Work package number	2	**Start date or starting event:**				M1
Work package title	Accelerator Physics					
Activity Type[1]	RTD					
Participant number	1					
Participant short name	CERN	UNILIV	FNAL	UNIMAN	INFN-Frascati	CEA
Person-months per participant:	240	56	67.2	56.4	60	
Participant number						
Participant short name	BNL	KEK	EPFL	STFC	DESY	LBNL
Person-months per participant:	9.6	19.2	48	30	24	48
Participant number						
Participant short name	SLAC	IFIC-CSIC	BINP			
Person-months per participant:	14.4	24	38.4			

Objectives

Task 2.1. Coordination and Communication

- To coordinate and schedule work package tasks
- To monitor work progress and inform the project management and work package participants
- To follow up the WP budget and use of resources
- To prepare internal and deliverable reports

Task 2.2. Optics and Layout Studies

- *To identify layout options for the Interaction Region (IR) upgrades.*
- *To identify optics solutions for the LHC upgrade.*

Task 2.3. Particle Simulation Studies

- *To study the field quality tolerances for new magnetic elements for the LHC upgrade.*
- *To evaluate the dynamic aperture and tolerances of the correction circuit settings.*

Task 2.4. Collective Effects Studies

- *To evaluate intensity limitations due to the machine impedance and to specify limits for the maximum acceptable impedance of new components in the LHC upgrade.*

Task 2.5. Beam-Beam Studies

- *To evaluate beam-beam effects for the LHC upgrade and to identify intensity limitations and minimum requirements for the beam separations in the IRs for the LHC upgrade.*

[1] Please indicate one activity per work package:
RTD = Research and technological development; DEM = Demonstration; MGT = Management of the consortium; OTHER = Other specific activities, if applicable (including any activities to prepare for the dissemination and/or exploitation of project results, and coordination activities).

- *To study the limitations imposed by beam-beam interactions.*

Task 2.6. Beam Parameter and Luminosity Optimization

- *To follow the LHC commissioning efforts and to feed the gained experience into the LHC upgrades studies.*
- *To determine optimum sets of beam parameters based on the outcome of Tasks 2.2, 2.3. 2.4 and the operational experience of the LHC.*

Description of work

Task 2.1. Coordination and Communication [CERN;UNILIV].

The activities of this task are for the work package leaders [CERN, UNILIV] to oversee and co-ordinate the work of all other work package tasks, to ensure the consistency of the work according to the project plan and to coordinate the WP technical and scientific tasks with tasks carried out by the other work packages when relevant. The coordination duties also include the organization of WP internal steering meetings, the setting up of proper reviewing, the reporting to the project management and the distribution of the information within the WP as well as to the other work packages running in parallel.

The task also covers the organization of and support to the annual meetings dedicated to the WP activity review and possible activity workshops or specialized working sessions, implying the attendance of invited participants from inside and outside the consortium.

Task 2.2. Optics and Layout Studies *[CERN; UNILIV; INFN Frascati; EPFL; BINP; UNIMAN; CSIC-IFIC]*

The goal of this task is to prepare reference lattice and optics files for various configurations that can be used for further beam dynamic studies (e.g. particle loss and heat deposition studies in the IRs and preparation of new configurations for the LHC cleaning insertions), to explore the performance limitations in terms of the optics design (e.g. chromatic aberrations, number of long-range beam-beam encounters, required minimum collimator apertures) and to generate critical magnet parameters (magnet length, gradient, and aperture) for the various scenarios for all linear magnet systems including the orbit correctors for generating the crossing angle generation and the skew quadrupole correction system. The generation of optics files implies the preparation of complete injection and collision optics files that feature continues transitions of the magnet gradients (squeeze). The optics studies should also provide estimates for the maximum acceptable linear optic errors, specify alignment and orbit tolerances for the machine and discuss correction strategies for these effects during operation for each of the following sub-tasks.

