental for the single-particle beam stability. In the same plot both round nominal configuration as well as flat optics configurations are shown. The above observations are presently favouring a working point with lower chromaticity in particular when in collision.

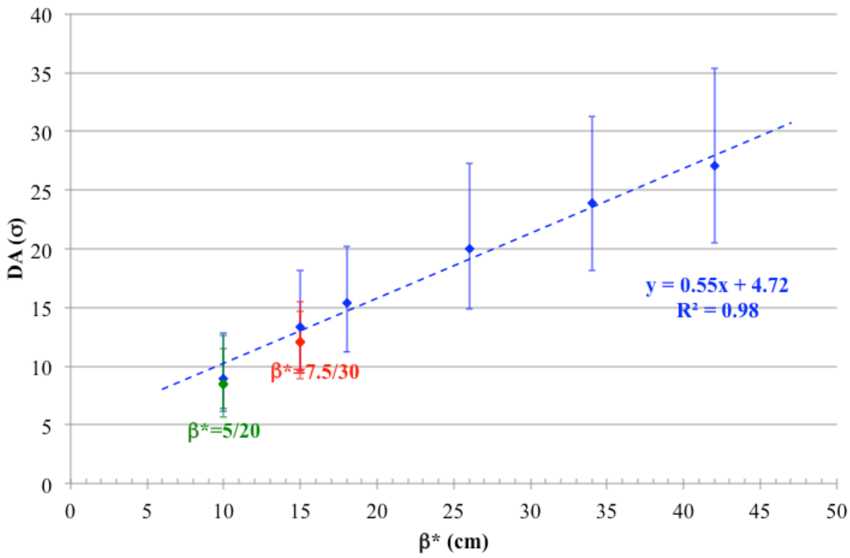


Figure 10: Dependence of the dynamic aperture on β^* value during the ATS squeeze. Flat optics configurations have also been considered.

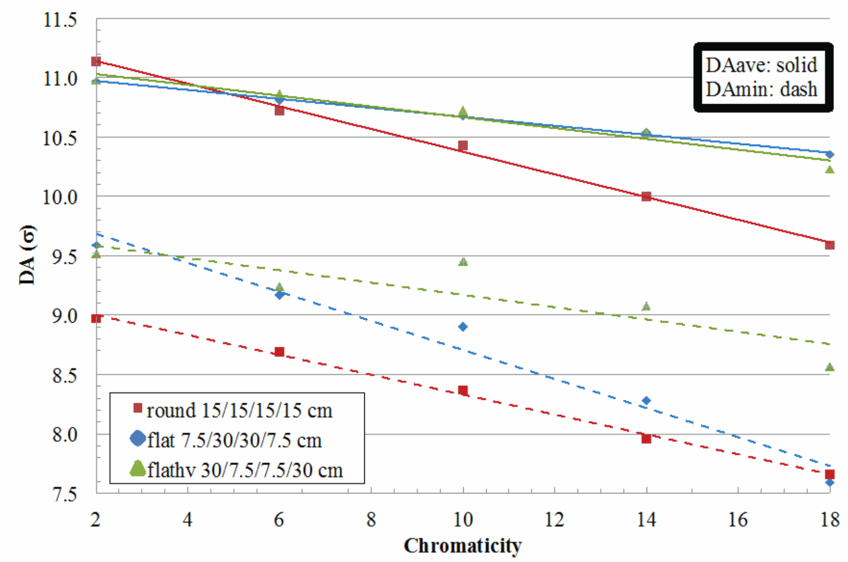


Figure 11: Dependence of the dynamic aperture on linear chromaticity at the end of the ATS squeeze. Flat optics configurations have also been considered.

The impact of the Landau octupoles on the DA has been also checked with numerical simulations. It turned out that the DA of the round optics is modestly reduced, about 0.6 σ, by the full strength octupoles, however, it falls below 8 σ. The average DA reaches 9 σ, with a much larger reduction (2 σ) indicating a smaller DA spread among different seeds.

The impact of the octupoles is stronger on flat optics: minimum and average DA are below 7 σ and 8 σ, respectively. These values are obtained for the nominal value (3) of the chromaticity. In case a larger value (18) is used, then the DA is further reduced just below 7 σ.

Another interesting feature to mention is that the presence of the strong octupoles makes the DA, both average and minimum, a nonlinear function of β^*.

Contractual milestones and deliverables

In the third reporting period, task 2.3 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule		Ahead of schedule	√	Minor delay		Significant delay	

2.2.2.4. Task 2.4: Intensity Limitations

Progress towards objectives and significant results

During Period 3, the studies of the intensity limitations related to impedance and electron cloud effects have continued. The effect of a double harmonic (800 MHz) RF system on the single-bunch stability limit has been studied in detail through HEADTAIL simulations, considering the HL-LHC impedance model (but without Crab Cavities). The effects of chromaticity, octupoles, bunch-by-bunch transverse damper and a phase error between the two RF systems (of ± 5 degrees) were considered. An increase of the single bunch transverse stability threshold by about a factor 4 can be obtained in Bunch Lengthening Mode (BLM) if combined with operation to high chromaticity (Q' ~ 15, + 550 A in the octupoles and the transverse damper with a damping time of 50 turns). In Bunch Shortening Mode (BSM) the impact of the 800 MHz system on the single bunch transverse stability threshold is marginal and it can lead to a slight reduction of the threshold according to the chromaticity settings.

Impedance measurements and simulations of the RF fingers proposed for installation in the triplets (5 per IP, i.e. 20 in total) revealed important resonances, when the bellow is compressed, due to the leak of electromagnetic fields through the RF fingers. A reduction of the depth of the convolutions of the bellow has been proposed to reduce this effect.

The HL-LHC operational scenarios (baseline – colliding at a β* of 70 cm – and ultimate – colliding at a β* of 46 cm –) were released, assuming in particular new Mo-Gr collimators with a 5 µm Mo coating installed in LSS7 only and Crab Cavities providing full compensation of the crossing angle in IP1 and IP5. The stability diagrams during the squeeze and collision processes were carefully studied in the presence of both octupoles and beam-beam effects.

Emphasis has been given to the study of the impact of the impedance of the Crab Cavities on beam stability. Benchmarking of single- and multi-bunch stability simulation codes, taking into account the realistic distributions of High Order Modes (HOMs) of both the BNL and ODU/SLAC designs, has been performed. The studies are currently being finalised and Fig. 5 clearly shows the single-bunch and coupled-bunch contributions to the instability growth rates, assuming the worst case of 16 Crab Cavities per beam with the lowest β* (15 cm). A reduction by at least a factor 3 is expected when operating with β* levelling for the ultimate scenario and a factor ~ 5 for the nominal scenario.

A further reduction of the impedance of the Crab Cavities by almost an order of magnitude is necessary given the large beta functions at their location. This can be obtained either by further optimization of the HOMs impedances, by a reduction of the number of Crab Cavities and optimization of the beta function. The possible mitigation of the impedance effects by an increase of the damping rate or of the bandwidth of the transverse damper is being studied.

As for the Crab Cavities the impedance of all the pieces of equipment being installed in regions with high beta functions (e.g. beam screens, beam position monitors, RF fingers) are being carefully scrutinized and followed-up with the corresponding Work Packages.

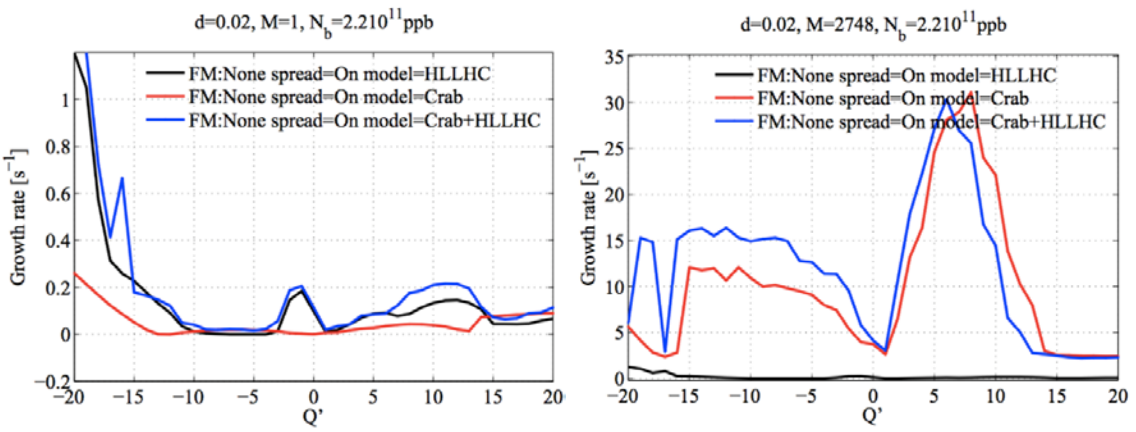


Figure 12: Instability growth rate from the DELPHI Vlasov solver in the presence of the bunch-by-bunch transverse damper (with 50 turns damping time) vs. chromaticity, without octupoles, with and without Crab cavities (updated DQW HOMs), for (left) a single bunch and (left) a single beam consisting of 2748 bunches. 16 Crab Cavities per beam have been considered (with a random frequency spread of 3 MHz for the HOMs of different cavities) for β^* = 15 cm.

The operation with 25 ns beam (for both LHC and HL-LHC) relies on beam-induced scrubbing: the LHC experience in 2015 will thus be of paramount importance to quantify how effectively scrubbing can mitigate electron cloud effects.

The multipacting thresholds and heat loads have been already estimated for i) the arc main magnets; ii) the matching quadrupoles; iii) the separation/recombination dipoles and iv) the inner triplets. The study of the impact of the shielding of the pumping holes ("baffles") is on-going following an upgrade of the pyECLOUD code required to make these studies possible.

The full electron cloud suppression should be possible for the arc dipoles but it seems very unlikely for the quadrupoles: the heat loads should be within the cryogenics cooling capacity and the impact on beam quality/stability is being assessed. These studies required an important code development activity to move from the (monolithic) HEADTAIL code to the modular and scriptable pyHEADTAIL code: it is now possible to use PyECLOUD to simulate the interaction between the beam and the electron cloud within the PyHEADTAIL code. First results revealed that after the reduction of the Secondary Emission Yield (SEY) through beam-induced scrubbing (SEY < 1.3), the electron cloud (alone) should not drive the beam unstable but the interplay between the electron cloud induced tune spread and the other sources of tune spreads and impedance/beam-beam effects should be studied in detail.

Finally, first tests performed with the electron cloud distribution from build-up simulations revealed significant changes with respect to the corresponding cases with uniform initial distribution (especially for the quadrupoles). Therefore, the instability thresholds and tune footprints should be ultimately updated with self-consistent distributions.

Contractual milestones and deliverables

In the third reporting period, task 2.4 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.2.5. Task 2.5: Beam-Beam Effects

Progress towards objectives and significant results

In accordance with the task work plan, the activities during the reporting period were concentrated on the following major subjects:

- Evaluation of the robustness of baseline scenario, including the impact of magnetic multipole errors, and dynamics of the so-called pacman bunches;
- Evaluation of the coherent beam stability and effects of noise in relation to the beam-beam interaction;
- Studies of alternative operational scenarios and possible performance improvement techniques.

Along item i) the main result is the establishment of baseline scenario performance during luminosity levelling, including the full machine model with multipole errors (Fig. 6). Studies predict that operation at the constant crossing angle of 590 μrad provides substantial margin in terms of minimum Dynamical Aperture during the entire levelling process. This may open the possibility of operating at a larger value of chromaticity if so demanded by the coherent beam stability or to reduce the normalized crossing angle or to increase the value of levelled luminosity (up to the ultimate 7.5×10^{34}cm^{-2}s^{-1}).

The dynamics of pacman bunches is deemed satisfactory: the expected variation of betatron tune within the train does not exceed 0.003, chromaticity of 2 units, and orbit shift reaches 0.3σ assuming orthogonal crossing planes in IR1 and IR5.

The additional impact of the beam-beam interactions in IP2 and IP8 on dynamic aperture has been studied. IP2 and IP8 will be operated at lower luminosity as compared to IP1 and IP5 and it is planned to use the transverse separation between the two beams to level the luminosities to 2×10^{31} cm^{-2}s^{-1} and 2×10^{33} cm^{-2}s^{-1}, respectively. The effect of IP8, although visible, in particular for one of the two polarities of the spectrometer magnet (see Figure 13) is compatible with the criterion of 6 σ dynamic aperture for the nominal and ultimate levelling scenarios corresponding to levelled luminosities of 5×10^{34} cm^{-2}s^{-1} and 7.5×10^{33} cm^{-2}s^{-1}, respectively, in the high luminosity experiments. The effect of IP2 on dynamic aperture was found to be small (within 0.5σ), even for a reduced external crossing angle, as compared to the nominal value of 340 μrad, and without separation. The combined effect of both IP2 and IP8 though was shown to be important and to preserve the 6σ DA, at least a 6 σ separation was needed in both IP2 and IP8 only in the extreme case of operation at the virtual luminosity in IP1 and 5. These results need further to be confirmed with the newest optics and multipole error table.

Along item ii) the significant progress includes the evaluation of luminosity degradation due to emittance growth induced by crab cavity phase and voltage noise and feedback system noise. The impact of these effects where simulated using the BeamBeam3D code, and all noise effects were included as random displacements in the IP with variable r.m.s. amplitude. Thereby, limits on the crab cavity phase and relative amplitude noise were established for a maximum emittance blow-up of 1 %/hour and found to be of the order of 10^{-5} rad and 10^{-5} in the presence of a transverse feedback with a damping time of 20 turns.

Item iii) work included the assessment of possible HL-LHC performance enhancement with the use of current-wire devices for compensation of long-range beam-beam interactions, including the establishment of an experimental test program in the actual LHC. An operational scenario was described that allows achieving the integrated luminosity performance close to baseline without the deployment of crab cavities.

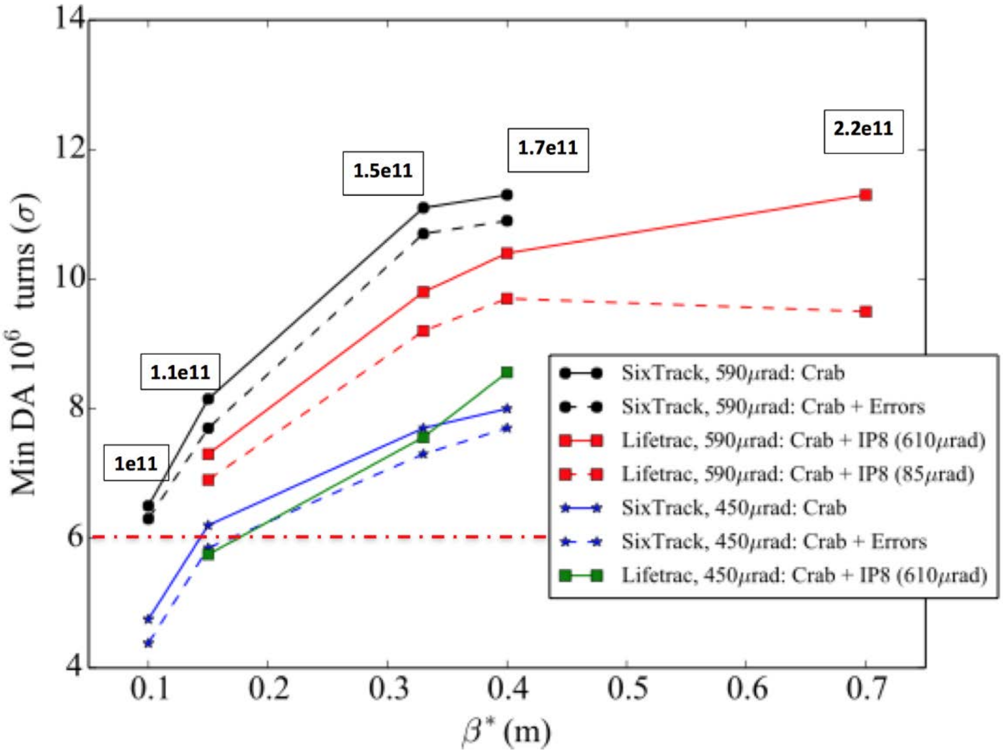


Figure 13: Minimum Dynamical Aperture (DA) during luminosity levelling at 5×1034cm-2s-1 simulated for the baseline scenario (round optics, full crab cavities) as a function of the beta-function, simulated with two beam-beam codes (SixTrack and Lifetrac). Dashed horizontal line depicts the target minimum DA. Solid lines show the results for machine with no multipole errors, dashed lines – with multipole errors. The studies were performed with HL-LHC optics V1.0. The two values of crossing angle in IP8 correspond to the different polarity of the spectrometer magnet, and a collision without transverse separation was assumed.

Contractual milestones and deliverables

In the third reporting period, task 2.5 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.2.6. Task 2.6: Beam Parameters and Luminosity Optimization

Progress towards objectives and significant results

As a result of the analysis conducted by the Tasks 2.2, 2.3, 2.4 and 2.5 a detailed set of beam and machine parameters have been defined for operation at nominal and ultimate luminosity assuming β* levelling in IP1 and 5 and levelling by separation in IP2 and IP8. The effort towards the elaboration of alternative scenarios to potentially mitigate technological risks or intensity limitations has progressed.

The detrimental effects of the electron cloud in the LHC (heat load in cold regions and emittance blow up) can be partly mitigated by using specially conceived filling patterns. The underlying idea is to use the flexibility of the injector complex to build bunch trains with long enough gaps interspersed, such as to prevent the build-up of an electron cloud along the beam in the LHC. A possible scheme (indicated as 8b+4e) consists in producing in the PS seven trains of eight bunches separated by four empty buckets.

The expected reduction in the heat load due to electron cloud on the beam screen of the LHC dipoles for this filling pattern as compared to that expected for the standard 25 ns filling pattern is shown in Figure 14 as a function of the Secondary Electron Yield (SEY). So far a minimum SEY of ~1.4 has been achieved in the main dipole beam screens after scrubbing.

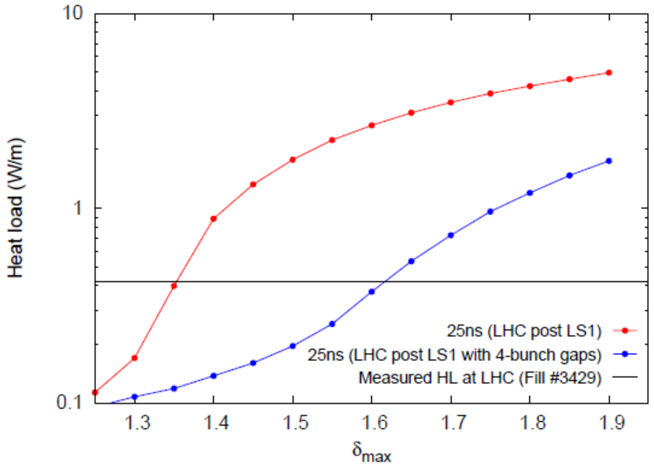


Figure 14: Expected heat load due to electron cloud in the beam screens of the LHC dipoles vs. SEY (δ_{max}) for the 25 ns standard filling pattern and 8b+4e scheme.

The parameters of this type of beam have been defined in collaboration with the members of the LHC Injector Upgrade Project and the corresponding beam and machine parameters in collision and expected integrated performance have been evaluated. The expected integrated luminosity, at constant average pile up of 140 events/crossing, is approximately 25% lower than that achievable with the nominal filling scheme. However the integrated luminosity achievable with the 8b+4e scheme is 25% higher than that achievable, for the same pile-up, with 50 ns beams that was considered so far as a back-up scenario in case sufficiently low Secondary Electron Yields could not be achieved in the arcs.

A review of the heavy-ion operational requirements and beam parameter specifications for Pb-Pb operation from post LS2 to LS4 in order to provide the luminosity requested by the experiments has been made and the beam parameters required at injection have been provided to identify the required upgrade actions in the injectors.

The possible impact of the HL-LHC civil engineering work close to IR1 and IR5 on LHC operation during Run III and in particular the effect of the vibrations induced on the magnetic elements in the IRs have been estimated showing that the resulting orbit oscillation could seriously affect luminosity production. As a result of that study, the planning for the civil engineering work has been completely revised with a large impact on the project schedule.

Contractual milestones and deliverables

The operation of the LHC and the machine studies conducted during Run I have provided important input for the validation of some of the choices that are at the base of the HL-LHC upgrade scenario but it has evidenced also some potential limitations. Progress has been made in their understanding, but some open points remain to be further studied to optimize the operational scenario and performance (e.g. stability during the squeeze and collision process, electron cloud effects with 25 ns beams). The required studies necessary for the collation of data for parameter optimization have been summarized in the Milestone Report MS32.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.3. WP3: Magnet Design

This WP manages the project, monitors progress and communicates information within and outside the consortium. It includes 6 tasks:

- Task 3.1: Coordination and Communication
- Task 3.2: Nb3Sn quadrupoles for the inner triplet
- Task 3.3: Separation dipoles
- Task 3.4: Cooling
- Task 3.5: Special Magnet Studies

2.2.3.1. Task 3.1: Coordination and Communication

Progress towards objectives and significant results

The work was presented and discussed in 20 WP3 meetings (see table below), plus

- Two collaboration meetings
  - o 4th Joint Hilumi LHC-LARP Annual Meeting 17-21 November, KEK https://indico.cern.ch/event/326148/
  - o 5th Joint Hilumi LHC-LARP Annual Meeting 11-13 May, FNAL https://indico.fnal.gov/conferenceDisplay.py?confId=9342
- Four reviews
  - o QXF cable review on 5-6th November 2014, CERN https://indico.cern.ch/event/338963/
  - o QXF design review on 10-12th December 2014, CERN https://indico.cern.ch/event/355818/
  - o Cost & schedule review March 2015, CERN (summary of the magnet session in https://indico.cern.ch/event/384124/)
  - o Sextupole corrector magnet review, 26th May, CERN http://indico.cern.ch/event/396055/
- Three steering committees of the collaborations
  - o CEA-CERN steering committee, 17th December 2014 at CERN https://indico.cern.ch/event/354019/
  - o CIEMAT-CERN steering committee, 26th May 2015 at CERN https://indico.cern.ch/event/396157/

- INFN-CERN steering committee, 30th June 2015 at CERN
  https://indico.cern.ch/event/395507/

An article on the advancement of the WP3 has been published on Accelerating News "First hardware of HL-LHC interaction region magnets" in issue 14. The CERN courier editorial board has expressed interest for this article, and has published it on the July 2015 number "HL-LHC begins the move from paper to hardware".