Studies of other task such as Task 2.3 ‘Single particle tracking studies’ and studies in other Work Packages of the HL-LHC upgrade project, such as WP3 ‘Collimation and cleaning efficiency studies’ and WP6 ‘Studies for failure modes and potential equipment damage’ require optics and lattice files for the full LHC machine. The work of Task 2.2. consist in the generation of all required lattice and optics files for the different configurations under consideration for the HL-LHC upgrade project. All files will be made available to all partner laboratories and collaborators in a central project database. Task 2.2. therefore *provides direct input into WP1 of the HL-LHC project.*

Sub-task 2.2.1: IR4 optics design:

- IR4 optics design with room for a global Crab cavity installations
- Generation of lattice and optics files for the full LHC machine using the new IR4 solution and the nominal configurations in the remaining insertions.

Sub-task 2.2.2: Study options for correcting chromatic aberrations:
Study potential remedies to correct chromatic aberrations from the optics focal system near the experiments (e.g. additional correction circuits in the matching and dispersion suppressor sections; local correction schemes with sextupole magnets in the matching section, an optimization of the triplet layout for minimizing chromatic aberrations rather than minimizing the maximum beta-function and the number of long-range beam-beam encounters and a comparison of the performance of a symmetric versus an asymmetric optics design).

Sub-task 2.2.3: Generate optics and lattice files for a single bore NbTi magnet solution with β^* < 0.5m:
Optics and Layout Design for a NbTi solution with $\beta^* < 0.5$m and optics design for round and flat beams featuring single bore triplet magnets and lattice and optics files for the full LHC machine. The flat beam option should include estimates of the maximum acceptable coupling and strategies for its correction. This task builds to a large extend on the exiting Phase 1 upgrade study.

Sub-task 2.2.4: Generate optics and lattice files for a single bore NbTi magnet solution with β^* < 0.5m and local Crab Cavities:
Optics and Layout Design for a NbTi solution with local crab cavities, $\beta^* < 0.5$m and optics design for round and flat beams featuring single bore triplet magnets and lattice and optics files for the full LHC machine. The flat beam option should include estimates of the maximum acceptable coupling and strategies for its correction. This task builds to a large extend on the exiting Phase 1 upgrade study.

Sub-task 2.2.5: Generate optics and lattice files for a 2-in-1 NbTi magnet solution with β^* < 0.5m:
Optics and Layout Design for a NbTi solution with $\beta^* < 0.5$m and optics design for round and flat beams featuring 2-in-1 triplet magnets and lattice and optics files for the full LHC machine. The flat beam option should include estimates of the maximum acceptable coupling and strategies for its correction. This task builds to a large extend on the exiting Phase 1 upgrade study.

Sub-task 2.2.6: Generate optics and lattice files for a single bore Nb3Sn magnet solution with β^* < 0.5m:
Optics and Layout Design for a Nb3Sn solution with $\beta^* < 0.5$m and optics design for round and flat beams featuring single bore triplet magnets and lattice and optics files for the full LHC machine. The flat beam option should include estimates of the maximum

acceptable coupling and strategies for its correction.

Sub-task 2.2.7: Generate optics and lattice files for a single bore Nb3Sn magnet solution with β^* < 0.5m and local Crab Cavities:
Optics and Layout Design for a Nb3Sn solution with local crab cavities, $\beta^* < 0.5$m and optics design for round and flat beams featuring single bore triplet magnets and lattice and optics files for the full LHC machine. The flat beam option should include estimates of the maximum acceptable coupling and strategies for its correction.

Sub-task 2.2.8: Generate optics and lattice files for a 2-in-1 Nb3Sn magnet solution with β^* < 0.5m:
Optics and Layout Design for a Nb3Sn solution with $\beta^* < 0.5$m and optics design for round and flat beams featuring 2-in-1 triplet magnets and lattice and optics files for the full LHC machine. The flat beam option should include estimates of the maximum acceptable coupling and strategies for its correction

Task 2.3 Particle Simulation Studies *[CERN; UNILIV;FNAL;INFN-Frascati; BNL; SLAC; KEK; STFC; BINP; CSIC-IFIC; Uniman]*
This task aims at studying the dependence of the Dynamic Aperture of the machine on the field quality of the magnetic focusing system and the separation-recombination dipole magnets next to the experiments for a selection of optics configuration from Task 1.

Studies of other Work Packages of the HL-LHC upgrade project, such as WP3 'Magnet design', WP5 'Collimation and cleaning efficiency studies' and WP6 'Studies for failure modes and potential equipment damage' require detailed information on the likely working configuration of the LHC. The work of Task 2.3. consist in the generation of magnet field quality specifications, specification of required correction circuits and proposals for potential working points for operation. All information will be made available to all partner laboratories and collaborators in a central project database. Task 2.2. therefore provides direct input into all work packages of the HL-LHC project.

Sub-task 2.3.1: Monte Carlo tracking studies:
Perform single particle Monte Carlo (different realizations for machine imperfections) tracking studies for selected configurations of Task 2.2 with the aim of defining the required field quality of the magnets and designing magnetic correction systems.

Sub-task 2.3.2: Preparation of simulation tools:
Prepare simulation tools for studying the effect of beam-beam interactions and non-linear fields on the single particle dynamics for operation with large crossing angles, flat beams and variation of the longitudinal bunch orientation along the machine with Crab cavities. The currently used programs for particle simulation studies such as MADX and Sixtrack do not yet offer all required tools and modules for the study of beam-beam interactions with large crossing angles, hour-glass effect and Crab cavity implementations.

Sub-task 2.3.3: Specification of required correction circuits:

Specify the required non-linear correction systems for the new insertions.

Sub-task 2.3.4: Study of optimum working points (tunes) for the upgrade:
• Evaluation of synchro-betatron resonances.
• Perform single particle tracking with the aim of identifying the optimum working point (tune values) for the two LHC beams..

Sub-task 2.3.5: Radiation and heat deposition studies:
• Quantify the expected radiation and heat deposition values for selected elements (e.g. triplet magnets, TAS and TAN, magnets in the collimation regions etc).

Task 2.4 Collective Effects Studies *[CERN; UNIMAN;INFN-Frascati; STFC; DESY; SLAC, BINP]*
This task will look after performance limitations arising from the interaction of the beam with itself and it's surrounding. The goal of this task is to define key parameters such as maximum acceptable impedance values and to identify optimum beam configurations (e.g. required chromaticity control and landau damping octupole settings) for the different scenarios of Task 2.2.

This task will provide critical input for estimates the potential performance reach of the upgraded LHC and therefore feed directly into WP1 and other tasks of WP2 of the LH-LHC project.

Sub-task 2.4.1:
• Impedance estimates and Wake field calculations for new components of the upgrade options.

Sub-task 2.4.2:
• Estimates for the required corrector circuit settings (chromaticity and Landau damping octupoles)

Sub-task 2.4.3:
• Provide estimates for the Intra Beam Scattering (IBS) growth rates for different beam parameters.

Task 2.5 Beam-Beam Studies *[CERN; FNAL; INFN-Frascati; BNL; UNIMAN;BNL; EPFL; STFC; LBNL; EPFL; BINP; KEK]*
This task will look after performance limitations arising from the interaction of the beam with the second proton beam. The goal of this task is to define key parameters such as minimum required beam separation and maximum acceptable beam brightness values and to identify optimum beam configurations (e.g. flat beam versus round beam IR design) for the different scenarios of Task 2.2.

This task will provide critical input for estimates the potential performance reach of the upgraded LHC and therefore feed directly into WP1 and other tasks of WP2 of the LH-LHC *project.*

Sub-task 2.5.1:
• Calculation of bunch-by-bunch orbit variations due to self-consistent treatment of the beam-beam interactions.

Sub-task 2.5.2:
• Study of compensation schemes for the long-range beam-beam interactions (e.g. DC and pulsed wire installations).

Sub-task 2.5.3:
• Study of compensation schemes for the head-on beam-beam interactions (correction of the linear and non-linear effect) (e.g. electron lens installation).

Sub-task 2.5.4:
• study of crab cavity beam-beam compensation scheme.

Task 2.6 Beam Parameter and Luminosity Optimization *[CERN; FNAL; LBNL]*
This task will evaluate the experience from the first years of LHC operation and determine the optimum choice for the beam parameters (e.g. minimum achievable emittances, optimum bunch length and minimum acceptable bunch spacing).
This task will provide optimized beam parameters and optics configurations for various scenarios of Task 2.1 based on the operational experience from the first years of LHC operation. It feeds directly into WP1, WP5, WP6 and other tasks of WP2 of the LH-LHC project.