Work Package and Task Leader meetings

Dates	*Type of meeting*	*Attendance*	*Indico link*
8.10.14	**WP3#54**	**12**	https://indico.cern.ch/event/439475/
9.10.14	**WP3#55**	**16**	https://indico.cern.ch/event/439480/
4.11.14	**WP3#56**	**8**	https://indico.cern.ch/event/439484/
21.1.15	**WP3#57**	**12**	https://indico.cern.ch/event/439488/
26.1.15	**WP3#58**	**7**	https://indico.cern.ch/event/439494/
19.2.15	**WP3#59**	**21**	https://indico.cern.ch/event/439496/
25.2.15	**WP3#60**	**10**	https://indico.cern.ch/event/439502/
4.3.15	**WP3#61**	**7**	https://indico.cern.ch/event/439505/
22.4.15	**WP3#62**	**12**	https://indico.cern.ch/event/439507/
29.4.15	**WP3#63**	**11**	https://indico.cern.ch/event/439509/
27.5.15	**WP3#64 (joint with WP7)**	**18**	https://indico.cern.ch/event/439511/
2.6.15	**WP3#65**	**8**	https://indico.cern.ch/event/439516/
4.6.15	**WP3#66 (joint with WP7)**	**14**	https://indico.cern.ch/event/439519/
10.6.15	**WP3#67**	**23**	https://indico.cern.ch/event/439565/
17.6.15	**WP3#68**	**10**	https://indico.cern.ch/event/439543/
1.7.15	**WP3#69**	**12**	https://indico.cern.ch/event/439544/
9.7.15	**WP3#70**	**15**	https://indico.cern.ch/event/439546/
15.7.15	**WP3#71**	**17**	https://indico.cern.ch/event/439555/
6.8.15	**WP3#72**	**12**	https://indico.cern.ch/event/439559/
12.8.15	**WP3#73**	**8**	https://indico.cern.ch/event/439563/
20.8.15	**WP3#74 (joint with WP10)**	**12**	https://indico.cern.ch/event/440045/

Contractual milestones and deliverables

- D 3.2) G. Ambrosio, P. Ferracin, et al., "Design study of the Nb_3Sn inner triplet" ACHIEVED, link to report
- D 3.3) T. Nakamoto, et al., "Design study of the separation dipoles" ACHIEVED (anticipated to August 2015), link to report

- D 3.4) R. Van Weelderen, et al., "Design study of the cooling" ACHIEVED link to report

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.3.2. Task 3.2: Nb3Sn quadrupoles for the inner triplet

Progress towards objectives and significant results

In November 2014 the measurements of the strand critical current both in the US and at CERN have shown that a significant part of the production for the short model is below the critical current specification. At that time, the MQXF had an operational gradient at 82% of the loadline, i.e. 18% margin, compared to the initial foreseen margin of 20%. For the worse part of the strand production, having a critical current 10% lower than specification, the margin would have been reduced to 15%. Two solutions were available: increasing the quantity of superconductor in the strand or lowering the operational current. The first option would have required to reduce the copper content of the strand, and therefore the margin for quench protection. The second option would have required longer magnets, entailing a reduction of performance. Since the quench protection was deemed to be already very critical, it was decided to reduce the operational current to 77% of the loadline, i.e. to bring the margin to 23%. The minor reduction of performance has been estimated to not critical from the project management. The increase of margin was also the advice of the international review committee on the QXF cable and on the QXF design carried in December 2014. In agreement with the WP2, the operational gradient has been therefore decreased from 140 to 132.6 T/m, and the magnet length increased from 4 .0 to 4.2 m (Q1 and Q3 half magnets) and from 6.8 to 7.15 m (Q2a and Q2b magnets). This first iteration on the layout also includes refined estimates for the magnet heads and interconnections.

During the winter 2014-2015 a major effort has been devoted to estimate the WP3 budget in terms of material and manpower, and to produce a first schedule until the project completion. The results have been presented in an international review in March 2015. For the MQXF, estimates have been carried out both in the US and at CERN. The study has identified a significant saving (7 MCHF) using a laminated structure. This option will be implemented in a short model to explore the potential and the drawbacks of this solution. A second possible saving is to have the triplet on the same power converter, instead than on two circuits. At the moment of writing, simulations have shown that this option looks viable from the point of view of magnet protection, and a global analysis of the circuit is being carried out to give the final agreement. This would entail a saving of about 3 MCHF in WP6 (powering) and WP7 (protection).

In June 2015, the first MQXF coil manufactured in US has been tested in a mirror configuration at FNAL (see Figure 15). The coil had a first quench at 70% of the short-sample limit, a second one at 76%, and reached 90% after 20 quenches. This was the first successful test proving the design of the MQXF coil. In summer 2015, two coils have been shipped from CERN to US (see

Fig. 2) and the first MQXF short model is being assembled in LBL. Test is foreseen for October 2015 in FNAL.

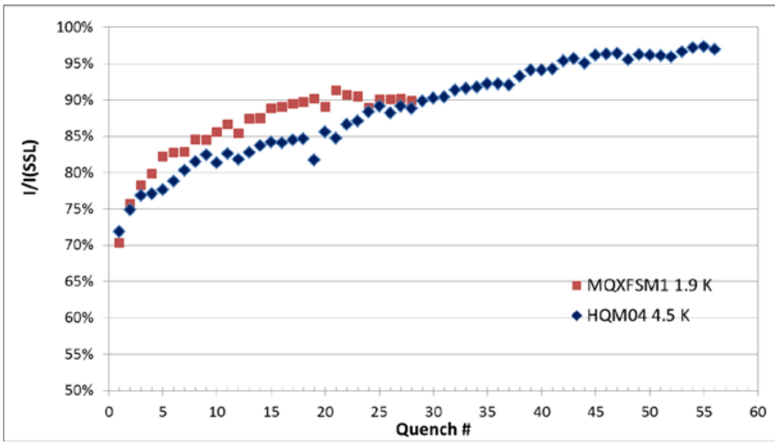


Figure 15: Training of QXF mirror magnet MQXFSM1 compared to HQ mirror HQM04 (left) and QXF mirror entering the FNAL test station

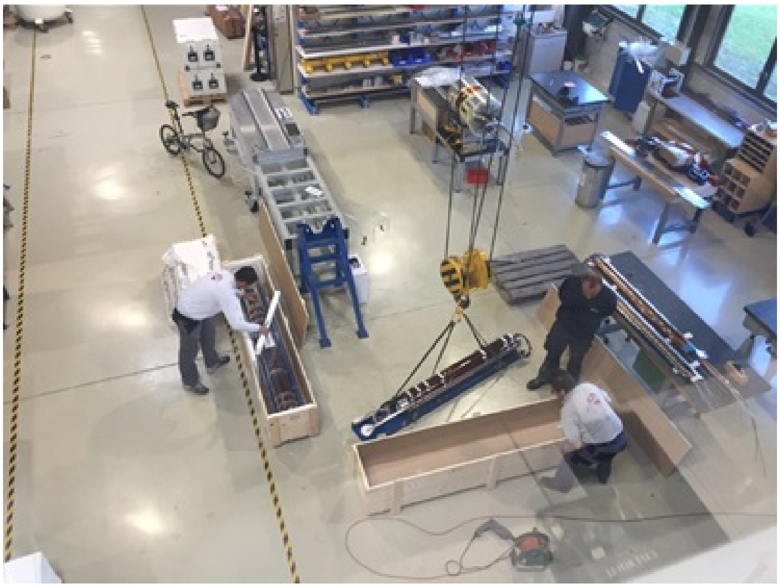


Figure 16: Preparation of shipping of two CERN coils to US

Contractual milestones and deliverables

In the third reporting period, task 3.2 had one deliverable D3.2 to submit.

- D3.2 Design study of the Nb3Sn inner triplet- ACHIEVED Link to report

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.3.3. Task 3.3: Separation dipoles

Progress towards objectives and significant results

The conceptual design of the separation dipole has been done in the previous period P2, and during November 2014 - October 2015 the engineering has been completed and construction of the short model has been started. First winding tests have given a positive feedback on the coil design, including end parts. A test of the assembly of the mechanical structure has shown that the alignment of the collared coil in the yoke had to be improved. For this reason, an iteration in the yoke and collar profile has been done, adding a notch to guarantee a better alignment (see Figure 17).

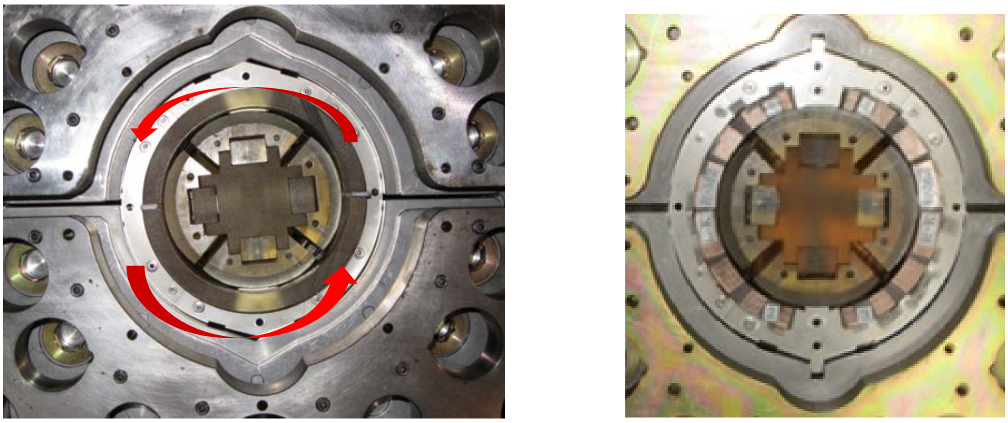


Figure 17 First version of the collar – yoke interface with rotation during assembly (left) and second iteration with alignment notch (right)

Based on the study of the separation dipoles, the option of a dogleg to increase the space available for crab cavities has been also considered, keeping the same D1, increasing the strength of D2 and the aperture separation, and adding a recombination dipole D3 to the lattice (see Figure 18).

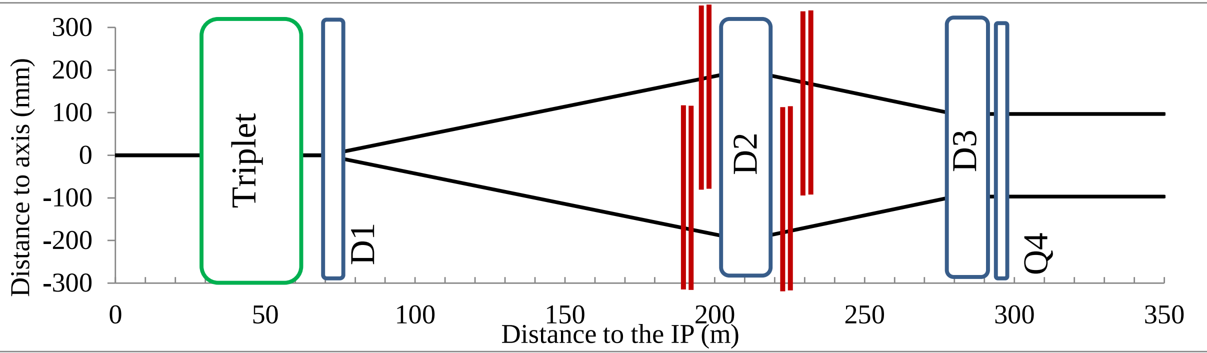


Figure 18: Conceptual study of a dogleg option.

The work on D2 carried out by the INFN-Genova collaboration has established a baseline with a 8-m-long magnet with 4.5 T bore field. Notwithstanding the different parameters of field, aperture, and operational margin, the operational current of D1 and D2 is very similar. This suggests powering D1 and D2 in series. This option would allow cost reduction in the WP6 (power converter) of the order of 1.4 MCHF. It is presently accepted from the WP3 side, and being studied from the point of view of the circuit, to see the implications for the other systems. A further outcome of the prepration work for the cost and schedule review is that quench heaters are much cheaper than energy extraction; since the heaters are a well-known technology for magnets in this range of field and energy density, use of Quench Heater as protection baseline has been adopted. The cost reduction is of the order of 6 MCHF for the main Nb-Ti magnets (D1, D2 and Q4).

Contractual milestones and deliverables

In the third reporting period, task 3.3 had one deliverable D3.3.

- D3.3 Design study of the separation dipoles - ACHIEVED, link to report

Planning, deviations and corrective actions

Task on schedule		Ahead of schedule	√	Minor delay		Significant delay	

2.2.3.4. Task 3.4: Cooling

Progress towards objectives and significant results

The baseline for the cooling at 1.9 K of the triplet, the orbit correctors, the nonlinear correctors and the separation dipole has been established. For the triplet, a second estimation of the temperature margin has been done taking into account of the reduced current of the magnet and of the details of the cross-section. Thanks to the reduction of the gradient from 140 to 132.6 T/m, the temperature margin in the coil has been increased from 3.5 to 4.1 K (see Figure 19). The lowest margin is located in a tiny region of the coil pole, and therefore with a minor modification of the shielding one could further increase this margin. This second iteration will be done in the fall 2015. For the ultimate luminosity the peak load is 6.7 mW/cm^3, i.e. a factor 8 smaller than the estimated quench level at 50 mW/cm^3.

The 4.2 K option has been studied by the CEA-Grenoble collaboration. The baseline has been kept at 1.9 K, since HEII provides a more efficient cooling and larger margins.

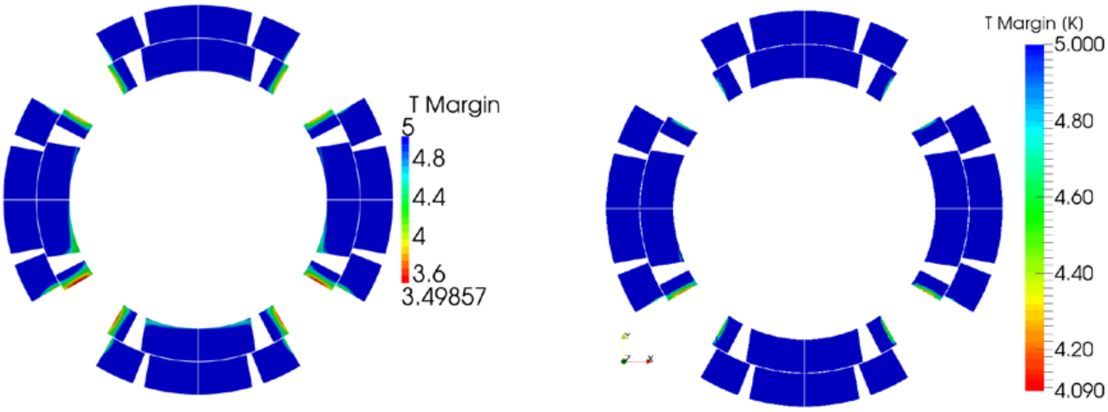


Figure 19: Temperature margin in the coil for the MQXF at 140 T/m (left) and at 132.6 T/m (right).

Contractual milestones and deliverables

In the third reporting period, task 3.4 had one deliverable D3.4, and one milestone MS41 to submit.

- D3.4 Design study of the cooling- ACHIEVED
- MS42 Study of the superfluid He cooling - ACHIEVED, link to report

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.3.5. Task 3.5: Special Magnet Studies

Progress towards objectives and significant results

The conceptual design of the two-in-one quadrupole Q4 has been completed in the previous period P2. The engineering has been completed in 2014; at the beginning of 2015, first winding tests have been carried out in Saclay showing a good design of the coil, including the end parts. In spring 2015, a joint work with WP2 (beam dynamics) and WP6 (powering) has shown that the very low magnet inductance endangers the beam stability with the present specifications on power converter stability. Taking also in consideration that the large operational current entails additional costs in the powering scheme, it has been decided to change the design to a two-layer-coil with smaller width cable (8.8 mm instead of 15.1 mm). The new design features an inductance value which is of one order of magnitude higher than the previous solution from 3 mH to 35 mH.

The work done in the framework of the cost and schedule review has also shown that the additional cost induced by the cable (that was for free in the 15.1 mm option, reusing short lengths of the LHC dipole cable) is lower than the cost reduction induced by the power converters (that are for free in the 8.8 mm option, requiring 6 kA converters already installed in the LHC). This major design change has been agreed with the CEA collaboration in June 2015. A first estimate of the induced delay is one year; this delay is proven to be not critical since during 2015 the HL-LHC installation has been moved from 2023 to 2024. The 8.8 mm cable option was already studied in the initial part of the design, and therefore a first guess of the cross-section and main parameters is available (see Figure 20).

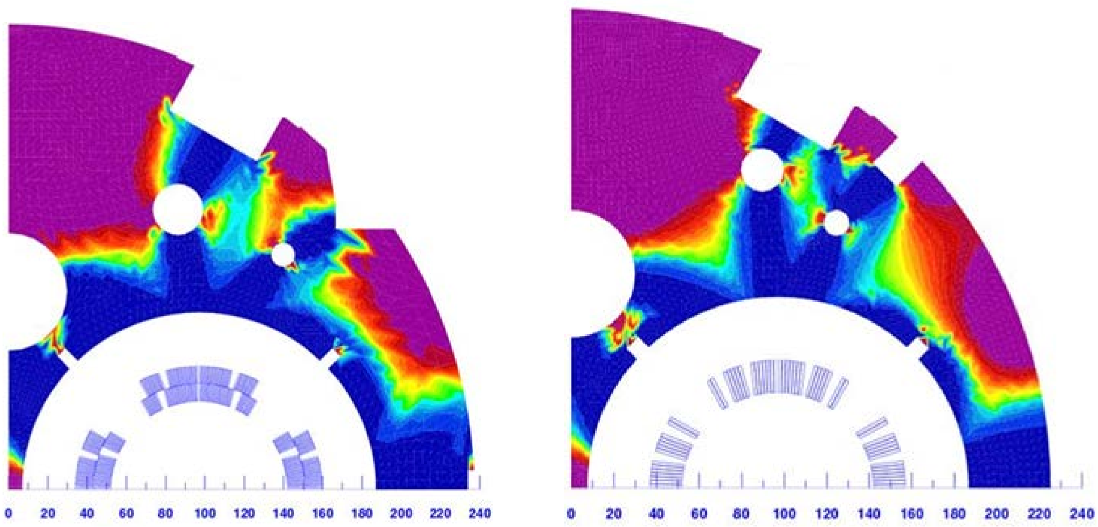


Figure 20: New layout with two layer 8.8 mm width cable (left) and first layout with one layer 15.1 mm width cable (right).

Contractual milestones and deliverables

In the third reporting period, task 3.5 had no deliverables nor milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.4. WP4: Crab Cavities

This WP manages the project, monitors progress and communicates information within and outside the consortium. It includes 6 tasks:

- Task 4.1: Coordination and Communication
- Task 4.2: Support studies
- Task 4.3: Compact Crab Cavity Design
- Task 4.4: SPS Test Prototype Cryomodule Design
- Task 4.5: Compact Crab Cavity Validation Prototyping

2.2.4.1. Task 4.1: Coordination and Communication

Progress towards objectives and significant results

In this period the HL-LHC cost & schedule review took place. A comprehensive technical plan, schedule and budget for the SPS tests, the pre-series and series production and installation in the LHC were presented. For the SPS test schedule, three possible plans were presented in order to get meaningful tests in the time available before LS2. Due to accumulated delays in cavity fabrication and cryomodule component procurement, it was unlikely that both cavities could be fully tested in the SM18 prior to an installation in the SPS in the baseline schedule. The baseline schedule consisted of cavity one being immediately installed in SPS in the 2017 EYETS while cavity 2 would be tested in SM18 at the end of 2017, and would be installed in SPS during the 2018 YETS. Plan C is to test both cavities in SM18 in 2017 and install only one cavity in SPS in the 2018 YETS, shown in Figure 21 After the C&S review the panel recommended and we have adopted plan C. This is due to the inherent risk in installation in SPS before sufficient testing and the difficulty of installing a cryomodule at any time other than the YETS. The current shift in LS2 will allow for a 1-full year of testing in SPS prior to the launch of the production series. The CM should remain in SPS until close to LS3. Due to recent shift in LHC planning, the delayed installation in the SPS will still provide adequate time prior to LS2 for the crab cavity tests.

Another issue discussed at the C&S review was the tight schedule for the series production. Any delays in the SPS test due to delay in the SPS cavity production and the possible LS2 delay would likely result in there being insufficient time to manufacture and install all 16 series cryomodules plus spares. In view of the progressive luminosity gain after LS3 and gain schedule contingency, the plan would be to only install half the crab system (8 Modules) plus all RF and Cryo infrastructure during LS3. Additional modules would then be installed in the following technical stops. The panel recommended that this contingency option should become the baseline and was accepted. It was also decided to retain both cavity designs (DQW and RFD) due to their natural topologies leading to horizontal and vertical crossings. The LHC has a different crossing orientation (vertical and horizontal) for ATLAS and CMS and hence two different designs are required Using different cavities for each interaction point reduces the chance of higher order modes overlap on all cavities, as each cavity will have a different spectrum. In addition having two separate designs mitigates risk during the development period leading up to the production phase. For these reasons it was decided to retain both cavity designs rather than down-select further to a single design.

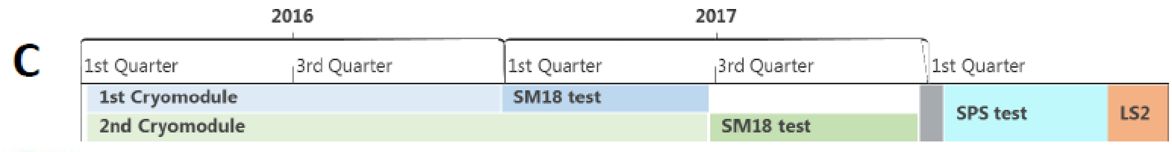


Figure 21: Timeline for the SPS tests (A. Macpherson, HL-LHC C&S review 2015).

Weekly collaboration meetings have been set-up between CERN, LARP, Niowave and Cockcroft/STFC.

The original baseline location for the SPS installation was in LSS4 currently hosting the COLDEX experiments which may need to run for longer period than originally anticipated. A new location (SPS-LSS6) has recently been endorsed as a suitable location after several interactions between HL-LHC & LIU teams. Work is now progressing to produce detailed plans for integration in this location.

The need of the different harmonic systems (800 MHz & 200 MHz) will depend on LHC Run II operations & experimental requests. A minimum effort programme is being assessed at present.

Work Package and Task Leader meetings

Dates	*Type of meeting*	*Venue*	*Attendance*	*Indico link*
May, 2015	**LARP/ HiLumi annual meeting**	**FNAL**	**200**	https://indico.fnal.gov/conferenceDisplay.py?confId=9342
November 2014	**HiLumi annual meeting**	**KEK**	**200**	https://espace.cern.ch/HiLumi/2014/SitePages/Home.aspx
Dec, 2014	**HOM review 1**	**CERN**	**20**	http://hilumilhc.web.cern.ch/content/crab-cavities-hom-review
April, 2015	**HOM review 2**	**JLAB**	**20**	http://indico.cern.ch/event/371427/
May, 2015	**Helium tank design review**	**CERN**	**20**	https://indico.cern.ch/event/391211/

Contractual milestones and deliverables

- D4.4 Compact Crab Cavity: Conceptual Design Report of possible Compact Crab Cavities compatible with a local scheme around the high luminosity interaction points of LHC, including the cavity geometry, sufficient suppression of wrong-order modes, the power coupler, the cryostat and the integration in the LHC. (Task 4.1 using inputs from 4.2, 4.3 & 4.5) [month 48] – ACHIEVED Link to report

Planning, deviations and corrective actions

New SPS test schedule is to test both cavities in SM18 in 2017 and install only one cryomodule in SPS in the 2018 YETS. The 2nd cryomodule to be tested in the SPS post LS2.

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.4.2. Task 4.2: Support studies

Progress towards objectives and significant results

SPS-LSS6 has recently been endorsed as a suitable location after several interactions between HL-LHC & LIU teams. After endorsement for LSS6, we will re-orient the CCTC to integrate the cryomodule, RF, Cryo & Services. The first feasibility report of LSS6 and space reservations for all components will be completed by autumn 2015. We are currently developing integrated planning for installation of all components in subsequent technical stops. The SPS cryomodule will have final installation in the 2018 YETS and the cryomodule will be left in SPS until LS2.

Contractual milestones and deliverables

In the third reporting period, task 4.2 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.4.3. Task 4.3: Compact Crab Cavity Design

Progress towards objectives and significant results

Following the cavity down-select in the second period, the RFD and DQW designs have been updated and frozen including the external interfaces. The HOM couplers were modified for ease of manufacture and to reduce the impedance of a few key modes. The effect of mechanical tolerance of the cavity and couplers on the impedance were studied and used to specify the tolerances on the cavity and HOM coupler production.

Two HOM coupler design reviews were completed during the period, one focussed on the electromagnetic design and the other on the mechanical design. At the request of USLARP, a review of the HOM coupler designs included in the crab cavity designs required for HL-LHC at CERN was hosted by Jefferson Lab on February 25th, 2015. The reviewers were Edward Daly, Frank Marhauser and Slava Yakovlev. The charge, agenda and presentations can be found at the following link:
https://indico.cern.ch/event/371427/timetable/#20150225.detailed.

The design team made presentations both in person and via videoconference. The meeting spanned the full day, roughly stayed on schedule and contained many healthy discussions on aspects related to RF, SRF, mechanical and cryogenic design. The review feed-back was as follows:

"The review team wishes to congratulate the design team on progress made for the two design approaches. It is very clear that significant progress has been made and that the designs are at a state where prototype fabrication can begin."

The reviewers had a few recommendations that were followed up after the workshop. Both cavities have had their impedances calculated up to 2 GHz as requested by the reviewers. The couplers were both simulated into a terminated load rather than a cavity to investigate their transmission spectra. The couplers were subsequently optimised to provide additional damping to a few high impedance modes. The RFD couplers were improved by altering the orientation of the hook on the horizontal-HOM coupler and to offset the vertical-HOM coupler. For the DQW a stray mode at 1.75 GHz was damped by modifying the pick-up.

The RF heating of the HOM couplers was investigated including the variation of thermal conductivity and surface resistance with temperature. The results show that provided a sufficiently high RRR Niobium is used, there are no thermal issues with both types of cavity.

A new effort to device a low power and a high power broadband coupler test box was carried out by STFC in collaboration with CERN. Several choices were studied and an overview of the designs were presented at the HOM review. The reviewers recommended to focus on a low power test box prior to embarking on a high power version. Further simplifications are necessary prior to a manufacture.

Contractual milestones and deliverables

In the third reporting period, task 4.3 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.4.4. Task 4.4: SPS Test Prototype Cryomodule Design

Progress towards objectives and significant results

In order to provide mechanical stiffness to the cavity/LHe vessel thick walls are required in the LHe vessel. There were some initial concerns about the deformation caused by welding such thick (13mm) Titanium plates which was verified by tests performed at CERN. This issue was resolved by utilising a novel bolted design, which provides mechanical stability, with small welds for vacuum integrity. The design provide stiffness to the cavities and minimises stress in the vessel. Channels will be utilised to avoid trapped LHe volumes. A comprehensive study on the thermo-mechanical aspects, machining, assembly and integration was performed. A dummy prototype is under fabrication to validate the concept.

A cold internal magnetic shield is required for each cavity in order to keep static magnetic fields below 1 μT. The limited space between the cavity and the LHe vessel requires a complex shield, which follows the cavity shape and several small holes to allow the flow of LHe. A dual shield scenario with a warm shield plus a cold internal shield is required due to the large apertures in the shield walls for couplers. This has been analysed considering a 200 μT external field. A close fitting made from 3 mm cryophy (cryogenic magnetic shield) is found to reduce the field at the cavity below 1 μT. The magnetic shield designs are now frozen and we are currently seeking quotes from manufacturers.

The cavity will be supported via the double wall tube of the FPC, however the lowest frequency mechanical vibration mode is below 25 Hz if this is the only support. Several additional supports were investigated including inter-cavity supports, tensioned rods, stiff rods and blades. Only the blades were found to increase the lowest vibration above 25 Hz hence these will be utilised. Increasing the thickness of the supports can push this up higher, but care must be taken to avoid higher order modes at 50 Hz. We are currently investigating integration of these supports into the cryomodule.

The actuation system of the tuner consists of a stepper motor, a harmonic gearbox, a roller screw and linear guide bearings. The concept is based on a design developed and already in use at JLAB. The actuation induces a relative movement between two titanium cylinders. The inner one is directly connected to the top of the cavity, the outer one to the bottom via a titanium frame. A symmetric deformation is thus applied simultaneously to the cavity top and bottom. The tuner design is well advanced and a prototype mock-up of the motor and actuator was produced to be used with the DQW proof of principle cavity in a cold test. The frame and test cryostat interface is under production and will soon be ready for testing.

The cryomodule design for each cavity is shown in Figure 22.

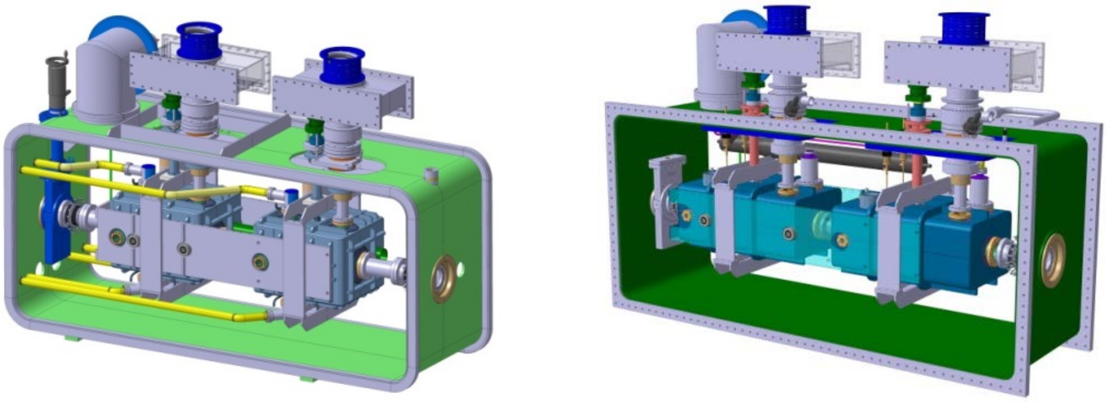


Figure 22: Cryomodule designs for the RFD (centre) and DQW (right) cavities (Courtesy EN-MME, FNAL & STFC-Daresbury Lab).

Two alignment systems have been investigated for HL-LHC, BCAM wire targets on the LHe tank and FSI targets on the flanges. In LHC warm remote control of cavity alignment is likely necessary to compensate for drift. In SPS we will only monitor the cavity alignment and will not correct remotely.

Contractual milestones and deliverables

The deliverable in this period is complete.

- D4.3) SPS Test Prototype Cryomodule Design: Technical Design Report for a 2-cavity cryomodule suited for a crab cavity validation test (Task 4.4) [month 38] – ACHIEVED – link to report

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.4.5. Task 4.5: Compact Crab Cavity Validation Prototyping

Progress towards objectives and significant results

During this period both prototype cavities were sent to CERN from the US and testing was repeated. Both cavities were found to have approximately similar performance in the CERN test station as in the US. For the RFD the cavity was delivered under vacuum and was not vented at CERN. A maximum voltage of 6.2 MV was achieved (compared to 7 MV at Jlab) at a Q_0 of 7.5×10^{9} corresponding to a residual resistance of 16nΩ. The DQW required a HPR before testing as there was some suspected cavity surface contamination. A maximum voltage of 4 MV was achieved (compared to 4.5 MV at BNL) at a Q_0 of 3.5×10^{9} corresponding to a residual resistance of 24 nΩ. Test results are shown in Figure 23. The DQW results are believed to have some uncertainties due to cable arcing and deterioration was found after the test. A re-test of the DQW is underway presently. A retest of the 4-rod crab cavity is also foreseen in this period due to suspected surface contamination in previous tests.

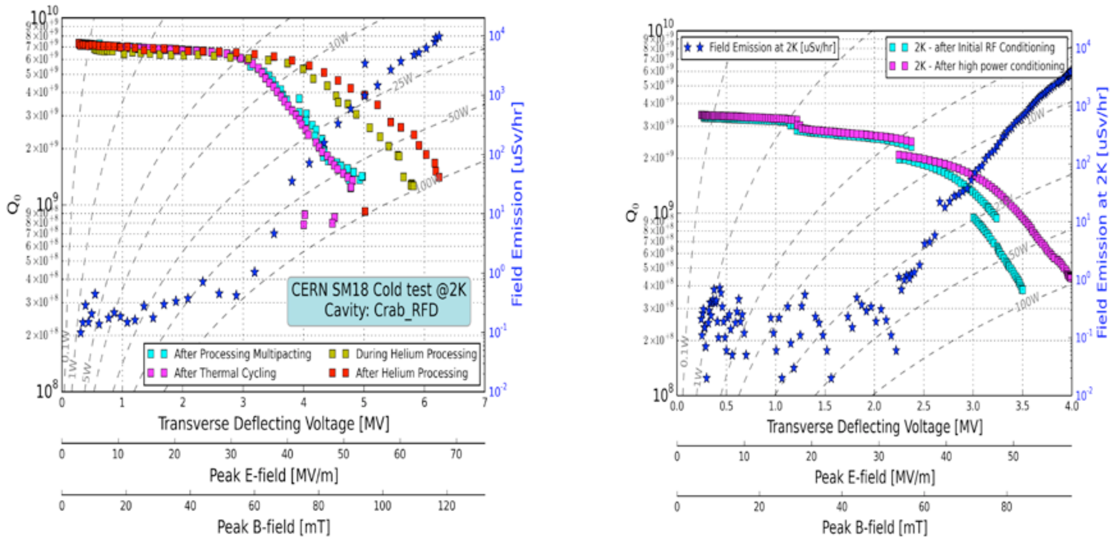


Figure 23: vertical test results at CERN SM18 for the RFD (left) and DQW (right).

The manufacture of the SPS prototypes of the dressed cavities is at an advanced stage. All parts for two of each cavity have been stamped at Niowave in the US, shown in Figure 24. They are currently being transferred to Jlab for assembly and e-beam welding. Once assembled, the cavities will undergo a bulk surface chemistry and 2-3 tests, the last one including the Helium vessel and HOM couplers. The first prototype of the DQW HOM coupler is currently under construction, having completed trials in Aluminium. Very good results were obtained on the machining of inner probe in bulk Niobium to maintain the tight tolerances specified by RF requirements. A prototype tuner was constructed including motor and actuation, a tuning frame and mock cryomodule interface is under production. A cold test of the tuner on the proof of principle DQW cavity is planned for September 2015. The power coupler fabrication is close to complete, the antenna hooks are complete, the coupler body is under brazing. The ceramic window had difficulties (bad metallisation, wrong size of the titanium flange), and a new component is currently under procurement. The cold magnetic shielding design is complete and is currently out for quotes. A dummy prototype fabrication of the LHe vessel has been launched for experimental verification of the assembly procedure, stress, vacuum integrity and other aspects of the design

Figure 24: Stamped parts for the DQW (top) and RFD (bottom) at Niowave.

Contractual milestones and deliverables

In the third reporting period, task 4.5 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.5. WP5: IR Collimation

This WP manages the project, monitors progress and communicates information within and outside the consortium. It includes 6 tasks:

- Task 5.1: Coordination and Communication
- Task 5.2: Simulations of Beam Loss in the Experimental IRs
- Task 5.3: Simulations of Energy Deposition in the Experimental IRs
- Task 5.4: Design of Collimation in the Experimental IRs

2.2.5.1. Task 5.1: Coordination and Communication

Progress towards objectives and significant results

The activities of the collimation WP5 have been successfully steered throughout the reference period. From the Coordination&Communication viewpoint, the main forum to steer the required WP5 activities is the on-going meeting series of the Collimation Upgrade Specification working group meeting (ColUSM), which reports to the HiLumi Steering meeting and to the relevant LHC panels for matters related to LHC interventions. This working group covers all the studies on the LHC collimation upgrades. Gathering the HiLumi-WP5 teams into this working group ensures that the HiLumi studies are fully integrated into the overall collimation upgrade plans and remain in synchronization with other collimation study programmes, like US-LARP and FP7-EuCARD[2]. It is important to note that the ColUSM also steers the collimation activities related to beam measurements and Machine Developments (MDs) at different CERN machines relevant for the HiLumi-WP5 studies.

From the technical point of view, one of the main activities followed up by the Task 5.1 was the change of baseline for different collimation upgrade items. A change of strategy for the production of dispersion suppressor (DS) collimators (TCLDs) and 11 T dipoles (the non-HiLumi WP11) had been put in place of the different LHC insertions. It has been decided to take out of the baseline the DS collimation solution around IR1/5 and alternative plans for IR2 have been studies. Task 5.1 organized the required studies to put the change in place. As an example, the present WP5 "baseline" and "option" items, as presented at the 2015 HL Cost&Schedule Review, are illustrated in the next figures (covering also the upgrade items that are not part of the FP7-HiLumi studies). The focus of the FP7-WP5 team is on the collimation upgrades for the IRs but the teams contributed also to other collimation studies.

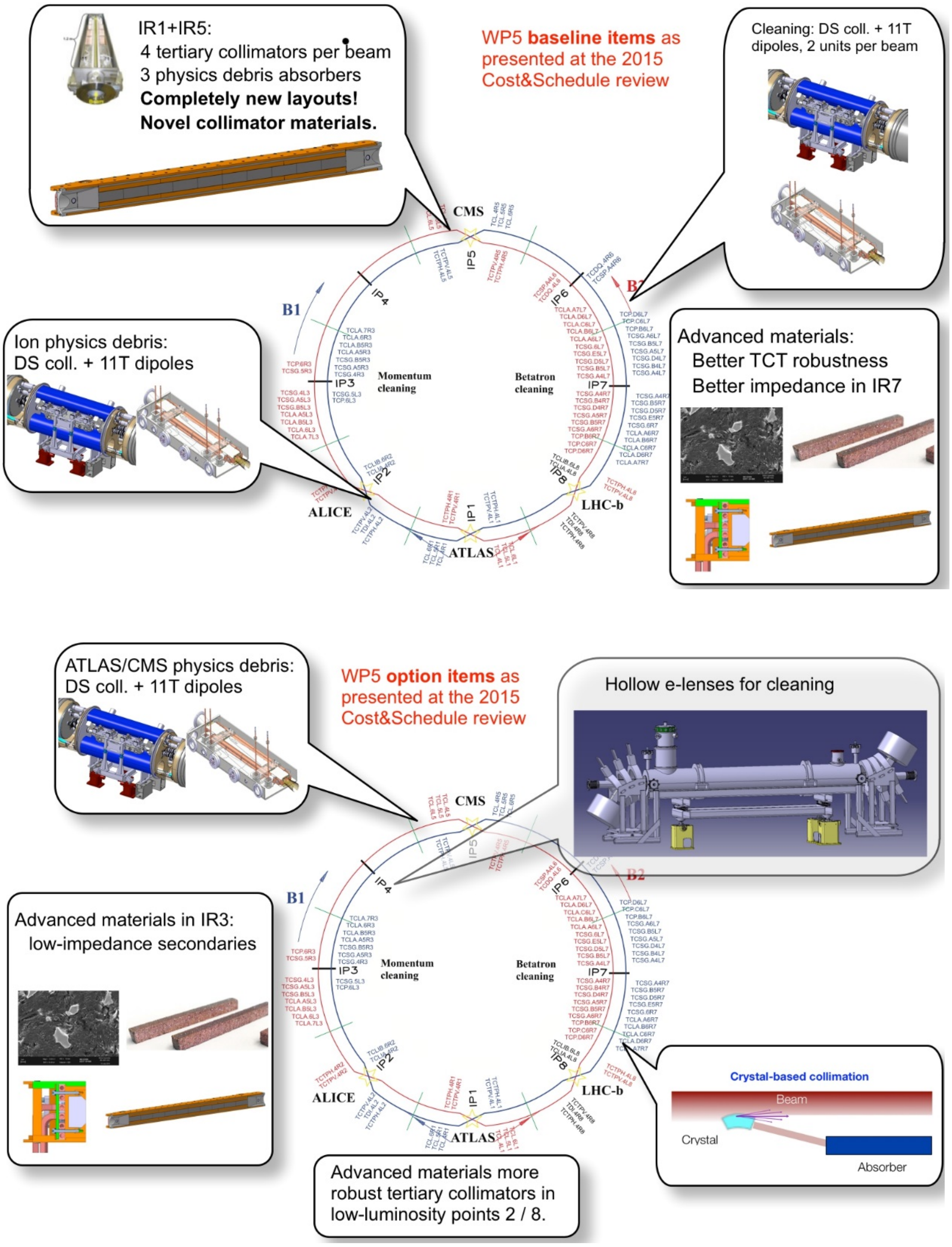


Figure 25: Illustrative scheme with the main "baseline" (top graph) and "option" collimation upgrade items for collimation within HL-LHC. The FP7-WP5 studies are focused on upgrades of the experiment IR insertions.

Work Package and Task Leader meetings

The collimation activities on WP5 are steered through the Collimation Upgrade Specification working group that meets regularly every 2-4 weeks, collecting together the various partners of collimation upgrade studies: CERN teams meet together with FP7-HiLumi partners, FP7-

EuCARD[2] partners and US-LARP collaborators. The ColUSM website can be accessed at this address:

http://lhc-collimation-upgrade-spec.web.cern.ch/lhc-collimation-upgrade-spec/Default.php

For studies relevant for different WP's within HiLumi, effort has been made to organize joint meetings with the various teams. For example, some 3-5 meeting have been organized as joint discussions with other WPs (WP2, but also the non-HiLumi WP8 and WP15). Several topics related for the collimation studies within EuCARD[2] have also been addressed, with participation to the collimation work package of EuCARD[2].

In addition to the technical steering of WP5 activities a few Task Leader meetings have been organized in order to prepare the key documents required in the reference period (Deliverable and Milestone documents, conceptual functional specifications and TDR).

Dates	*Type of meeting*	*Venue*	*Attendance*	*Indico link*
Nov.2014-Oct.2015	*Collimation Upgrade Specification meeting (~20 meetings in ref. period)*	*CERN*	*10-20*	*https://lhc-collimation-upgrade-spec.web.cern.ch/lhc-collimation-upgrade-spec/Default.php* *http://indico.cern.ch/category/5693/*
May 2015	*Collimation session at US-LARP collaboration meeting*	*FNAL*	*20*	*https://indico.fnal.gov/conferenceDisplay.py?confId=9342*

Contractual milestones and deliverables

In the third reporting period, task 5.1 had two deliverables D5.6, D5.7 and two milestone MS52 and MS53 to submit.

- D5.6 Technical design IR collimation – ACHIEVED link to report
- D5.7 Design report and functional specification – ACHIEVED link to report
- MS52 Verification of new IR collimation solution in simulations. Possible iteration in design – ACHIEVED link to report
- MS53 Final report – ACHIEVED link to report

Planning, deviations and corrective actions

The work has proceeded according to plan and neither deviations nor corrective actions have been necessary.

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.5.2. Task 5.2: Simulations of Beam Loss in the Experimental IRs

Progress towards objectives and significant results

Some of the main results by the Task 5.2 team achieved can be summarized in the following list:

- Improved integration of the conceptual layout solutions for incoming and outgoing collimation in IR1/5 into the new optics version (see Figure 26);
- Validation in simulations of the cleaning solutions for the incoming beam in IR1/5: cases of betatron halo cleaning (contributions from RHUL) and fast failure cases;

- Validation in simulations of the IR7 dispersion suppressor cleaning designed for protons for ion at HL-LHC (see Figure 27);
- Study of alternative solutions for DS collimation in IR7 with reduced a number of collimators and 11 T dipoles (see Figure 27);
- Iteration on ion cleaning solutions for collision debris cleaning in IR2;
- Study LHC aperture and provide inputs to other work packages for calculations of impedance and aperture margins;
- Validation in simulations of a new length of TCLD collimators (60 cm instead than 80 cm are required to ease the TCLD integration between cold magnets);
- The team triggered and defined simulation of collimator robustness for different failure scenarios and beam impact parameters relevant for the HL beam parameters.

Other important additional activities carried out by the Task 5.2 team include the participation to simulations of collimation performance with collimators based on new materials (synergy with EuCARD[2]); implementation of hollow e-lens simulations (a first implementation in the simulation tool Merlin was performed, in synergy with US-LARP collimation team); study of crystal collimation for the LHC IR7; participation to LHC collimation commissioning with focus on the understanding of possible limitation performance limitation for HL; participation to HL-relevant machine studies.