Sub-task 2.6.1:
• Evaluate the geometric luminosity reduction factor for various configurations of Task 2.2 and look into options for luminosity leveling (e.g. via Crab cavities or crossing angle variations).

Sub-task 2.6.2:
• Evaluate options for optimizing the luminosity production by variation of beam parameters during a fill (e.g. tune, beam separation, emittance [radiation damping] etc.).

Sub-task 2.6.3:
• Determine optimum beam parameter values (e.g. initial emittance, beam brightness, bunch length and bunch separation) for different scenarios of Task 2.2.

Deliverables

D2.1) P*OLF*: Preliminary Optics and Layout Files:
Optics (injection, collision and squeeze transition with crossing angle configurations) and lattice files in MADX format with specification of the required magnet parameters (strength and aperture) for each sub-task. (Task 2.2) *[M12]*

D2.2) IST: Implementation of simulation tools:
Preparation of simulation tools for numerical simulations. (Task 2.3.2) *[M12]*

D2.3) F*OLF*: Final Optics and Layout Files:
Optics (injection, collision and squeeze transition with crossing angle configurations) and lattice files in MADX format with specification of the required magnet parameters (strength and aperture) for each sub-task. (Task 2.2) *[M24]*

D2.4) P*MFQ*: Preliminary Magnet Field Quality specification:
Optics (injection, collision and squeeze transition with crossing angle configurations) and lattice files in MADX format with specification of the required magnet parameters (strength and aperture) for each sub-task. (Task 2.2) *[M24]*

D2.5) *CMS: Corrector Magnet specifications:*
Specification of required magnetic correction circuits for selected configurations of Task 2.2. (Task 2.3.3) *[M36]*

D2.6) *TZB: Total Impedance Budget estimate:*
Estimate of the total Impedance of the modified LHC machine. (Task 2.4.1) *[M36]*

D2.7) BIL: *Beam Intensity Limitations:*
Estimate of intensity thresholds for beam instabilities. (Task 2.4.2) *[M36]*

D2.7) *BPT: Beam Parameter Variations:*
Estimate of beam parameter variations (e.g. tune and orbit) due to collective effects (e.g. self consistent orbit variations from bunch to bunch), with and without compensation schemes in place. (Task 2.4.3) *[M36]*

D2.8) *MWP: Machine Working Point proposal:*
Proposal for potential machine working points for selected configurations of Task 2.2. (Task 2.3.4) *[M48]*

D2.9) *BPS: Beam Parameter Set for maximum performance reach:*
Optimized Parameter sets for selected configurations of Task 2.1. (Task 2.5.1) *[M48]*

Milestones

Milestone name	Work package(s) involved	Expected date [2]	Means of verification[3]
POL: Distribution of Preliminary Optics and Lattice files to all work packages	2 (Task 2.2)	M12	Publication on web
FOL: Distribution of Final Optics and Lattice files to all work packages	2 (Task 2.2)	M24	Publication on web
MFQ: First Version of Magnet Field Quality specifications for selected configurations	2 (Task 2.3)	M24	Publication in form of Project report
MCS: Specification of required magnet correction circuits	2 (Task 2.3)	M36	Publication in form of Project report
WPS: Working Point specification for selected configurations of Task 2.2.	2 (Task 2.3)	M48	Publication on web
ZWU: Impedance and Wakefield Estimates and instability threshold predictions.	2 (Task 2.4)	M36	Publication in form of Project report
BPV: Beam Parameter Variations due to collective effects.	2 (Task 2.4)	M36	Publication in form of Project report
PBP: Provisional estimates for Beam Parameter configurations for selected scenarios of Task 2.1.	2 (Task 2.5)	M36	Publication on web
FBP: Final Beam Parameter configurations for selected scenarios of Task 2.1.	2 (Task 2.5)	M48	Publication in form of Project report

[2] Measured in months from the project start date (month 1).

[3] Show how you will confirm that the milestone has been attained. Refer to indicators if appropriate. For example: a laboratory prototype completed and running flawlessly; software released and validated by a user group; field survey complete and data quality validated.