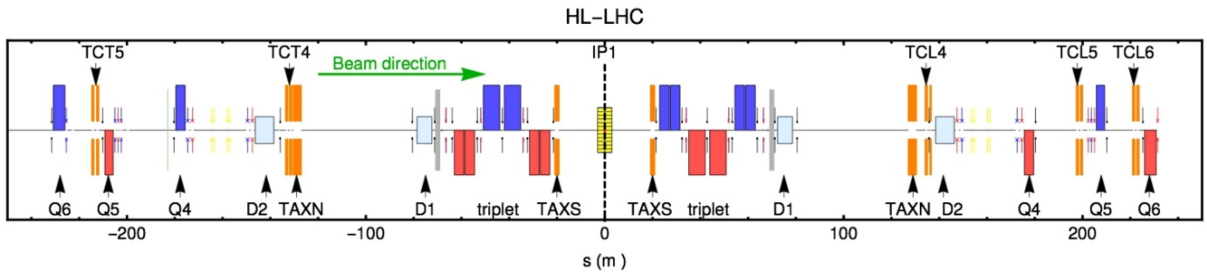


Figure 26: Proposed technical solution for IR1/5: the layout elements for B1 are shown as a function of the longitudinal coordinate around IP1. Layouts for the other beam and around IP5 are equivalent. Two pairs of horizontal and vertical TCT collimators in front of the Q5 magnet (TCT5) and immediately downstream of the D2 dipole (TCT4) ensure the collimation of the incoming beam. Three horizontal TCL collimators shield the matching section downstream of the TAXN and the DS further downstream from physics debris losses. For protons, it is estimated that this layout is sufficient without additional TCLD collimators in the DS. Work presented at IPAC2015 by R. Bruce et al.

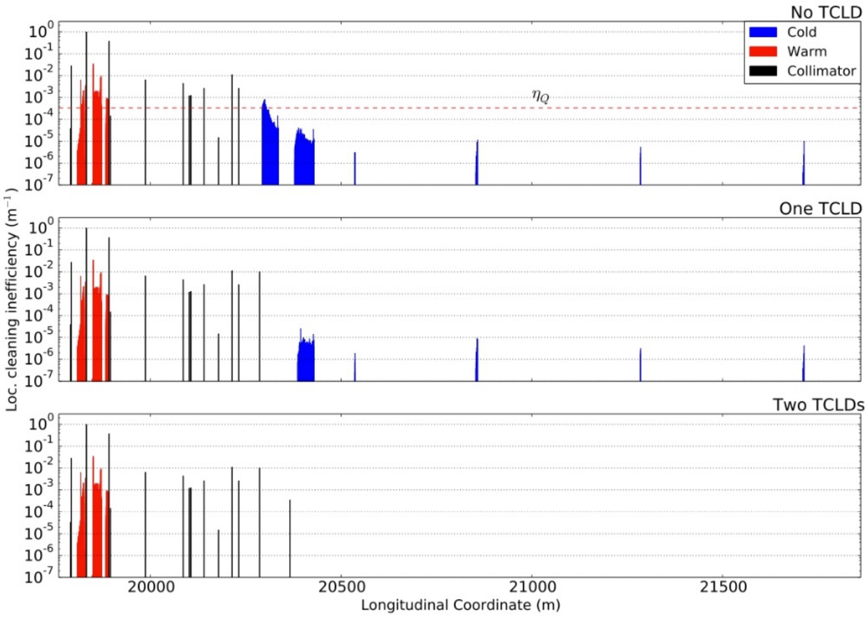


Figure 27: Effect on ion losses downstream of IR7 from TCLD collimators in the DS: cases with two (bottom graph) and 1 (middle) collimators installed with 11 T dipoles are compared with the case without (top), showing that one can gain more than a factor 50 in DS losses with one TCLD only. See presentation by P. Hermes at the 57th ColUSM. Also published at IPAC2015.

Contractual milestones and deliverables

In the third reporting period, the Task 5.2 had no deliverables and milestones to submit but participated very actively to the completion of the Deliverable and Milestone documents submitted by Task 5.1.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.5.3. Task 5.3: Simulations of Energy Deposition in the Experimental IRs

Progress towards objectives and significant results

The collimation energy deposition studies proceeded well and provided the required results to validate collimation solutions elaborated for the various LHC points. The main achievements of the last reference period were

- the elaboration of the new IR1/5 layout in the TAXN/D2 region for the outgoing beams in IR1/5 (see Figure 28);
- the assessment of energy deposition around IR2 for alternative scenarios for ion cleaning with TCLD collimators and no 11 T dipole, elaborated by Task 5.2;
- iteration on cleaning performance in IR7 with different configuration and settings f the cleaning insertion.

In addition, the team of Task 5.3 also contributed significantly to the simulations of the collimator jaw and material tests at HiRadMat, providing the required energy depositions inputs for the materials relevant for HL-LHC.

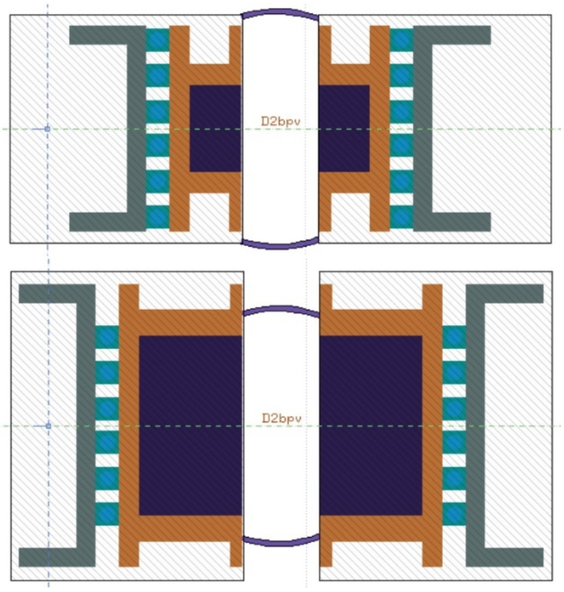


Figure 28: Sketch of a new collimator design – TCLX- based on a transversally thicker jaw as required to absorb more efficiently the collision products generated in the high-luminosity IR1/5 in HL-LHC. The feasibility of this design, to be integrated in the tight transverse space in the common regions around the experiments, is being addressed by Task 5.4. Presented by F. Cerutti at the 4th HiLumi Annual meeting.

Contractual milestones and deliverables

In the third reporting period, task 5.3 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule		Ahead of schedule	√	Minor delay		Significant delay	

2.2.5.4. Task 5.4: Design of Collimation in the Experimental IRs

Progress towards objectives and significant results

The Task 5.4 proceeded well in the reference period and the main achievements can be summarized as it follows:

- Finalization of the design of the TCLD collimators (dispersion suppressor collimator for the integration in the 11 T dipoles). An updated design (see Figure 29) was required following a change of jaw length and a new integration in the cold magnets (see Figure 30);
- New design for the integration of the TCLD collimator between cold magnets, through a new cryogenic by-pass design (see Figure 30);
- Preliminary study of new collimator designs in the IR1/5: new TCLX (see previous section) and potentially new tertiary collimators with enlarged stroke.

In addition, the collimation design team contributed to the design of new secondary collimators in IR7 and to the design of the jaw experiments at the CERN HiRadMat facility, successfully carried out in July 2015.

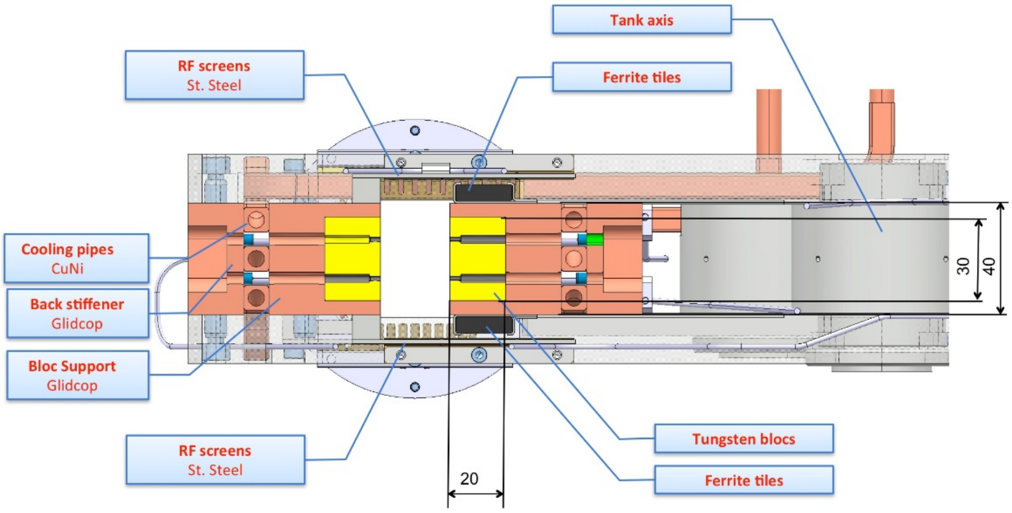


Figure 29: New design of the TCLD collimation for dispersion suppressor cleaning. The previous design needed to be completely upgraded following a new integration of the cryogenic by-bass for the installation of the collimators (see Figure 30). In addition, the baseline jaw length was changed from 80 cm to 60 cm to ease the collimator integration. Courtesy of L. Gentini, see 52nd ColUSM.

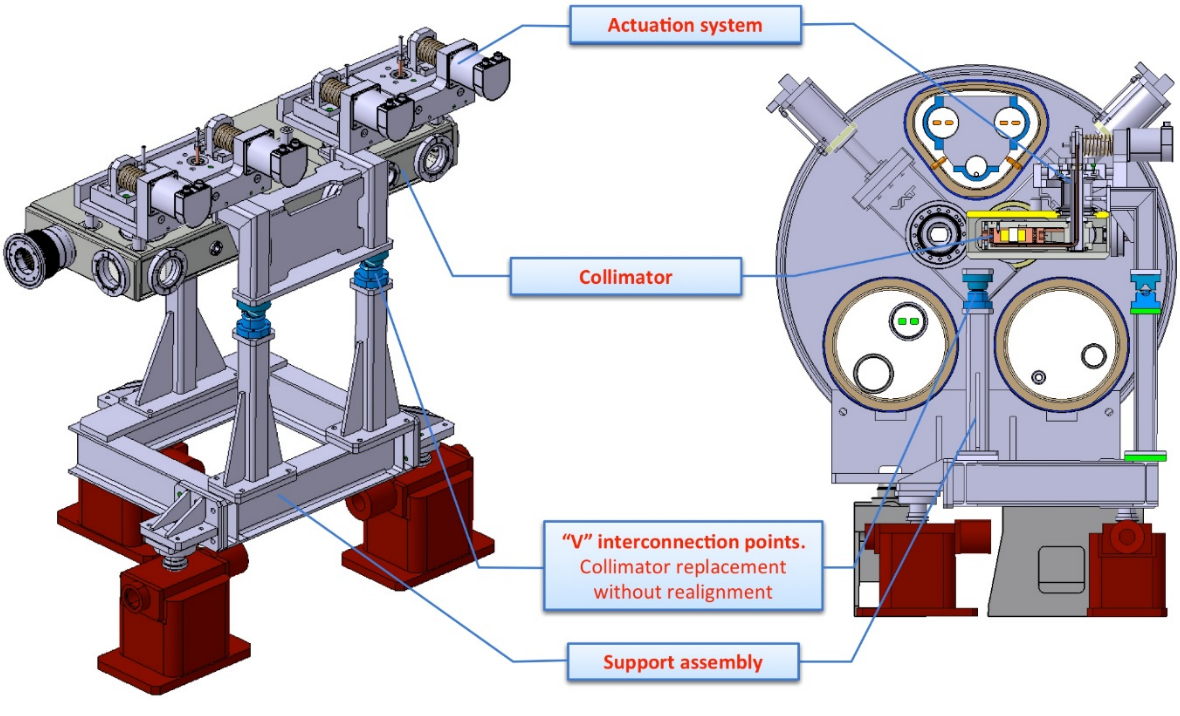


Figure 30: 3D drawing of the TCLD collimator on his support (left) and cross section at the location of the TCLD collimator between cold magnets (right). This new solution followed the change of design for the cryogenic by-pass, as presented by D. Ramos at the xxth ColUSM. Courtesy of L. Gentini, see 52nd ColUSM.

Contractual milestones and deliverables

In the third reporting period, task 5.4 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.6. WP6: Cold Powering

This WP manages the project, monitors progress and communicates information within and outside the consortium. It includes 6 tasks:

- Task 6.1: Coordination and Communication
- Task 6.2: LHC Cryogenics: Cooling and Operation
- Task 6.3: Electrical transfer and cryostats: thermo-electrical and mechanical models
- Task 6.4: Energy deposition and material studies

2.2.6.1. Task 6.1: Coordination and Communication

Task 6.1 worked on the coordination of the activities performed within the Work Package 6 and on the coordination and performance at CERN of work complementary to that carried out within Task 6.2, Task 6.3 and Task 6.4. Collaboration meetings took place at CERN, SOTON, LASA, and in Japan, USA and France on the occasion of international workshops and conferences, and via video-conferences. The latters enabled participation of all Task leaders and of a large number of collaborators from the different institutes. Participation in the global meetings chaired by the Hi-Lumi management was assured, as well as on-time completion of milestones and deliverables.

Progress towards objectives and significant results

In addition to the coordination of the Work Package global activity, the main achievements of Task 6.1 can be summarized as follows:

1) Full characterization of 20 kA range superconducting MgB_2 cables, up to 40 m long, measured in the same cooling configuration as proposed for the LHC (helium gas at 5 K to 25 K): measurement of critical currents, development of electrical joints, development and construction of tools for the integration of the cables in long cryostats;
2) Development with industry of the MgB_2 wire today proposed for the Superconducting Link project: procurement of 80 km of wire being delivered in unit lengths of above 500 m;
3) In-depth characterization of electro-mechanical and magnetic properties of the MgB_2 wires;
4) MgB_2 material studies aiming at quantifying the effect of porosity in the MgB_2 filaments on the electro-mechanical properties of different generations of superconducting wires;
5) Detailed integration studies of the Cold Powering Systems at LHC P7 and start of integration studies at LHC P1 and P5;
6) Performance of quench propagation studies and measurements on 20 kA range MgB_2 cables operated in helium gas. This work was in collaboration with and complementary to the activity of Task 6.3;
7) Adaptation of the Superconducting Link design to the changes of the magnet system and powering layouts (operating currents and number of circuits).

Work Package and Task Leader meetings

Dates	*Type of meeting*	*Venue*	*Attendance*	*Indico link*
27-10-2014	**Video-conference**	**-**	**10**	https://indico.cern.ch/event/349113/
28-10-2014	**Video-conference**	**-**	**10**	https://indico.cern.ch/event/349120/

17-21 Nov 2014	**Joint Hi-Lumi LHC LARP Meeting**	**Kyoto JP**	**18**	https://espace.cern.ch/HiLumi/2014/SitePages/Home.aspx
26-11-2014	**Technical meeting (system design)**	**SOTON UK**	**7**	-
02/12/2012	**Review LHC P7**	**CERN**	**30**	-
09/12/2015	**Technical meeting (transport and integration)**	**CERN**	**20**	-
Jan 2015	**Meeting with FLUKA team (1 week)**	**CERN**	**3**	-
10-14 May 2015	**Conference RESMM15**	**East Lancing USA**	**30**	https://indico.fnal.gov/conferenceDisplay.py?confId=8709
May 2015	**Meeting with FLUKA team (2 weeks)**	**CERN**	**3**	-
17-18 September 2015	**Meeting at LASA (Task 6.4)**	**LASA, Milano**		-
September 2015	**Technical meeting**	**Lyon France**	**2**	-

Contractual milestones and deliverables

In the third reporting period, task 6.1 had 4 milestones to submit:

- MS58 - Cryostat for current leads ACHIEVED – Link to report
- MS59 - Thermo-electric models and cryostat conceptual design ACHIEVED – Link to report
- MS60 - Energy deposition studies ACHIEVED – Link to report
- MS61 – Material Studies ACHIEVED – Link to report

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.6.2. Task 6.2: LHC Cryogenics: Cooling and Operation

The cryogenic cooling schemes elaborated during the previous reporting periods were analysed and maintained as valid baseline for the cooling and operation of the new Cold Powering Systems conceived during the reference year.

Progress towards objectives and significant results

While the cooling schemes remained unchanged, Task 6.2 contributed to the activity of the Work Package 6 with: a) the quantification of the cost of the cryogenic components for the Cold Powering Systems (pipes, mechanical and cryogenic interfaces, control equipment) that will be integrated in the LHC machine; b) the support for the operation of the cryogenics for the tests that were performed at CERN in the Superconducting Link test station in the SM-18; c) the discussion/elaboration of the impact on the cryogenic cooling of alternative powering layouts that are being analysed for the electrical feeding of the LHC High-Luminosity magnets.

Contractual milestones and deliverables

In the third reporting period, task 6.2 had no deliverables and milestones to submit.

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.6.3. Task 6.3: Electrical transfer and cryostats: thermo-electrical and mechanical models

During the reference period, Task 6.3 has focused on finalising the novel design concept of the Distribution Feedboxes and on updating the thermo-electrical studies of the Superconducting Link system.

Progress towards objectives and significant results

The thermo-electrical studies included calculations related to both thermal stability analysis of the MgB_2 superconducting lines and calculations of AC losses/coupling effects in the newly developed MgB_2 superconducting wires.

An advanced modelling of the effect of local disturbances on the thermal stability of MgB_2 gas-cooled cables was performed. A new method for the estimation of the minimum quench energy (MQE) based on the stationary normal zone equations was formulated. By using the solution for the Minimum Propagation Zone (MPZ) and MQE of the critical state superconductors, an analytical MQE formulation for power-law superconductors and gas cooling was obtained and applied for the analysis of the thermal stability of the Superconducting Links. Main results from calculations indicate that: a) the MQE is lower at lower operating temperatures of the superconducting lines - the MgB_2 cables will operate in the range from 25 K down to 4.2 K; b) addition of stabilizer represented by a copper braid central to the superconducting cables increases the MQE; c) effectiveness of gas cooling on thermal stability requires significant reduction of the hydraulic diameter of the line, at the cost of an increase of the pressure drop of the gas circulating in the cryogenic envelope.

Calculations of AC losses and coupling effects confirmed the validity of the design choice of the twist pitch (100 mm) of the superconducting filaments in the newly developed MgB_2 wires and quantified the positive effect of the high resistivity Ni/Monel matrix in the uncoupling of the filaments. For comparison, modelling of coupling effects in Bi-2212 superconducting wires having superconducting filaments embedded in the low resistivity silver matrix was performed.

The design of a novel Distribution Feebox connecting the current leads to the Superconducting Link was elaborated. The novelty of the design consists in separating the current leads from the cryogenic envelope housing the electrical joints between the leads and the Superconducting Link (see Figure 31). This design was proposed and studied in details for the Cold Powering Systems proposed for integration at LHC P7 – where transport and integration issues were very challenging. The same concept will be considered for the Cold Powering Systems that will be integrated at LHC P1and P5.

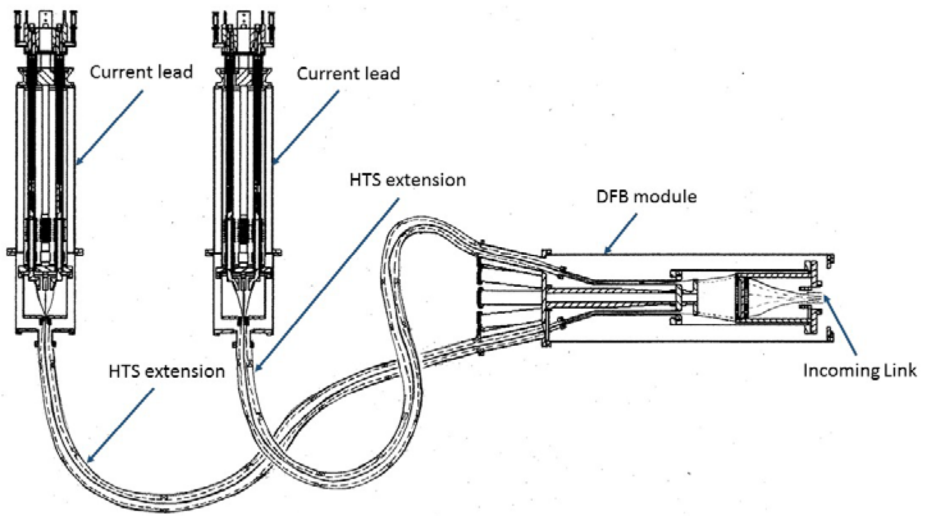


Figure 31: New concept of Distribution Feedbox. The current leads are connected to the cables in the Superconducting Link inside the Distribution Feedbox (DFB) module.

Contractual milestones and deliverables

In the third reporting period, task 6.3 had three deliverables D6.5, D6.7, D6.8.

- D6.5 Thermo-electrical studies- ACHIEVED – Link to report
- D6.7 Cryostat drawings and report- ACHIEVED – Link to report
- D6.8 Final design report - ACHIEVED – Link to report

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.2.6.4. Task 6.4: Energy deposition and material studies

This task was focused on the study of the energy deposition on the cryogenic/superconducting components of the Cold Powering Systems that will be located at LHC P1 and P5. Maps of energy deposition from particle debris were estimated taking into account the most updated geometries and locations of the Cold Powering Systems in the LHC tunnel.

Progress towards objectives and significant results

The evaluation of the energy deposition in the Superconducting Links was done for superconducting lines located at about 1 m distance from the beam pipe. The geometry of the lines was implemented in the FLUKA Monte Carlo code, initially without and then, in May 2015, with the beam screen around the beam pipe. The detailed results of the calculations are summarized in Deliverable 6.6**.** In Figure 32, the calculated energy deposition and Displacement per Atom (DPA) at LHC P1 are reported. The simulations were obtained with a statistics of 33000 events and all normalized to 3000 fb^{-1}. The cut-off settings were 1 keV for hadrons, 1 MeV for electron and positrons, 0.1 MeV for photons; slow neutrons were taken into account down to thermal energies. The calculated maximum dose and DPA are respectively 0.1 MGy and 10^{-6}. These values are not expected to be critical during the LHC lifetime.

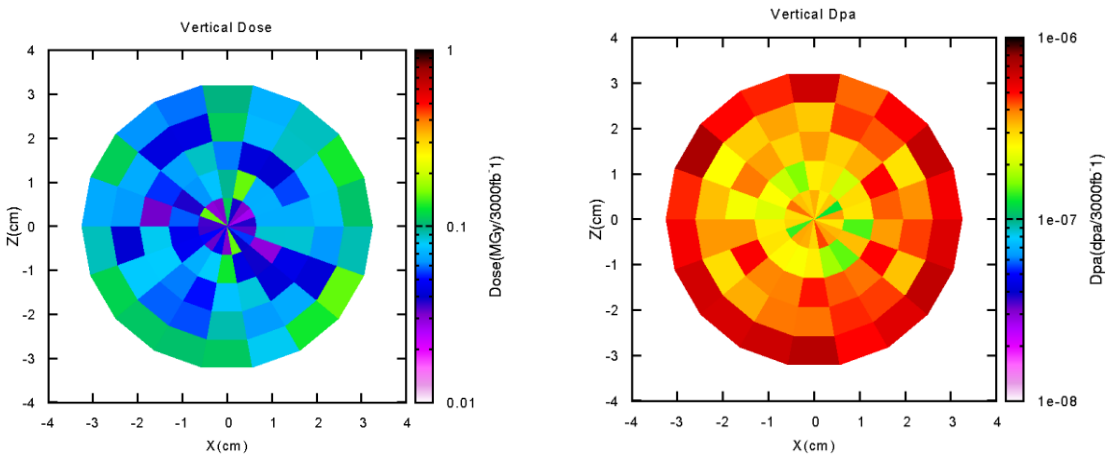


Figure 32: Dose (left) and DPA (right) in the cable envelope of the Superconducting Links.

Contractual milestones and deliverables

In the third reporting period, task 6.4 had one deliverable to submit.

- D6.6 Energy deposition studies- ACHIEVED – Link to the report

Planning, deviations and corrective actions

Task on schedule	√	Ahead of schedule		Minor delay		Significant delay	

2.3. PROJECT MANAGEMENT DURING THE PERIOD

2.3.1. Consortium management tasks and achievements

The management has assured the standard tasks of coordinating the various WPs, the Institutes of the consortium and of assuring a coherent progress of the design study. The project coordination extends well beyond the WPs under the responsibility of the FP7 program: the total HL-LHC project counts some 17 tasks directly linked to High luminosity LHC and two special technological task linked to the project for technology affinity. This is shown by the scheme in Figure 33.

In addition to the standard work of organizing meetings and institutional committees, the HiLumi LHC managements has fulfilled two special task in this third and last period of the Design Study

- Coordinate and prepare the passage of the project High Luminosity LHC from the design phase (supported by this FP7 Design Study) to the construction phase.
- Organize the Cost and Schedule Review.

The results of t work on the first task is synthetized in the Deliverable D1.11. A new governance model is proposed and has been accepted by the collaboration and by the CERN management; a new project office organization, more tailored to follow up a large construction project, has been put in place.

The second task is part of the assessment stage that was foreseen between the PDR (Preliminary Design Report), issued at the end of the 3rd year of the design study, and the TDR (Technical Design Report) that contains the final choice to reach the luminosity goals of the project. The Cost and Schedule Review, held at CERN in March 2015, consisted in a three days scrutiny carried out by a panel of fourteen international experts. The outcome has been highly positive and this success has been the base for the insertion of the total HL-LHC cost as project in the CERN budget until 2026, as mentioned in the Medium Term Plan document approved by the CERN Council in September 2015.

Figure 33: Scheme of the entire High Luminosity LHC project structure: the first six WPs are under the umbrella FP7 Design Study. WP18 and WP19 are technological work packages, not part of the HL-LHC core study.

Figure 34: The C&S Review panel during the close-out talk of the chair, Dr. N. Holtkamp (left corner, standing) at CERN.

2.3.2. Problems and solutions

There are no problems to report during P3.

2.3.3. Changes in the consortium and/or legal status of beneficiaries

No changes in the consortium have occurred during P3.

2.3.4. Project meetings

Dates	***Type of meeting***	***Venue***	***Attendance***	***Indico link***

22/01/2015	Parameter & Lay-out Committee meetings	CERN	25	http://indico.cern.ch/event/364435/
12/03/2015	Parameter & Lay-out Committee meetings	CERN	20	http://indico.cern.ch/event/378400/
02/12/2014	15th HL-LHC TC	CERN	25	http://indico.cern.ch/event/348921/
05/02/2015	16th HL-LHC TC	CERN	28	http://indico.cern.ch/event/369701/
12/02/2015	17th HL-LHC TC	CERN	21	http://indico.cern.ch/event/360044/
26/02/2015	18th HL-LHC TC - Preparation Cost & Schedule Review	CERN	28	Restricted
05/03/2015	HL-LHC and LIU Cost and Schedule Review: Rehearsal session	CERN	30	Restricted
19/03/2015	20th HL-LHC TC	CERN	21	http://indico.cern.ch/event/345500/
16/04/2015	21st HL-LHC TC	CERN	13	http://indico.cern.ch/event/373539/
30/04/2015	22nd HL-LHC TC	CERN	32	http://indico.cern.ch/event/373541/
28/05/2015	HL-LHC TC	CERN	41	http://indico.cern.ch/event/373542/
11/06/2015	HL-LHC TC	CERN	23	http://indico.cern.ch/event/373544/
18/06/2015	HL-LHC TC	CERN		http://indico.cern.ch/event/373545/
23/07/2015	HL-LHC TC	CERN		http://indico.cern.ch/event/373546/
27/08/2015	HL-LHC TC	CERN		http://indico.cern.ch/event/373547/
24/09/2015	HL-LHC TC	CERN		http://indico.cern.ch/event/373548/
22/10/2015	HL-LHC TC	CERN		http://indico.cern.ch/event/373549/
05/11/2015	HL-LHC TC	CERN		http://indico.cern.ch/event/373550/
19/05/2015	Meeting with E. Zanon	CERN		http://indico.cern.ch/event/394844/
25-26/06/2015	HiLumi LHC goes to Industry	CERN		http://indico.cern.ch/event/387162/overview

2.3.5. Project planning and status

WP	***1***				***2***					***3***					***4***				***5***			***6***		
task	***2***	***3***	***4***	***5***	***2***	***3***	***4***	***5***	***6***	***2***	***3***	***4***	***5***	***6***	***2***	***3***	***4***	***5***	***2***	***3***	***4***	***2***	***3***	***4***
ahead		√				√					√									√				
On time	√		√	√	√		√	√	√	√		√	√	√	√	√	√	√	√		√	√	√	√
Minor delay																								

late																								

2.3.6. Budget adjustments

There have been no budget adjustments over the third period. However, following the submission of the financial claims at the end of P3, there may be a redistribution of the EC funding between some beneficiaries, to be decided by the Collaboration Board.

2.3.7. Impact of deviations from planned milestones and deliverables

Deliverable/Milestone	Delay	Impact
MS22 Industry Forum on the HL-LHC opportunities	9 months	The milestone has been delayed to M42 (April 2015) due to the shift of the LS1 and a consequent shift in the HL-LHC schedule. The delay in the milestone had enabled the consortium to prepare a solid overview of the technological and purchase opportunity for industry and then to organize the forum. The delay in this milestone has not affected any other deliverables or milestones.
D1.10 HiLumi LHC Technical Design Report	1 month	The final technical deliverable of the project was submitted in M49 in order to take into consideration all changes requested by the WP leaders at the Final HiLumi meeting. This delay had no effect on any other milestones or deliverables.
D6.6 Energy Deposition Studies	--	The deliverable D6.6 was achieved and submitted to CDS in M43 - May 2015 (see timestamp). The delayed submission to the EU portal is not linked to a delay in the achievement of the deliverable and therefore has no impact on the project.

2.3.8. Communication (Task 1.6: Dissemination of Information and Industry outreach)

Progress towards objectives and significant results

The goal of Task 1.6 Dissemination of Information and Industry outreach is to perform effective dissemination of information and innovation inside and outside the members of the consortium and in particular to Industry.

The task has been active in the 3rd period as well to promote its activities within the consortium and to external stakeholders. To this end more than 750 project related events were held, including the 4th and 5th Joint HiLumi LHC/ LARP Annual Meetings and the Joint LARP CM24/ HiLumi Collaboration Meeting.

Figure 35: Poster for the 5th Joint HiLumi-LHC / LARP Annual Meeting.

Website

The full speed of all work packages, including the non-EU funded ones, is still attracting interest in the HL-LHC activities and in the website. The new HiLumi-LHC user-friendly website, designed during period 2, is providing users a more interactive, colourful and visual experience. Thanks to the new features, the project website http://cern.ch/hilumilhc is successfully fulfilling its role of main tool of dissemination of project results. The website is designed to allow the audience to easily access up-to-date information about the project development, event announcements and all project materials.

The password-protected intranet https://espace.cern.ch/HiLumi is serving as an effective tool to enhance the management of the project and its work packages, and facilitate communication and information flow among the network. Specifically, the intranet WP workspaces are used by project members to share documents, disseminate internal information and publicize project-related events.

The graph below shows the unique visitors and total visits over the 3rd period (between November 2014 and October 2015) on the HiLumi website, with a steady increase in unique visitors since January 2015 and a noticeable peak in July 2015. Peaks were registered around the publication of Accelerating News issues and the "HiLumi LHC goes to Industry" event held on 25th-26th June 2015, which saw the participation of more than 160 industry representatives.

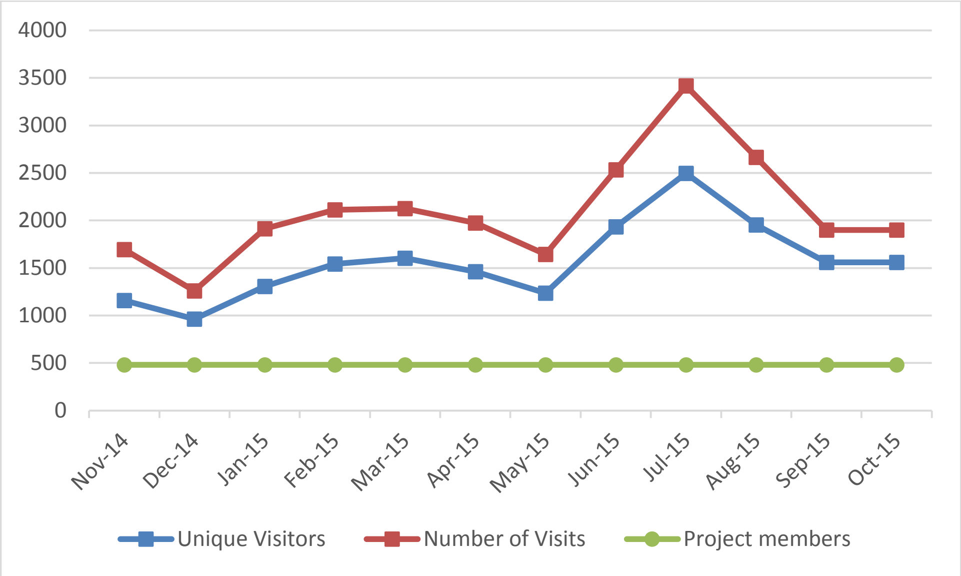


Figure 36:Traffic to the HiLumi website in the 3rd period.

The following chart shows the distribution of HiLumi LHC website visitors per country. The great majority of visitors arrived from Switzerland, the United States, and the UK, but also France, Netherlands, Germany, Albania, Japan and Russia are represented on the Top 10 list for countries of origin of website visitors. An increase of visitors coming from Canada, Romania, Poland and Ukraine has also been registered.

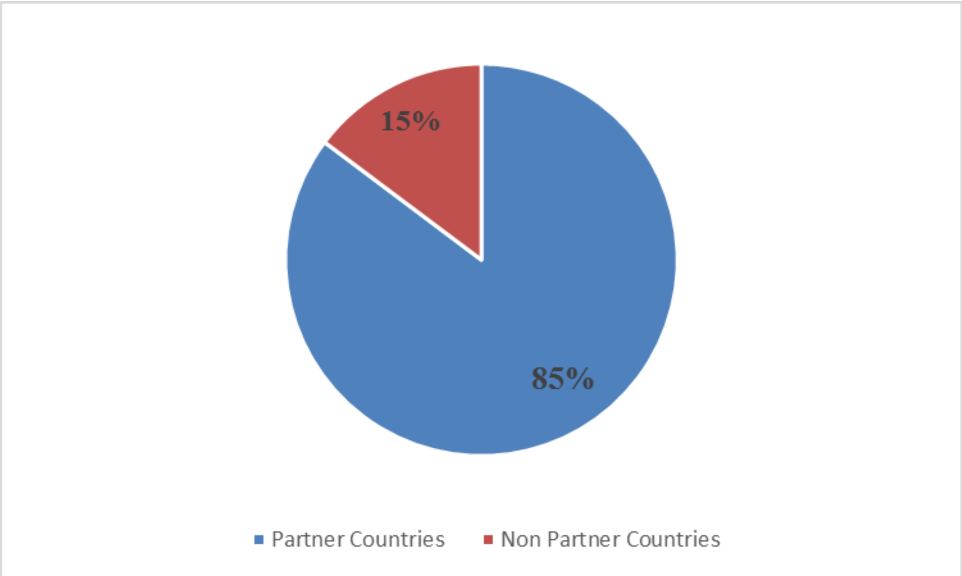
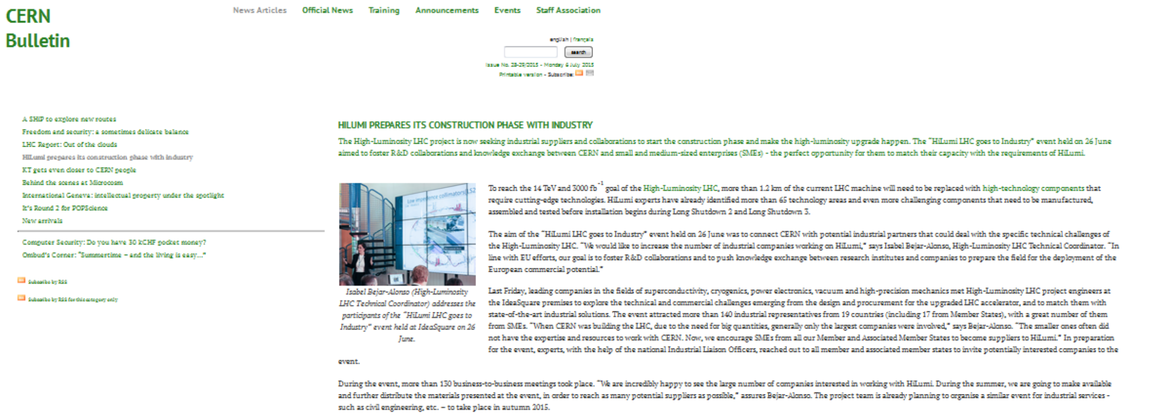


Figure 37: Chart of visitors to HiLumi LHC website by country in the 3rd period.

Publications

Articles on HiLumi have also been written for the CERN Bulletin, CERN Courier, Italian newspapers, etc.

Table 1: HiLumi-LHC articles featured on the CERN Bulletin and the CERN Courier.



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Issue No. 28-29/2015 - Monday 6 July 2015

A SHiP to explore new routes
Freedom and security: a sometimes delicate balance
LHC Report: Out of the clouds
HiLumi prepares its construction phase with industry
KT gets even closer to CERN people
Behind the scenes at Microcosm
International Geneva: intellectual property under the spotlight
It's Round 2 for POPScience
New arrivals
Computer Security: Do you have 30 kCHF pocket money?
Ombud's Corner: "Summertime – and the living is easy..."

HILUMI PREPARES ITS CONSTRUCTION PHASE WITH INDUSTRY

The High-Luminosity LHC project is now seeking industrial suppliers and collaborations to start the construction phase and make the high-luminosity upgrade happen. The "HiLumi LHC goes to Industry" event held on 26 June aimed to foster R&D collaborations and knowledge exchange between CERN and small and medium-sized enterprises (SMEs) - the perfect opportunity for them to match their capacity with the requirements of HiLumi.

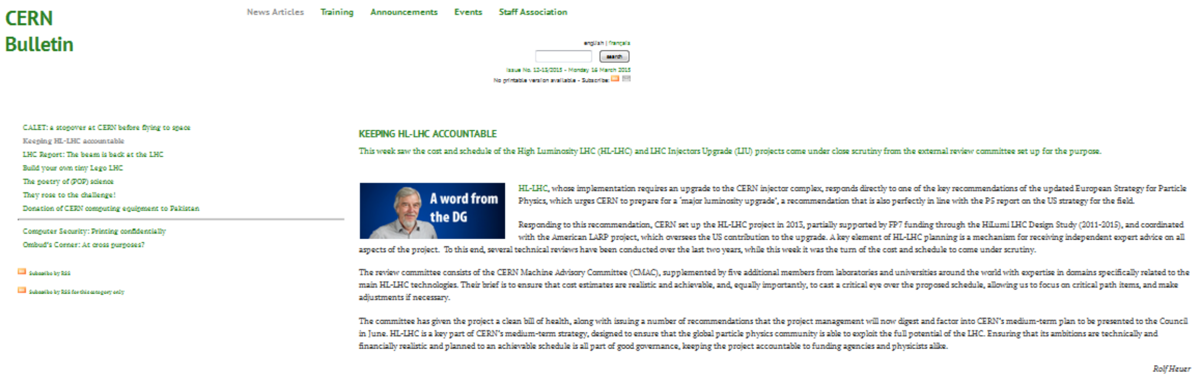
Isabel Bejar-Alonso (High-Luminosity LHC Technical Coordinator) addresses the participants of the "HiLumi LHC goes to Industry" event held at IdeaSquare on 26 June.

To reach the 14 TeV and 3000 fb^{-1} goal of the High-Luminosity LHC, more than 1.2 km of the current LHC machine will need to be replaced with high-technology components that require cutting-edge technologies. HiLumi experts have already identified more than 65 technology areas and even more challenging components that need to be manufactured, assembled and tested before installation begins during Long Shutdown 2 and Long Shutdown 3.

The aim of the "HiLumi LHC goes to Industry" event held on 26 June was to connect CERN with potential industrial partners that could deal with the specific technical challenges of the High-Luminosity LHC. "We would like to increase the number of industrial companies working on HiLumi," says Isabel Bejar-Alonso, High-Luminosity LHC Technical Coordinator. "In line with EU efforts, our goal is to foster R&D collaborations and to push knowledge exchange between research institutes and companies to prepare the field for the deployment of the European commercial potential."

Last Friday, leading companies in the fields of superconductivity, cryogenics, power electronics, vacuum and high-precision mechanics met High-Luminosity LHC project engineers at the IdeaSquare premises to explore the technical and commercial challenges emerging from the design and procurement for the upgraded LHC accelerator, and to match them with state-of-the-art industrial solutions. The event attracted more than 140 industrial representatives from 19 countries (including 17 from Member States), with a great number of them from SMEs. "When CERN was building the LHC, due to the need for big quantities, generally only the largest companies were involved," says Bejar-Alonso. "The smaller ones often did not have the expertise and resources to work with CERN. Now, we encourage SMEs from all our Member and Associated Member States to become suppliers to HiLumi." In preparation for the event, experts, with the help of the national Industrial Liaison Officers, reached out to all member and associated member states to invite potentially interested companies to the event.

During the event, more than 130 business-to-business meetings took place. "We are incredibly happy to see the large number of companies interested in working with HiLumi. During the summer, we are going to make available and further distribute the materials presented at the event, in order to reach as many potential suppliers as possible," assures Bejar-Alonso. The project team is already planning to organise a similar event for industrial services - such as civil engineering, etc. – to take place in autumn 2015.



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Issue No. 12-13/2015 - Monday 16 March 2015

CALET: a stopover at CERN before flying to space
Keeping HL-LHC accountable
LHC Report: The beam is back at the LHC
Build your own tiny Lego LHC
The poetry of (POP) science
They rose to the challenge!
Donation of CERN computing equipment to Pakistan
Computer Security: Printing confidentially
Ombud's Corner: At cross purposes?

KEEPING HL-LHC ACCOUNTABLE

This week saw the cost and schedule of the High Luminosity LHC (HL-LHC) and LHC Injectors Upgrade (LIU) projects come under close scrutiny from the external review committee set up for the purpose.

A word from the DG

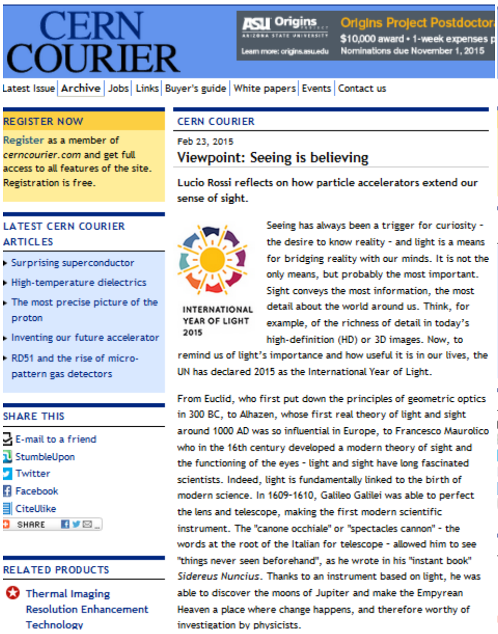
HL-LHC, whose implementation requires an upgrade to the CERN injector complex, responds directly to one of the key recommendations of the updated European Strategy for Particle Physics, which urges CERN to prepare for a 'major luminosity upgrade', a recommendation that is also perfectly in line with the P5 report on the US strategy for the field.

Responding to this recommendation, CERN set up the HL-LHC project in 2013, partially supported by FP7 funding through the HiLumi LHC Design Study (2011-2015), and coordinated with the American LARP project, which oversees the US contribution to the upgrade. A key element of HL-LHC planning is a mechanism for receiving independent expert advice on all aspects of the project. To this end, several technical reviews have been conducted over the last two years, while this week it was the turn of the cost and schedule to come under scrutiny.

The review committee consists of the CERN Machine Advisory Committee (CMAC), supplemented by five additional members from laboratories and universities around the world with expertise in domains specifically related to the main HL-LHC technologies. Their brief is to ensure that cost estimates are realistic and achievable, and, equally importantly, to cast a critical eye over the proposed schedule, allowing us to focus on critical path items, and make adjustments if necessary.

The committee has given the project a clean bill of health, along with issuing a number of recommendations that the project management will now digest and factor into CERN's medium-term plan to be presented to the Council in June. HL-LHC is a key part of CERN's medium-term strategy, designed to ensure that the global particle physics community is able to exploit the full potential of the LHC. Ensuring that its ambitions are technically and financially realistic and planned to an achievable schedule is all part of good governance, keeping the project accountable to funding agencies and physicists alike.

Rolf Heuer



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Viewpoint: Seeing is believing
Lucio Rossi reflects on how particle accelerators extend our sense of sight.

INTERNATIONAL YEAR OF LIGHT 2015

Seeing has always been a trigger for curiosity - the desire to know reality - and light is a means for bridging reality with our minds. It is not the only means, but probably the most important. Sight conveys the most information, the most detail about the world around us. Think, for example, of the richness of detail in today's high-definition (HD) or 3D images. Now, to remind us of light's importance and how useful it is in our lives, the UN has declared 2015 as the International Year of Light.

From Euclid, who first put down the principles of geometric optics in 300 BC, to Alhazen, whose first real theory of light and sight around 1000 AD was so influential in Europe, to Francesco Maurolico who in the 16th century developed a modern theory of sight and the functioning of the eyes - light and sight have long fascinated scientists. Indeed, light is fundamentally linked to the birth of modern science. In 1609-1610, Galileo Galilei was able to perfect the lens and telescope, making the first modern scientific instrument. The "canone occhiale" or "spectacles cannon" - the words at the root of the Italian for telescope - allowed him to see "things never seen beforehand", as he wrote in his "instant book" *Sidereus Nuncius*. Thanks to an instrument based on light, he was able to discover the moons of Jupiter and make the Empyrean Heaven a place where change happens, and therefore worthy of investigation by physicists.

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The International Year of Light

The International Year of Light

INTERNATIONAL YEAR OF LIGHT 2015

On 20 December 2013, the UN General Assembly proclaimed 2015 as the International Year of Light and Light-based Technologies (IYL 2015). The aim is to raise awareness about how these technologies provide solutions to global challenges in energy, education, agriculture and health.

In its quest to "see" the fundamental structure of matter, high-energy particle physics goes beyond the wavelengths of light to the wavelengths of particle beams. Over the years, developments in the accelerators that create those beams have led to new ways of producing light that have a big impact on other disciplines.

To celebrate the IYL 2015, this issue of *CERN Courier* looks at how brilliant, accelerator-based X-ray free-electron lasers are enabling exciting new studies in biology (see XFELs in the study of biological structure). Meanwhile, as Lucio Rossi points out in Viewpoint, accelerators provide the finest form of "light", and experiments can now "see" down to distances as small as 10^{-20} m (see Viewpoint). The High-Luminosity LHC project (see A luminous future for the LHC) will allow CERN's collider to cast still more of this fine light on matter. Finally, Inside Story (see Inside story) looks at how light and particle physics came together in the life of one physicist.

Under Accelerating News newsletter http://www.acceleratingnews.eu several stories from HiLumi were promoted. In total 3 Accelerating News issues were published in the 3rd period, featuring 4 HiLumi LHC-related articles with highlights from different work packages. The reader base of the newsletter has remained stable at 1350 subscribers, after reaching a peak of 1450 in April 2015.

The following chart shows the distribution of Accelerating News website visitors and subscribers per month. The number of unique visitors registers multiple peaks which correspond with the releases of the issues.

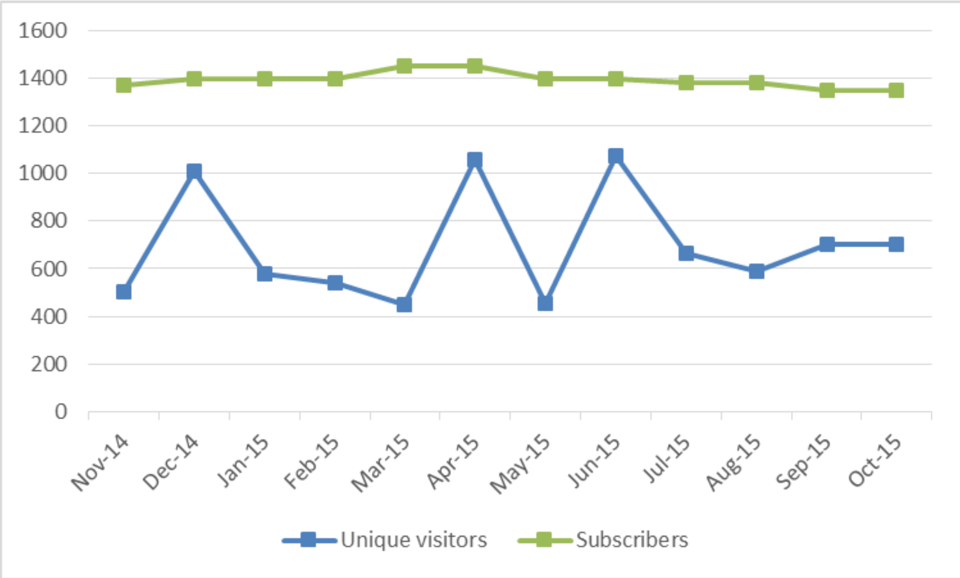


Figure 38: Chart of unique visitors and subscribers to Accelerating News website in the 3rd period.

Approximately 89% of the visitors of Accelerating News website arrived from partner countries, mostly from Switzerland, the United States, UK and France. The remaining 11% accesses the website from non-partner countries, including the Netherlands, China and Ukraine.

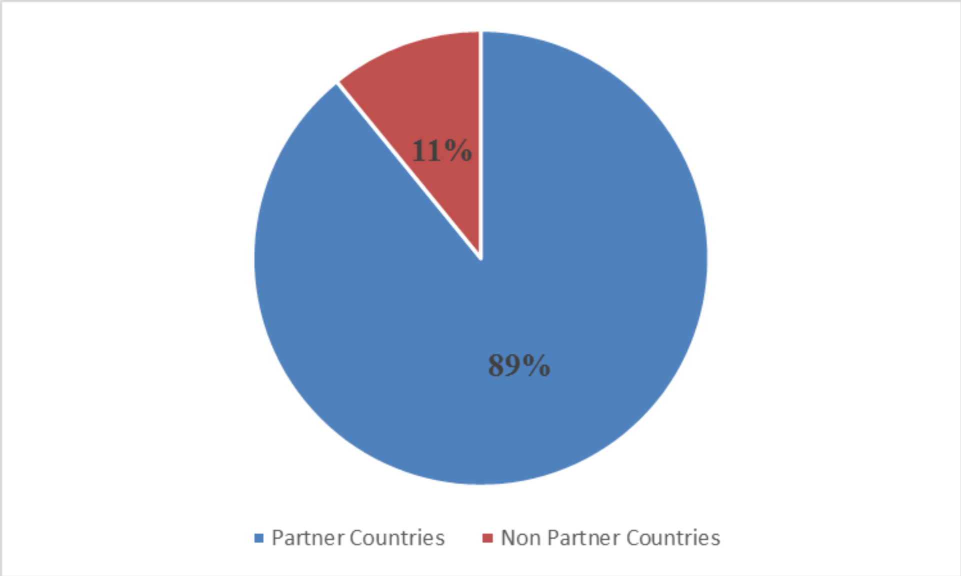


Figure 39: Chart of visitors to Accelerating News website by country in the 3rd period.

The 3rd Period has witnessed some changes in the Accelerating News editorial team: Emma Cooper, representing the Science and Technology facilities Council (STFC), took over the role of UK Editor in April 2015. Furthermore, in June 2015 Alexandra Welsch, representing Cockroft Institute's lead Marie Curie Networks, joined the editorial team.

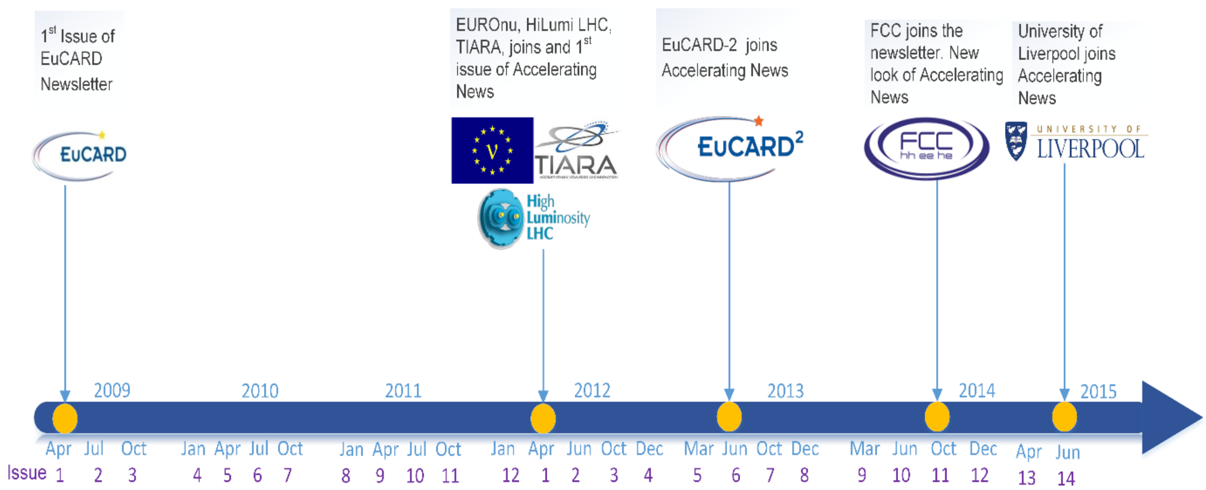
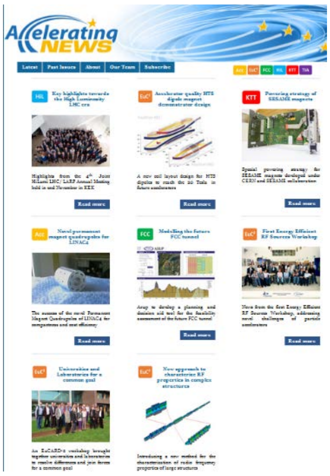
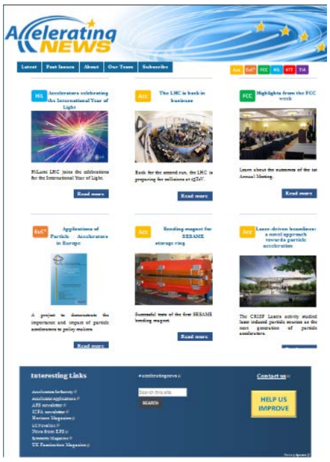


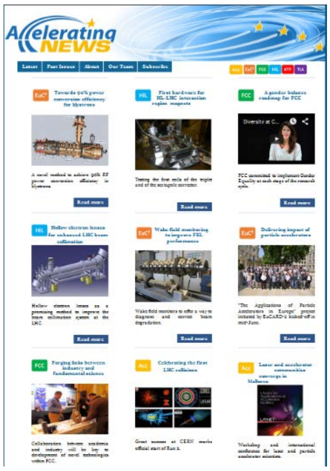
Figure 40: Timeline of the evolution of Accelerating News.

Figure 41: Accelerating News related tweets.

Table 2: Accelerating News issues between November 2014 and October 2015







Issue 12	Issue 13	Issue 14

The publications related to HiLumi LHC can be added and browsed by type and work package. As of 8 September 2015, the publications logged in the database amount to a total of 251 records. Publications related to the umbrella HL-LHC project can also be browsed on CDS with using the “HL-LHC” search keyword.

Outreach Activities

The year 2015, a century after the publication of Einstein's Theory of General Relativity in 1915, has been proclaimed the International Year of Light and light-based technologies by the UN General Assembly. CERN is taking this opportunity to communicate about the High Luminosity LHC project. In addition, light has been chosen as the main theme of CERN's participation in the 2015 Researchers' Night. Light" as "luminosity" is the underlying theme of the communication campaign launched to increase awareness of CERN's High Luminosity LHC (HL-LHC). The campaign includes special events throughout 2015. The year started with a special greetings card that was selected as CERN's official seasons greetings card for 2015.

Figure 42: CERN official season greeting card for 2015, inspired by HiLumi-LHC.

The events are published on http://cern.ch/go/light website.

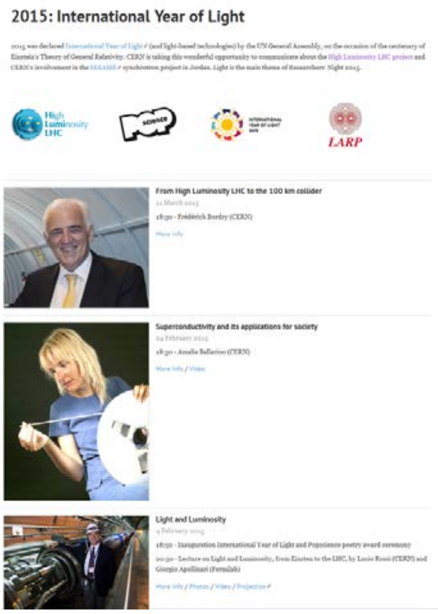


Figure 43: CERN website dedicated to the International Year of Light.

For the Inauguration event a special projection show was also organized on the Geneva iconic Globe which is located on CERN premises but publicly accessibly for anyone. This event featured a live intervention from Giorgio Apollinari as Head of LARP.

Figure 44: "Light & Luminosity" CERN talks for the International Year of Light.

The public lectures continued through the year with a great interest from the local communities. All events were live webcast and available under the CERN webcast pages.

HiLumi LHC was also contributed to the popular Light2015 UNESCO blog. A special short video on the HiLumi LHC superconducting magnets was also shown at the Reseracher' Night on 25 September at Pathe Balexert Cinema in Geneva. A short English version is also available on CDS.

To close the celebrations of the Year of Light and to celebrate the 5th HiLumi LHC-LARP Annual Meeting a special evening will be organized for the memebrs of the project management and Collaboration Board. This event called "Light, Luminosity and HiLumi Sonifications" and will feature live LHC and simulated high luminosity events sonified and projected on the cinema screen. The will be accompanied by poetry readings and inspired by light and physics.

Outreach has also been enhanced with lectures and public talks, mostly by the Project Coordinator. Prof. Dr. Lucio Rossi has been invited to give more than 80 outreach talks in total, with more than 20 in the second period. In average of an audience of 268 people of different ages and different backgrounds, including science festivals, schools and universities seminars, colloquia. The countries of the talks ranged from US to Japan, including several places in Europe. The talks to the public were always followed by intense discussions, which indicated the success of these informative events. The list of events is available: http://goo.gl/4REsq. Some talks had an audience of an impressive number of more than 1000 people, e.g. the plenary talk given during the ASC 2014 conference. The Project Coordinator was also featured several articles in public newspapers, e.g. Liberta, Corriere della Sera, etc, as well as in scientific magazines and newsletters.

Industry outreach

According to the objective of:

- Increasing awareness of EU economic operators, and to connect CERN with all the potential industrial partners, fostering collaboration, technical exchange, developing a dialog between all stakeholders.

- Investigating bridging solutions between industrial, scientific and commercial concerns to be included in our future Call for Tender.
- Providing a structured environment for debate, communication and exchange on information and ideas on important topics of the Hi-Lumi project.
- Disseminating technical requirements on components and equipment's object of the project scope and disseminating the potential business opportunities opened up by the HI-LUMI LHC for European industries and SME,

an **Industry Forum** has been organized. The original plan was to implement it at month 36. Later on, it was decided to synchronize it with the C&S review outcome and with relevant decisions of the CERN Council. In this way the opportunity has opened up to provide companies with freshly updated information, more precise as for the schedule and the budget.
In fact, on **25-26 June 2015**, leading companies in the fields of **superconductivity, cryogenics, power electronics, electrical engineering and mechanics** have been invited to meet CERN management, procurement and legal officers as well as High Luminosity LHC project engineers at the CERN premises. This has allowed participants to explore the technical and commercial challenges emerging from the design and procurement of the LHC upgrade accelerator, and to match them with state-of-the-art industrial solutions. This event has to be considered a milestone in the transition to the construction phase of the project.

A total of about 150 industries representatives have been welcomed with a working dinner on June 25th, at the CERN Restaurant, after that more than 100 among them, according to the expressed interested, have been showing the CERN facilities of SM18, cavity and collimation workshops. The participants on the following day have attended the presentations given in IdeaSquare (and simultaneously web casted in auditorium in B13-2).

Several presentations focusing on the technical aspect of the procurement to come, the **project and the schedule, the legal framework** have been made. The agenda of the event is consultable at the link: https://indico.cern.ch/event/387162/ where also it can be consulted the list of companies that have been participating.

On Friday 26th afternoon, after the technical presentations, almost 100 business-to-business short round-table discussions on topics relevant to the High Luminosity LHC project have been arranged according to participant specific requests, in order to meet the needs of clarification from industries. In addition, on request of the ILOs, a special meeting has been held in the afternoon between the ILOs and CERN Procurement and KT, to discuss ways to improve the participation of industries to such type of events, and to smooth the geographical distribution.

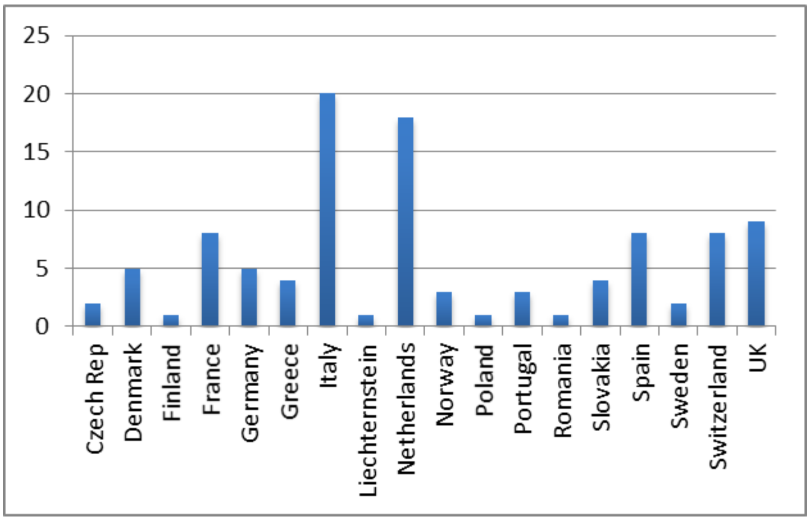


Figure 45: The distribution of registered industry/countries to Hi-Lumi info day.

Communication between beneficiaries and cooperation with other projects

In addition to the activities already mentioned under " Task 1.5: Liaison with Detector and Injector Upgrades", the communication between beneficiaries and with other projects has been enhanced by Accelerating News, which aims at bringing together news related to the accelerator community.

An example of successful cooperation with other projects is provided by the FP7 "BEST Paths" project, which focuses on the application of the SC links of the HiLumi LHC. The cables and cable test developed in the framework of the project triggered the interest of industry and of the French electricity transmission network.

2.3.9. Status of key performance indicators

Work Package	Key Performance Indicator	Description	Method to Measure	Estimated Target	Status at end of P3
1	Quality of Deliverable Reports	The reports should be clear in the scope, in the criteria used to evaluate the resources and concise without missing necessary information.	Acceptance rate of Deliverable Reports by EC	To have at max one iteration with EC officials/experts on the two main Reports, the PDR (D1.5) and the TDR (D1.10)	All 18 deliverables and 10 milestones were achieved. With this, the project delivered all contractual milestones & deliverables. The acceptance rate of the EC officer has been 100%, so far.
1	Quality of design activities	Scientific output of HiLumi: journal papers or articles and presentations at relevant conferences produced by design activities	Number of journal, reports (excluding HiLumi MS or Deliverable reports), and conference publications	More than 60	In this period, 13 peer reviewed publications were generated. The project was also represented at the biggest accelerator conferences, e.g. IPAC2014 and IPAC 2015. The total number of publications is already above the final target.
2	Quality of injected beam	A particle beam, with a given time structure, can be characterised by two main parameters: number of particles per bunch and normalized emittance. Both parameters have a critical role in luminosity.	Improvement of injected beam parameters at the end of HiLumi studies.	Bunch populations: +30% Emittance: -20%.	The proton beam parameters for the nominal scheme and for the alternative 8b+4e are challenging but achievable. The Pb beam parameters have been recently reviewed in order to meet the experiments' requirements and the necessary upgrades in the injectors are being defined.

2	Timely inputs from WP2 to other WPs	Accelerator Physics is a critical WP since it feeds into many other WPs: delays in certain deliverables will strongly impact on the whole programme.	Delay with respect to deadline for D2.2, D2.3 and D2.4.	Cumulative delay of the three deliverables must not exceed 3 months.	All the milestones have been met and the deliverables provided within the defined timescale.
3	Effective collaboration with non-EU laboratory	The WP on Magnets strongly depends on the effectiveness of collaboration of EU and non-EU partner.	Common review between EU and non-EU partners	A review every four months in average.	Three reviews done: • QXF cable review on 5-6th November 2014, CERN https://indico.cern.ch/event/338963/ • QXF design review on 10-12th December 2014, CERN https://indico.cern.ch/event/355818/ • Cost & schedule review March 2015, CERN (summary of the magnet session in https://indico.cern.ch/event/384124/
3	Coordination with WP not included in the HiLumi	The WP on 11 T dipole and WP on Energy depostzion (part of the HL-LHC project but not included in the FP7 Hi Lumi, LHC) shares many technologies with WP3: collaboration is critical for success	Number of formal exchange between WP3 and non-HuilUmi WP	12 documented exchanges	https://indico.cern.ch/event/439511/ (with WP7) https://indico.cern.ch/event/439519/ (with WP7) https://indico.cern.ch/event/326148/timetable/#20141120.detailed (with WP10) https://indico.cern.ch/event/326148/timetable/#20141120.detailed (with WP12) https://indico.cern.ch/event/326148/timetable/#20141118.detailed (with WP7) https://indico.fnal.gov/conferenceTimeTable.py?confId=9342#20150512.detailed (with WP7) https://indico.cern.ch/event/440045/ (with WP10)
4	Effective collaboration with non-EU laboratories	The WP on Crab Cavity strongly depends on the effectiveness of colla-boration of EU and non-EU partner.	Common review between EU and non-EU partners.	A review every four months in average.	Alessandro Ratti from LBNL has joined the Steering Committee for US-LARP and the recently created WP4 management Regular contact and co-ordination between Alex and CERN has been key. In addition regular web meetings with all international partners have been organised with the teams developing

					the US cavity designs. The participation of the USA laboratory is key for success of the project. In addition, a new agreement with KEK for advanced processing of CC (beyond the initial scope as beneficiary) has reinforced the International collaboration outside Europe.
4	Decision elliptical vs. compact crab cavity	WP4 had to choose between the two alternative approaches: elliptical or compact, local or global. An early decision optimized resources for the study.	Better progress with compact crab cavities, possibility to widen scope of the study to include SPS tests.	Originally, decision was to be made in 2015. Target was achieved early.	The decision was made to progress the compact designs and terminate the elliptical development work. The decision was made early allowing effort to optimize resources towards compact cavity development. This has led to rapid accelerator ready maturity of the compact cavities.
5	MD (Machine Development) runs for collimation	WP5 is critically depends on the performance details of LHC. So it is expected that a good work will generate necessity of study runs (MD = Machine Development) in LHC	Number of officially assigned MDs in LHC or injector accelerators	One per year of running	The WP5 participated actively to the system commissioning in 2015. Relevant activities for HL include the experience gained with the new collimator design with integrated orbit pickups for local orbit measurements. Specific MDs requested by the collimation team, and relevant for HL, include: crystal collimation, active halo control studies, collimation impedance an beta* reach. In total, one can count ~5 dedicated MDs and more than 5 that were requested for the LHC but are also relevant for HL. WP5 participated also to the collimation jaw and material tests at HiRadMat in July 2015 (1 week of data taking) and to the SPS MD with the SLAC rotatable collimator deign (about 5 shifts: more than the 2 requested because of a stop of the SPS that left ore time for MDs, in Aug. 2015).
5	Coordination with Energy deposition WP	WP5 will collect and use many inputs also coming from WP on Energy Deposition (a non-	Number of meetings of exchange between WP5 and WP on energy deposition	An exchange meeting, in whatever form, every four months	The WP10 is regularly represented at the ColUSM and reports there on collimation activities. A total of 5 presentations took place in the reference period. In addition, energy deposition studies are carried out also at RHUL to address HL background issue. At the ColUSM

		HiLumi WP), to shield losses coming from collision debris (in addition to the losses from primary beam)			we also had 2 presentations from WP2 (impedance) and WP8 (failure scenarios affecting experiments).
6	Anticipated use of SC link in LHC	If studies of WP6 are timely done, there is the possibility of using these types of cable also in the consolidation program of LHC, before the LHC upgrade for high luminosity, with big advantage for the operation, or in other accelerator/devices	Decision of early installation of first SC link in LHC or in other accelerator (CERN or outside CERN)	A decision of use it by 2014.	A complete and detailed design of a Cold Powering system for LHC P7 was ready by end of 2014. The design included boundary condition imposed by transport and installation in the LHC underground areas. For the moment LHC do not need this anticipated installation of SC links, however the work done makes it possible, if needs would emerge during LHC Run2.
6	Test of cold powering systems using superconducting links	WP6 will run in parallel with the tests of superconducting links of the type needed for the LHC consolidation program. This will enable the validation of the models elaborated within Task 6.3 and it will bring direct input to the Task 6.2	Benchmarking of thermoelectrical models	Meeting for exchange and discussion of information by 2013	Several tests were completed in 2015 for qualifying the Superconducting Links performance both in steady-state and transient conditions. To be noted that CERN and FP7-Hilumi LHC has made world record value of transport current at high temperature: I = 2x25 kA at 25 K.

3. DELIVERABLES AND MILESTONES TABLES

3.1. DELIVERABLES

Table 1. Deliverables

Del. no.	Deliverable name		Lead beneficiary	Nature	Dissemination level[1]	Delivery date from Annex I (proj month)	Actual / Forecast delivery date	Status Not submitted/ Submitted	Contractual Yes / No	Comments
Period 3										
D1.8	2nd Periodic Report	1	1	R	RE	38	39	Submitted	Yes	Report
D1.9	Final QA Management plan	1	1	R	PP	44	45	Submitted	Yes	Report
D1.10	HiLumi LHC Technical Design Report	1	1	R	PU	48	49	Submitted	Yes	Report
D1.11	Collaboration model for the HL-LHC construction phase	1	1	R	PU	48	46	Submitted	Yes	Report
D1.12	Final plan for use and dissemination of foreground	1	1	R	PU	48	48	Submitted	Yes	Report
D1.13	3rd Periodic Report	1	1	R	PP	48	46	Submitted	Yes	Report
D1.14	Final Project Report	1	1	R	PP	48	50	Submitted	Yes	Report

[1] **PU** = Public; **PP** = Restricted to other programme participants (including the Commission Services); **RE** = Restricted to a group specified by the consortium (including the Commission Services); **CO** = Confidential, only for members of the consortium (including the Commission Services).

D3.2	Design study of the Nb3Sn inner triplet	3	1	R	PU	48	43	Submitted	Yes	Report
D3.3	Design study of the separation dipoles	3	15	R	PU	48	43	Submitted	Yes	Report
D3.4	Design study of the cooling	3	1	R	PU	48	45	Submitted	Yes	Report
D4.3	SPS Test Prototype Cryomodule Design	4	1	R	PU	38	38	Submitted	Yes	Report
D4.4	Compact Crab Cavity	4	1	R	PU	48	48	Submitted	Yes	Report
D5.6	Technical design IR collimation	5	1	O	PU	42	43	Submitted	Yes	Report
D5.7	Design report and functional specification	5	1	R	PU	48	46	Submitted	Yes	Report
D6.5	Thermoelectrical studies	6	10	R	PP	42	43	Submitted	Yes	Report
D6.6	Energy Deposition studies	6	5	R	PU	42	40	Submitted	Yes	Report
D6.7	Cryostat drawings and report	6	10	O	PP	45	44	Submitted	Yes	Report
D6.8	Final design report	6	1	R	PP	46	48	Submitted	Yes	Report

3.2. MILESTONES

Table 2. Milestones

Mil. no.	Milestone name	Lead beneficiary	Delivery date from Annex I	Achieved (Y/N)	Actual / Forecast achievement date	Comments
Period 3						
MS23	Final evaluation of the baseline and most probable alternative	1	38	Yes	38	Report
MS24	Chart for Industry participation to the HL-LHC construction	1	44	Yes	48	Report
MS25	Organization of the final Annual Collaboration Meeting	1	48	Yes	48	Report
MS32	Collation of data for parameter optimization	11	39	Yes	39	Report
MS52	Verification of new IR collimation solution in simulations. Possible iteration in design	1	42	Yes	43	Report
MS53	Final report	1	48	Yes	48	Report
MS58	Cryostat for current leads	10	40	Yes	42	Report
MS59	Thermo-electrical models and cryostat conceptual design	10	42	Yes	39	Report
MS60	Energy deposition studies	5	42	Yes	39	Report
MS61	Material studies	5	44	Yes	45	Report

ANNEX I: LIST OF PUBLICATIONS

WP 1 (Period 3: 6 publications)	
1	P. Catapano, IYL2015 al CERN: Einstein, luce e… luminosità, CERN, Geneva (2015)
2	Communications Office, HiLumi – At CERN the biggest particle physics project over the next decade: Interview with Lucio Rossi, High Luminosity LHC project coordinator, CERN, Geneva (2015)
3	G. Apollinari, O. Bruning, L. Rossi, High Luminosity LHC Project Description, CERN, Geneva (2014)
4	S. Fartoukh, Pile up management at the high-luminosity LHC and introduction to the crab-kissing concept, CERN, Geneva (2014)
5	A. Szeberenyi, Accelerators celebrating the International Year of Light. April 2015. http://acceleratingnews.web.cern.ch/content/accelerators-celebrating-international-year-light
6	A. Szeberenyi, Key highlights towards the High Luminosity LHC era. December 2014. http://acceleratingnews.web.cern.ch/content/recent-progress-hilumi-project-0
WP 2 (Period 3: 16 publications)	
1	M. Fitterer, S. Fartoukh, M. Giovannozzi, R. De Maria, (2015) Crossing scheme and orbit correction in IR1/5 for HL-LHC, CERN-ACC-2015-0014.
2	M. Fitterer, S. Fartoukh, M. Giovannozzi, R. De Maria, (2015) Beam Dynamics Requirements for the Powering Scheme of the HL-LHC Triplet, in proceedings of IPAC15, TUPTY035
3	R. De Maria, S. Fartoukh, M. Fitterer, (2015) HLLHCV1.1 Optics Version for the HL-LHC Upgrade, in proceedings of IPAC15, TUPTY037
4	R. De Maria, M. Fitterer, (2015) BPM Tolerances for HL-LHC Orbit Correction in the Inner Triplet Area, in proceedings of IPAC15, TUPTY038
5	M. Giovannozzi, E. McIntosh, Y. Cai, Y. Nosochkov, M.-H. Wang, (2015) Dynamic Aperture Studies for the LHC High Luminosity Lattice, in proceedings of IPAC15, MOPMN003
6	E. Métral et al., HL-LHC Operational Scenarios, CERN-ACC-NOTE-2015-0009
7	J. Barranco, Effect of crab cavity non linearities without and with beam-beam: results of weak-strong simulations, 4th joint HiLumi LHC-LARP Annual Meeting, 17-21 November 2014 KEK, https://indico.cern.ch/event/326148/session/14/contribution/34/attachments/633102/871319/Barranco_HLLHC2014.pdf
8	J. Qiang, Noise Effect on Emittance Blow-up, Joint HiLumi LHC-LARP Meeting and 24th LARP Collaboration, https://indico.fnal.gov/getFile.py/access?contribId=36&sessionId=13&resId=0&materialId=slides&confId=9342
9	J. Qiang, T. Pieloni, J. Barranco, K. Ohmi, Beam-Beam Simulation of Crab Cavity White Noise for LHC Upgrade, in proceedings of IPAC15, TUPTY076
10	J. Qiang, S. Paret, T. Pieloni, K. Ohmi, Strong-Strong Beam-Beam Simulation of Bunch Length Splitting at the LHC, , in proceedings of IPAC15, TUPTY077
11	A. Valishev, D. Shatilov, C. Milardi, M. Zobov, (2015) Numerical Analysis of Parasitic Crossing Compensation with Wires in DAFNE, in proceedings of IPAC15, TUPTY073
12	S. Fartoukh, D. Shatilov, A.Valishev, (2015) An Alternative High Luminosity LHC with Flat Optics and Long-Range Beam-Beam Compensation, in proceedings of IPAC15, MOPMA022
13	M. Crouch, B. Muratori, R. Appleby, Analytical Approach to the Beam-Beam Interaction with the Hourglass effect, in proceedings of IPAC15, MOPJE082.
14	M. Crouch, B. Muratori, R. Appleby, Strong-Strong Simulations of β^* Levelling for Flat and Round Beams, in proceedings of IPAC15, TUPTY070.
15	R. Tomas, 80 bunch scheme option for HL-LHC - physics potential, 14th HL-LHC Parameter and Layout Committee Meeting, 12th March 2015, https://indico.cern.ch/event/378400/contribution/1/attachments/754906/1035543/SLIDES.pdf
16	J. Jowett, HL-LHC Heavy-Ion Beam Parameters at LHC Injection, EDMS Document n. 1525065 v.0.2. https://edms.cern.ch/file/1525065/0.2/HL-LHC-IONS-1525065-00-20.docx
WP3 (Period 3: 7 publications)	

1	S. Izquierdo Bermudez, G. Ambrosio, R. Bossert, D. Cheng, P. Ferracin,S. T. Krave, J. C. Perez, J. Schmalzle, and M. Yu, 'Coil End Optimization of the Nb3Sn Quadrupole for the High Luminosity LHC', presented at ASC 2014, *IEEE Trans. Appl. Supercond.* 25 (2015) 4001504. CERN-ACC-2015-0023 http://cds.cern.ch/record/1989121/files/CERN-ACC-2015-0023.pdf
2	M. Juchno, G. Ambrosio, M. Anerella, D. Cheng, H. Felice, P. Ferracin, J. C. Perez, H. Prin, and J. Schmalzle, 'Support Structure Design of the Nb3Sn Quadrupole for the High Luminosity LHC', presented at ASC 2014, *IEEE Trans. Appl. Supercond.* 25 (2015) 4001804.
3	H. Bajas, G. Ambrosio, M. Anerella, M. Bajko, R. Bossert, L. Bottura, S. Caspi, D. Cheng, A. Chiuchiolo, G. Chlachidze, D. Dietderich, H. Felice, P. Ferracin, J. Feuvrier, A. Ghosh, C. Giloux, A. Godeke, A. R. Hafalia, M. Marchevsky, E. Ravaioli, G. L. Sabbi, T. Salmi, J. Schmalzle, E. Todesco, P. Wanderer, X. Wang, and M. Yu, 'Test Results of the LARP HQ02b Magnet at 1.9 K', presented at ASC 2014, *IEEE Trans. Appl. Supercond.* 25 (2015) 4003306.
4	T. Nakamoto, M. Sugano, Q. Xu, H. Kawamata, S. Enomoto, N. Higashi, A. Idesaki, M. Iio, Y. Ikemoto, R. Iwasaki, N. Kimura, T. Ogitsu, N. Okada, K. Sasaki, M. Yoshida, and E.Todesco, 'Model Magnet Development of D1 Beam Separation Dipole for the HL-LHC Upgrade ', presented at ASC 2014, *IEEE Trans. Appl. Supercond.* 25 (2015) 4000505.
5	G. Volpini, F. Alessandria, G. Bellomo, F. Broggi, A. Paccalini, D. Pedrini, A. Leone, M. Quadrio, L. Somaschini, M. Sorbi, M. Todero, C. Uva, P. Fessia, E. Todesco and F. Toral, 'NbTi Superferric Corrector Magnets for the LHC Luminosity Upgrade', presented at ASC 2014, *IEEE Trans. Appl. Supercond.* 25 (2015) 4002605.
6	M. Segreti, J. M. Rifflet, E. Todesco, 'A Nb-Ti 90 mm Double-aperture Quadrupole for the High Luminosity LHC Upgrade', presented at ASC 2014, *IEEE Trans. Appl. Supercond.* 25 (2015) 4001905.
7	E. Todesco, First hardware for HL-LHC interaction region magnets. June 2015. http://acceleratingnews.web.cern.ch/content/first-hardware-hl-lhc-interaction-region-magnets
WP 4 (Period 3: 12 publications)	
1	S. Pattalwar et al, Key Design Features of **Crab**-Cavity Cryomodule for HiLumi LHC, IPAC14, Dresden
2	B. Hall et al, Testing and Dressed Cavity Design for the HL-LHC 4R **Crab** Cavity, IPAC 14, Dresden
3	B. Yee-Rendon et al, Fast **Crab** Cavity Failures in HL-LHC, IPAC14, Dresden
4	S. Verdu-Andres, Design and Prototyping of HL-LHC Double Quarter Wave Crab Cavities , IPAC 15, Richmond, US
5	Z. Li, FPC and Hi-Pass Filter HOM Coupler Design for the RF Dipole Crab Cavity for the LHC HiLumi Upgrade, IPAC 15, Richmond, US
6	S. De Silva Design and Prototyping of a 400 MHz RF-dipole Crabbing Cavity for the LHC High-Luminosity Upgrade, IPAC 15, Richmond, US
7	H. Park, Engineering Study of Crab Cavity HOM Couplers for LHC High Luminosity Upgrade, IPAC 15, Richmond, US
8	B. Xiao, Higher Order Mode Filter Design for Double Quarter Wave Crab Cavity for the LHC High Luminosity Upgrade, IPAC 15, Richmond, US
9	B. Xiao, Cryogenic Test of Double Quarter Wave Crab Cavity for the LHC High Luminosity Upgrade, IPAC 15, Richmond, US
10	Q. Wu, Crab Cavities:Past, Present, and Future of a Challenging Device**,** IPAC 15, Richmond, US
11	Binping Xiao, Luís Alberty, Sergey Belomestnykh, Ilan Ben-Zvi, Rama Calaga, Chris Cullen, Ofelia Capatina, Lee Hammons, Zenghai Li, Carlos Marques, John Skaritka, Silvia Verdú-Andres, and Qiong Wu, Design, prototyping, and testing of a compact superconducting double quarter wave crab cavity, Phys. Rev. ST Accel. Beams 18, 041004 (2015) - Published 28 April 2015
12	M. Navarro-Tapia, R. Calaga, Bead-Pull Measurements on the Fundamental Mode of the Double-Quarter-Wave Crab Cavity, CERN, Geneva (2015)
WP 5 (Period 3: 12 publications)	
1	H. Garcia et al., Beam Cleaning in Experimental IRs in HL-LHC for Incoming Beam, Proceedings of IPAC15, Richmond, VA, USA (2015)
2	R. Bruce et al., Collimator Layouts for HL-LHC in the Experimental Insertions, Proceedings of IPAC15, Richmond, VA, USA (2015)
3	P. Hermes et al., Betatron Cleaning for Heavy Ion Beams with IR7 Dispersion Suppressor Collimators, Proceedings of IPAC15, Richmond, VA, USA (2015)

4	J. Snuverink et al., Beam Delivery Simulation - Recent Developments and Optimization, Proceedings of IPAC15, Richmond, VA, USA (2015)
5	E. Quaranta et al., Updated Simulation Studies of Damage Limit of LHC Tertiary Collimators, Proceedings of IPAC15, Richmond, VA, USA (2015)
6	E. Quaranta et al., Collimation Cleaning at the LHC with Advanced Secondary Collimator Materials, Proceedings of IPAC15, Richmond, VA, USA (2015)
7	S. Redaelli et al., Plans for Deployment of Hollow Electron Lenses at the LHC for Enhanced Beam Collimation, Proceedings of IPAC15, Richmond, VA, USA (2015)
8	H. Rafique et al., Simulation of Hollow Electron Lenses as LHC Beam Halo Reducers using Merlin, Proceedings of IPAC15, Richmond, VA, USA (2015)
9	R. Kwee et al., Beam Induced Background Simulation Studies at IR1 with New High Luminosity LHC Layout, Proceedings of IPAC15, Richmond, VA, USA (2015)
10	E. Cooper, S. Redaelli, Hollow electron lenses for enhanced LHC beam collimation. June 2015. http://acceleratingnews.web.cern.ch/content/hollow-electron-lenses-enhanced-lhc-beam-collimation
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ANNEX II: ACRONYMS

a-C	Amorphous carbon
ADT	Transverse damper
ALARA	As low as reasonable achievable
ASIC	Application specific integrated circuit
ATS	Achromatic telescopic squeezing
AUG	Emergency stop buttons
BCMS	Bach compression and beam merging scheme
BETS	Beam energy tracking system
BFPP	Bound-free pair production
BGV	Beam gas vertex profile monitor
BIS	Beam interlock system
BLM	LHC beam loss monitoring system
BPM	Beam position monitor
BRAN	TAN luminosity monitor
BS	Beam screen
BSRT	Synchrotron radiation telescope monitor
CC	Crab cavities
CCB	Cold compressor box
CDD	CERN design directory
CDP	Conductor development programme
CFC	Carbon fibre carbon composites
CMOS	Complementary metal-oxide-semiconductor
COTS	Commercial-off-the-shelf
CVD	Chemical vapour deposition
DA	Dynamic Aperture
DAC	Digital-to-analog converter
DAQ	Data acquisition
DF	Distribution feedbox
DFBAM	Distribution feedbox for arc – IR 7/L
DFBAN	Distribution feedbox for arc – IR 7/R
DPA	Displacements-per-atom
DQW	Double quarter wave cavity
DSs	Dispersion suppressors
DVB	Cryogenic distribution valve box
DWR	Extraction resistors
EC	Electron cloud
EE	Energy extraction systems
ElQA	High voltage qualification
EMD	Electromagnetic dissociation

ERA	European Research Area
ESFRI	European Strategy Forum on Research Infrastructure
EUCARD	Enhanced European Coordination for Accelerator Research and Development
EYETS	Extended yearly technical stop
FMCM	Fast magnet current change monitors
FNAL	Fermi National Accelerator Laboratory
HEB	Hollow electron beam
HL-LHC	High Luminosity Large Hadron Collider
HFM	High-field magnet
HOM	High-order modes
HTS	High temperature superconductor
IBS	Intra-beam scattering
IP	Interaction point
IR	Interaction region
IT	Inner triplet magnets
LARP	LHC Accelerator Research Program
LBDS	LHC beam dumping system
LCB	Lower cold box
LIU	LHC injector complex upgrade
LLRF	Low level RF
LRBB	Long-range beam–beam
LS[X]	Long shutdown [Id Number]
LSS	Long straight section
LVDT	Linear variable differential transformer
MB	Main LHC dipoles
MBH	11 T dipole
MBU	Multiple bit upsets
MCDO	Magnet corrector decapole/octupole
MCS	Magnet corrector sextupole
MD	Machine development
MIM	Multi-band instability monitor
MKB	Diluter dump kicker
MKI	Magnet injection kicker
MP3	Magnet circuits, powering and performance panel
MPP	Machine protection panel
MPS	Machine protection system
MQY	Insertion region wide aperture quadrupole
MS	Matching section
NEG	Non-evaporable getter
NIEL	Non-ionizing energy losses

NIMS	National Institute of Materials Science
P5	Particle Physics Project Prioritization Panel
PIC	Powering interlock system
PIT	Powder-in-tube process
PLC	Programmable logic controller
PU	Pile-up
QPS	Quench protection system
QRL	cryogenic distribution line
QV	Quench buffer
r.m.s.	Root mean square
R2E	Radiation To Electronics
RF	Radio frequency
RFD	RF dipole cavity
RHQT	Rapid-heating, quenching transformation
RRP	Restacked rod process
SC	Superconductor
SCL	Superconducting link
SCRF	Superconducting radio frequency
SEE	Single event effects
SEU	Single bit upsets
SEY	Secondary electron yield
SIL	Safety integrity level
SM	Service module
SPS	Super Proton Synchrotron
SPT	Scheduled proton physics time
SR	Synchrotron radiation
SRF	Superconducting radio frequency
TAXN	Target absorber for insertion region neutrals
TAXS	Target absorber for insertion region secondary
TCAP	Target collimator absorber passive
TCDQ	Collimator for Q4 protection
TCL	Long collimator
TCLA	Target collimator long absorber
TCLD	Auxiliary collimators in DS area
TCPP	Primary collimator with BPM
TCSG	Target collimator secondary graphite
TCSMP	Secondary collimator metallic prototype
TCSP	Secondary collimator with pick-up
TCSPM	Secondary collimator with pick-up metallic
TCT	Target collimators tertiary

TCTP	Target collimator tertiary with pick-up
TCTPM	Target collimator tertiary with pick-up metallic
TDE	Target dump for ejected beam
TDI	Beam absorber for injection
TID	Total ionizing dose
TMCI	Transverse mode coupling instability
TS[X]	Technical stop [Id number]
UA[X]	Service and access tunnel [point number]
UCB	Upper cold box
UFO	Falling particles
UJ[X]	Service cavern [point number]
UPS	Uninterruptable power supplies
VCT	Vacuum chamber transition
VDWB	Vacuum – dump lines – window
VELO	Vertex locator
WBTN	Wide band time normalizer
WCS	Warm compressor station
WIC	Warm magnet interlock system

ANNEX III: GLOSSARY AND DEFINITIONS

Term	**Definition**
$\boldsymbol{\beta^*}$	Optical β-function at the IP.
$\boldsymbol{\eta}$	Machine slip factor.
$\boldsymbol{\eta_D}$	Normalized dispersion, $\eta D = D/\sqrt{\beta}$, where D is the machine dispersion.
$\boldsymbol{\gamma}$	Optic gamma function, $\gamma(s) = (1 + \alpha 2(s))/\beta(s)$ where $\beta(s)$ is the optical betatron function along the machine and $\alpha(s) = -\frac{\mathrm{d}\beta}{2\,\mathrm{d}s}$.
$\boldsymbol{\gamma_r}$	The relativistic gamma factor.
Abort gap	Area without any bunches in the bunch train that fits the time required for building up the nominal field of the LHC dump kicker.
Arc	The part of the ring occupied by regular half-cells. Each arc contains 46 half cells. The arc does not contain the dispersion suppressor.
Arc cell	Consists of two arc half-cells and presents the basic period of the optic functions.
Arc half-cell	Periodic part of the LHC arc lattice. Each half-cell consists of a string of three twin aperture main dipole magnets and one short straight section. The cryo magnets of all arc half-cells follow the same orientation with the dipole lead end pointing upstream of Beam 1 (downstream of Beam 2).
Batch	PS batch: train of 72 bunches that is injected into the SPS in one PS to SPS transfer. SPS batch: Train of 4 × 72 or 3 × 72 bunches that is injected into the LHC in one SPS to LHC transfer.
Beam 1 and Beam 2	Beam 1 and Beam 2 refer to the two LHC beams. Beam 1 circulates clockwise in Ring 1 and Beam 2 circulates counter clockwise in Ring 2. If colours are used for beams, Beam 1 is marked blue and Beam 2 is marked red.
Beam cleaning	Removal of the large amplitude (larger than 6 σ) particles from the beam halo. The LHC has two beam cleaning insertions: one is dedicated to the removal of particles with large transverse oscillation amplitudes (IR7) and one dedicated to the removal of particles with large longitudinal oscillation amplitudes (IR3). These insertions are also referred to as the betatron and momentum cleaning or collimation insertions.
Beam crossing angle	Dedicated orbit bumps separate the two LHC beams at the parasitic beam crossing points of the common beam pipe of Ring 1 and Ring 2. The crossing angle bumps do not separate the beams at the IP, but only at the parasitic crossing points. These orbit bumps generate an angle between the orbit of Beam 1 and Beam 2 at the IP. The full angle between the orbit of Beam 1 and Beam 2 is called the crossing angle. In IR2 and IR8 the crossing angle orbit bumps consist of two separate

	contributions. One external bump generated for the beam separation at the parasitic beam crossing points and one internal bump generated by the experimental spectrometer and its compensator magnets. The LHC baseline foresees vertical crossing angles in IR1 and IR2 and horizontal crossing angles in IR5 and IR8.
Beam half-life	Time during beam collision after which half the beam intensity is lost.
Beam screen	Perforated tube inserted into the cold bore of the superconducting magnets in order to protect the cold bore from synchrotron radiation and ion bombardment.
Beam types	**Pilot beam:** consists of a single bunch of 0.5×10^{10} protons. It corresponds to the maximum beam current that can be lost without inducing a magnet quench. **Commissioning beam:** beam tailored for a maximum luminosity with reduced total beam power (i.e. increased operational margins related to beam losses and magnet quenches) and possibly smaller beam sizes (i.e. increased mechanical acceptance in terms or the transverse beam size and larger tolerances for orbit and β-beat). **Intermediate beam:** beam tailored for a high accuracy of the beam measurements with reduced total beam power (i.e. increased operational margins related to beam losses and magnet quenches). **Nominal beam:** beam required to reach the design luminosity of $L = 10^{34}$ cm^{-2} s^{-1} with $\beta^* = 0.55$ m ($\rightarrow$ normalized emittance $\varepsilon_n = 3.75$ μm; $N_b = 1.15 \times 10^{11}$; $n_b = 2808$). **Ultimate beam:** beam consisting of the nominal number of bunches with nominal emittances (normalized emittance of 3.75 μm) and ultimate bunch intensities ($I = 0.86$ $A \rightarrow N_b = 1.7 \times 10^{11}$). Assuming the nominal value of $\beta^* = 0.55$ m and 2808 bunches, the ultimate beam can generate a peak luminosity of $L = 2.3 \times 10^{34}$ cm^{-2} s^{-1} in the two high luminosity experiments.
BPM	Beam position monitor.
Bunch	Collection of particles captured within one RF bucket.
Bunch duration	The bunch duration is defined as $$\sigma_t = \frac{\sigma_s}{v},$$ where σ_s is the bunch length and v is the speed of the particles in the storage rings.
Bunch length	The bunch length is defined as the r.m.s. value of the longitudinal particle distribution in one RF bucket. The bunch length is denoted as σ_s.
Busbar	Main cable that carries the current for powering the magnets outside the magnet coil.

Channel	The two apertures of the double bore magnets form two channels through the LHC. Each arc has one outer and one inner channel.
Cold mass	The cold mass refers to the part of a magnet that needs to be cooled by the cryogenic system, i.e. the assembly of magnet coils, collars, iron yoke, and helium vessel.
Crossings	The two machine channels cross at the experimental insertions, i.e. at IP1, IP2, IP5, and IP8.
Cryo magnet	Complete magnet system integrated into one cryostat, i.e. main magnet coils, collars and cryostat, correction magnets, and powering circuits.
DA	See dynamic aperture
Damper	Transverse or longitudinal feedback system used to damp injection oscillations and/or multi-bunch instabilities of a beam.
Damping time	Time after which an oscillation amplitude has been reduced by a factor $1/e$. **Longitudinal emittance damping time:** Half of the longitudinal amplitude damping time for a Gaussian approximation of the bunch distribution. **Transverse emittance damping time:** half of the transverse amplitude damping time for a Gaussian approximation of the transverse bunch distribution. If no explicit mentioning of the types of damping times is given the damping times refer to the amplitude damping times.
Decay and snap back	Persistent current decay is a change in the persistent current contribution to the total magnetic field in superconducting magnets powered at constant current (e.g. at injection). This effect varies among magnets and is a function of the powering history (i.e. previous current cycles). When the magnet current is changed (e.g. during the acceleration ramp) the magnetic field comes back to the original value before the decay. This effect is called snap back and occurs for the LHC main dipole magnets within the first 50 A change of the LHC ramp.
Dispersion suppressor	The dispersion suppressor refers to the transition between the LHC arcs and insertions. The dispersion suppressor aims at a reduction of the machine dispersion inside the insertions. Each LHC arc has one dispersion suppressor on each end. The length of the dispersion suppressors is determined by the tunnel geometry. Each LHC dispersion suppressor consists of four individually powered quadrupole magnets that are separated by two dipole magnets. This arrangement of four quadrupole and eight dipole magnets is referred to as two missing dipole cells. For the machine lattice these two missing dipole cells are referred to as one dispersion suppressor. However, reducing the dispersion at the IPs to zero requires a special powering of two more quadrupole magnets on each side of the arc. In terms of

	the machine optics the dispersion suppressor refers therefore to the two missing dipole cells plus one additional arc cell.
Dogleg magnets	Special dipole magnet used for increasing the separation of the two machine channels from standard arc separation. The dogleg magnets are installed in the cleaning insertions IR3 and IR7 and the RF insertion IR4.
Dynamic aperture	Maximum initial oscillation amplitude that guarantees stable particle motion over a given number of turns. The dynamic aperture is normally expressed in multiples of the RMS beam size (σ) and together with the associated number of turns.
Eddy currents	Eddy currents are screening currents that tend to shield the interior of a conductor or a superconducting cable from external magnetic field changes. In the case of a strand the eddy currents flow along the superconducting filaments in the strand (without loss) and close across the resistive matrix of the strand (copper for the LHC). In the case of a cable the eddy currents flow along the strands (without loss) and close resistively at the contact points among strands in the cable. Eddy currents are also referred to as coupling currents.
Energy spread	The energy spread is defined as the ’RMS’ value of the relative energy deviations from the nominal beam energy in a particle distribution. The energy spread is denoted as $\sigma_{\delta E/E0}$.
Experimental insertion region	Insertion region that hosts one of the four LHC experiments.
Filament	Superconducting filaments are fine wires of bulk superconducting material with typical dimension in the range of a few microns. The superconducting filaments are embedded in the resistive matrix in a strand.
Hourglass effect *H*	Luminosity loss due to longitudinal modulation of beta function over the length of the bunch for small β^*.
Insertion region (IR)	Machine region between the dispersion suppressors of two neighboring arcs. The insertion region consists of two matching sections and, in the case of the experimental insertions, of two triplet assemblies and the separation/recombination dipoles.
Interaction point (IP)	Middle of the insertion region (except for IP8). In the insertions where the two LHC beams cross over, the IP indicates the point where the two LHC beams can intersect. In IR8 the experimental detector is shifted by 3/2 RF wavelength and the IP refers to the point where the two LHC beams can intersect and does not coincide with the geometric centre of the insertion.
Ions	The LHC foresees collisions between heavy ions, $^{208}Pb^{82+}$ (fully stripped) during the first years (208 is the number of nucleons, 82 the number of protons of this particular nucleus).
Ions, nominal scheme	Approximately 600 bunches per beam, with 7×10^7 Pb ions each, are colliding at 2.76 TeV/u to yield an initial luminosity of $L = 1.0 \times 1027$ cm^{-2} s^{-1} where $\beta^* = 0.5$ m.

Ions, early scheme	Approximately 60 bunches per beam, with 7×10^7 Pb ions each, are colliding to yield an initial luminosity of $L = 5.0 \times 10^{25}$ cm^{-2} s^{-1} with ($\beta^* = 0.5$ m).
Lattice correction magnets	Correction magnets that are installed inside the short straight section assembly.
Lattice version	Lattice version refers to a particular hardware installation in the tunnel. It is clearly separated from the optics version and one lattice version can have more than one optics version.
Left, right	See the definition under 'right and left'.
Long-range interactions	Interaction between the two LHC beams in the common part of Ring 1 and Ring 2 where the two beams are separated by the crossing angle orbit bumps.
Long straight section (LSS)	The quasi-straight sections between the upstream and downstream dispersion suppressor of an insertion, including the separation/recombination dipole magnets.
Longitudinal emittance	The longitudinal emittance is defined as: $\epsilon_s = 4\pi\sigma_t\sigma_{\delta E/E0}E_0,$ where σ_t is the bunch duration in seconds, and $\sigma_{\delta E/E0}$ the relative energy spread.
Luminosity half-life	Time during beam collision after which the luminosity is halved. The luminosity half-life is generally smaller than the beam half-life.
Luminous region	The 3D distribution of the collision event vertices.
Luminosity reduction	**Geometric luminosity reduction factor due to beam offset R:** Reduced beam overlap due to transversal offset of collisions, frequently used for reduction of luminosity (levelling) and VdM scans. Luminosity reduction factor due to crossing angle S: reduced beam overlap due to tilted bunch shape due to crossing angle. Total luminosity reduction factor $F = R^*H^*S$ (Strictly speaking here there is no direct multiplication, but provides a reasonable indication of the different contributions, while dominated by the crossing angle contribution).
Machine cycle	The machine cycle refers to one complete operation cycle of a machine, i.e. injection, ramp-up, possible collision flat-top, ejection, and ramp-down. The minimum cycle time refers to the minimum time required for a complete machine cycle.
Machine statistics	Run time: annual time allocated to running with beam [days]. Scheduled physics time: annual time allocated to physics (excluding initial beam commissioning, scrubbing, TS, recovery from TS, MDs, special physics) [days]. Physics efficiency: time with both beams present and stable beams, versus scheduled physics time [%]. Machine availability: time during which the machine is in a state allowing operations to take beam and run through a nominal physics cycle, versus run time [%].

	Turnaround time: time between the end of one and the start of the next physics run/data taking by the experiments (delimited by the loss of beam presence/beam dump back to declaration of stable beams) [hours]. Recovery time: time between the end of one cycle and the readiness for injection of new particles for the next cycle (delimited by the loss of beam presence/beam dump and resumption of the normal operational cycle) [hours].
Magnet quench	Loss of the superconducting state in the coils of a superconducting magnet.
Main lattice magnets	Main magnets of the LHC arcs, i.e. the arc dipole and quadrupole magnets.
Matching section	Arrangement of quadrupole magnets located between the dispersion suppressor and the triplet magnets (or the IP for those insertions without triplet magnets). Each insertion has two matching sections: one upstream and one downstream from the IP.
$\boldsymbol{n_1}$	The effective mechanical aperture n_1 defines the maximum primary collimator opening in terms of the r.m.s. beam size that still guarantees a protection of the machine aperture against losses from the secondary beam halo. It depends on the magnet aperture and geometry and the local optics perturbations.
$\boldsymbol{N_b}$	Number of particles per bunch.
$\boldsymbol{n_b}$	Number of bunches per beam.
Nominal bunch	Bunch parameters required to reach the design luminosity of L = 1034 cm−2 s−1 where β* = 0.55 m. The nominal bunch intensity is N_b = 1.15 × 1011 protons.
Nominal powering	Hardware powering required to reach the design beam energy of 7 TeV.
Normalized transverse emittance	The beam emittance decreases with increasing beam energy during acceleration and a convenient quantity for the operation of a hadron storage rings (and linear accelerators) is the 'normalized emittance' defined as $$\epsilon_n = \epsilon \gamma_r \beta_r,$$ where γ_r and β_r are the relativistic gamma and beta factors $$\beta_r = \frac{v}{c}$$ $$\gamma_r = \frac{1}{\sqrt{1-\beta_r^2}}$$ where v is the particle velocity and c the speed of light in vacuum. The nominal normalized transverse emittance for the LHC is ε_n = 3.75 µm.
Octant	An octant starts in the center of an arc and goes to the centre of the next downstream arc. An octant consists of an upstream and a downstream half-octant. A half-octant and a half-sector cover

	the same part of the machine even though they may not have the same number.
Optical configuration	An optical configuration refers to a particular powering of the LHC magnets. Each optics version has several optical configurations corresponding to the different operational modes of the LHC. For example, each optics version has a different optical configuration for injection and luminosity operation, and for luminosity operation the optics features different optical configurations corresponding to different β^* values in the four experimental insertions of the LHC.
Optics version	The optics version refers to a consistent set of optical configurations. There can be several different optics versions for one lattice version.
Pacman bunches	Bunches that do not experience the same number of long-range beam–beam interactions left and right from the IP.
Parallel separation	Dedicated orbit bumps separate the two LHC beams at the IP during injection, ramp, and the optics squeeze. The total beam separation at the IP is called the parallel separation. The LHC baseline foresees horizontal parallel separations in IR1 and IR2 and vertical separations in IR5 and IR8.
Parasitic crossing points	Positions in the common part of the Ring 1 and Ring 2 where the two beams can experience long-range interactions.
Persistent currents	Persistent currents are eddy currents with (ideally) infinitely long time constants that flow in the bulk of the superconducting filaments of a strand and tend to shield the interior of the filament from the external magnetic field changes. These screening currents close inside the superconducting filament, with zero resistance (in steady state). Hence, for practical purposes, they do not decay in time and for this reason they are referred to as ‘persistent’.
Physics run	Machine operation at top energy with luminosity optics configuration and beam collisions.
Pile-up	**Event pile-up μ:** number of visible inelastic proton–proton interactions in a given bunch crossing. Average pile-up: mean value of the pile-up over a fill (averaged over all bunchcrossings). Peak pile-up: maximum pile-up in any bunch crossing at any time (usually at the start of the fill). Peak average pile-up: mean pile-up at the beginning of the fill. It corresponds to the peak luminosity of the fill. In practice, it is determined as the maximum of the pile-up values obtained by averaging over all bunch crossings within time intervals of typically one minute. Average pile-up density: number of inelastic proton–proton interactions in a given bunch-crossing divided by the size of the luminous region in *Z*.

Pilot bunch	Bunch intensity that assures no magnet quench at injection energy for an abrupt loss of a single bunch but is still large enough provide BPM readings. The pilot bunch intensity of the LHC corresponds to 0.5×10^{10} protons in one bunch.
Piwinski parameter	Parameterization of reduced beam overlap due to finite crossing angle.
Ramp	Change of the magnet current. During the beam acceleration the magnets are 'ramped up' and after the end of a physics store the magnets are 'ramped down'.
Resistive matrix	One of the two main constituents of the strand. The resistive matrix embeds the filaments in the strand and provides a low resistance current shunt in case of quench (transition of superconducting material to the normal state).
RF bucket	The RF system provide a longitudinal focusing that constrains particle motion in the longitudinal phase space to a confined region called the RF bucket.
Right, left	Describes the position in the tunnel relative to an observer inside the ring looking out (same definition as for LEP).
Ring 1 and Ring 2	There are two rings in the LHC, one ring per beam. Ring 1 corresponds to Beam 1, which circulates clockwise, and Ring 2 corresponds to Beam 2, which circulates counter-clockwise in the LHC.
Satellite bunch	Collection of particles inside RF buckets that do not correspond to nominal bunch positions. The nominal bunch spacing for the LHC is 25 ns, while the separation of RF buckets is 2.5 ns. In other words, there are nine RF buckets between two nominal LHC bunch positions that should be empty.
Sector	The part of a ring between two successive insertion points (IP) is called a sector. Sector 1-2 is situated between IP1 and IP2.
Separation/recombination magnets	Special dipole magnets left and right from the triplet magnets that generate the beam crossings in the experimental insertions.
Short straight section (SSS)	Assembly of the arc quadrupole and the lattice corrector magnets. Each SSS consists of one quadrupole magnet, one beam position monitor (BPM), one orbit corrector dipole (horizontal deflection for focusing and vertical deflection for defocusing quadrupoles), one lattice correction element (i.e. trim or skew quadrupole elements or octupole magnets). and one lattice sextupole or skew sextupole magnet.
Special straight section (SPSS)	Quadrupole assemblies of the insertion regions. The SPSS features no lattice corrector and sextupole magnets and has only orbit correction dipole magnets and BPMs.
Spool piece correction magnets	Correction magnets directly attached to the main dipole magnets. The spool piece correction magnets are included in the dipole cryostat assembly
Strand	A superconducting strand is a composite wire containing several thousands of superconducting filaments dispersed in a matrix with suitably small electrical resistivity properties. The

	LHC strands have Nb-Ti as their superconducting material and copper as the resistive matrix.
Superconducting cable	Superconducting cables are formed from several superconducting strands in parallel, geometrically arranged in the cabling process to achieve well-controlled cable geometry and dimensions, while limiting strand deformation in the process. Cabling several strands in parallel results in an increase of the current carrying capability and a decrease of the inductance of the magnet, easing protection. The LHC cables are flat, keystoned cables of the so-called Rutherford type.
Super pacman bunches	Bunches that do not collide head-on with a bunch of the other beam in one of experimental IPs.
Synchrotron radiation damping times	**Longitudinal amplitude damping time:** the ratio of the average rate of energy loss (energy lost over one turn divided by the revolution time) and the nominal particle energy. **Transverse amplitude damping time:** time after which the transverse oscillation amplitude has been reduced by a factor *1/e* due to the emission of synchrotron radiation. For a proton beam it is just twice the longitudinal amplitude damping time due to the emission of synchrotron radiation. If no explicit mentioning of the types of damping times is given the damping times refer to the amplitude damping times.
TAN	Target absorber neutral: absorber for the neutral particles leaving the IP. It is located just in front of the D1 separation/recombination dipole magnet on the side facing the IP.
TAS	Target absorber secondaries: absorber for particles leaving the IP at large angles. It is located just in front of the Q1 triplet quadrupole magnet on the side facing the IP.
Transverse beam size	The transverse beam size is defined as the r.m.s. value of the transverse particle distribution.
Transverse emittance	The transverse emittance is defined through the invariance of the area enclosed by the single particle phase space ellipse. The single particle invariant under the transformation through the storage ring is given by $$A = \gamma x^2 + 2\alpha x x' + \beta x'^2,$$ where α, β, and γ are the optical functions. The area enclosed by the single particle phase space ellipse is given by $$\text{area of ellipse} = \pi A$$. For an ensemble of particles the emittance is defined as the average of all single particle invariants (areas enclosed by the single particle phase space ellipsoids divided by π). The transverse betatron beam size in the storage ring can be written in terms of the beam emittance as

	$$\sigma_{x,y}(s) = \sqrt{\beta_{x,y}(s)\epsilon_{x,y}},$$ where $\beta x,y$ (s) is the optical β-function along the storage ring. The transverse emittance is given by the following expression: $$\epsilon_z = \sqrt{\langle z^2\rangle\langle z'^2\rangle - \langle zz'\rangle^2}; z = x,$$ where it is assumed that the particle coordinates are taken at a place with vanishing dispersion and where ⟨ ⟩ defines the average value of the coordinates over the distribution. z and z' are the canonical transverse coordinates ($z = x,y$).
Triplet	Assembly of three quadrupole magnets used for a reduction of the optical β-functions at the IPs. The LHC triplet assembly consists in fact of four quadrupole magnets but the central two quadrupole magnets form one functional entity. The LHC has triplet assemblies in IR1, IR2, IR5, and IR8.
Tune	Number of particle trajectory oscillations during one revolution in the storage ring (transverse and longitudinal).
Ultimate bunch intensity	Bunch intensity corresponding to the expected maximum acceptable beam–beam tune shift with two operating experimental insertions. Assuming the nominal emittance (normalized emittance of 3.75 µm) the ultimate bunch intensity corresponds to 1.7×10^{11} protons per bunch.
Ultimate powering	Hardware powering required to reach the ultimate beam energy of 7.54 TeV, corresponding to a dipole field of 9 T.
Upstream and downstream	Always related to the direction of one of the two beams. If no beam is specified then Beam 1 is taken as the default. This implies that stating a position as being 'upstream' without indicating any beam is equivalent to stating that the position is to the left.