ISBN: 978-3-95450-252-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IPAC2026-MOP1091

CHALLENGES OF LONG SHUTDOWN 3 FOR THE LHC: FROM PREPARATION TO EXECUTION

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Abstract

The Long Shutdown 3 (LS3) of the Large Hadron Collider (LHC) represents a pivotal phase in the lifecycle of CERN's accelerator complex. The unprecedented complexity of LS3 arises from the challenge of integrating the High-Luminosity LHC (HL-LHC) upgrade, together with multiple key projects, extensive maintenance and consolidation activities, into a single coherent schedule with a fixed duration of 47 months. Achieving this goal requires precise orchestration of interventions and effective management of resources shared across different facilities. This paper first outlines the LS3 preparation framework for the LHC, with an emphasis on the adopted methodology to accomplish the LS3 objectives and the preparation of the LHC schedule. It also investigates the main challenges associated with LS3 execution and presents the strategies and tools used to address them. A unifying environment for monitoring and reporting is introduced, a platform that integrates interactive dashboards designed to streamline the progress visualisation and ensure a reliable reporting throughout the LS3 period.

INTRODUCTION

Between 2026 and 2030, the CERN accelerator complex will undergo its third long shutdown, LS3 [1], following LS1 (2013–2015) [2] and LS2 (2018–2021) [3].

The goal of LS3 is to ensure a reliable long-term operation and an increased luminosity target for the next physics run (Run4), while fulfilling safety and regulatory requirements. These objectives are addressed through a comprehensive programme of extended maintenance, consolidation activities, and upgrades across the accelerator chain.

A key element of the LS3 in the LHC is the implementation of the High-Luminosity LHC, which aims to increase the integrated luminosity delivered over the lifetime of the accelerator by approximately one order of magnitude [4]. The HL-LHC project consists in replacing full portions of the machine (1.2 km of the 26.7 km ring) and related infrastructures with entirely new equipment, primarily in the long straight sections around two of the four main experiments, ATLAS and CMS [4], resulting in the most extensive upgrade of the LHC since its construction. The detectors of these two experiments will be also upgraded during LS3 to fully exploit the significantly increased number of collisions [5, 6].

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CHALLENGES FACED IN LS3 PREPARATION

The main challenge in the preparation of LS3 within the LHC is to ensure that the HL-LHC installation scope, accounting for ~50% of the total LS3 activities duration, fit within the fixed 47-month shutdown period defined by the CERN long-term schedule [1], thereby defining the critical path of LS3.

In addition, resource and personnel limitations play a critical role. As CERN service groups work per technical domain and not per facility (e.g., electrical engineering), resources allocated to activities in the LHC are also shared across the wider CERN accelerator complex. This means that delays affecting other machines can propagate to the overall LHC schedule, and viceversa, generating domino effects that must be anticipated in the preparation phase, when possible.

Preparation and execution are conditioned by the interdependence between the LHC and adjacent facilities, including accelerators, experimental areas, and LHC experiments. Transport spans multiple infrastructures, requiring detailed scheduling to coordinate interface openings, access conditions, and operational sequencing to minimise bottlenecks.

LS3 Preparation Framework

The preparation of LS3 is orchestrated by the Accelerator Coordination and Engineering group (EN-ACE) and pivots around a well-established methodology developed by the group successfully validated during LS1 and LS2 [7–9]. This methodology consists of combining expertise in safety, integration, configuration and layout, site coordination and scheduling to prepare and coordinate programmed stops of the CERN accelerator complex [7–9]. This is complemented by Electrical Safety and Lock-out (ESL), and Support, Strategy and Projects (SSP), tackling the criticality of electrical safety and tools management during LS3.

A significant part in LS3 preparation is the role of the HL-LHC project. Its installation planning was initiated well in advance of the LS3 preparation (started in 2021), driving the overall shutdown duration and the boundary conditions for the other activities. Its broad scope also required the involvement of a vast number of CERN groups. This setting differs from LS2, whose time interval was driven by consolidation needs coming from the injectors chain: on the LHC side indeed, the main project Diode Insulation and Superconducting Magnets Consolidation (DISMAC), was initiated

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after the LS2 preparation started, and executed by a subset of CERN groups within a period (2019–2020) that had margin with respect to the shutdown duration [3]. HL-LHC acted as technical coordination point for the project-involved groups, structuring the installation sequence supported by EN-ACE, that integrated and consolidated it with the associated constraints and logistics in the global LS3 schedule.

LHC Schedule Optimisation Strategies

An overview of the LS3 schedule for the LHC was first provided in 2024 [10], and the baseline 1.0 will be released in June 2026. Several schedule assumptions define the framework under which activities can be scheduled and, where possible, parallelised after a dedicated risk assessment, involving temporary access configurations, safety systems, and worksite interfaces. For example, a set of activities in the critical path are authorised to occur during the warm-up from 80K to 300K, when normally access is not granted due to a significant risk of helium spill.

In 2024, the overall duration of LS3 was estimated at 51.5 months [11], and substantial optimisations involving the critical path were vital to fit within the total duration of 47 months. First, the duration of selected critical activities was reduced by refining their level of detail. In addition, part of the HL-LHC cabling campaign on the LS3 critical path was anticipated during physics operation between the Year-End Technical Stop (YETS) 2025–26 and LS3. This was made possible by modifications to the LHC access configuration implemented during YETS, where preparatory activities for LS3 were also carried out.

In particular, an initial segment was installed in the HL-LHC galleries (new infrastructures built to accommodate the HL-LHC services [12]), whereas the remaining segment will be deployed in the LHC tunnel during LS3, including its connection to the pre-installed cables via patch panels. Besides the critical path analysis, a systematic assessment of the near-critical path was conducted, whose activities may become critical under deviations from the baseline. As with the primary critical path, they are distributed across the two main HL-LHC locations, and will require groups to adjust planning and reallocate resources in response to evolving schedule conditions. The critical path has no schedule contingency, whereas the near-critical path presents a limited margin of approximately two weeks. Outside these paths, there exists contingency evaluated from the end of magnet training to the start of machine check-out (i.e. final checks before beam operation). In particular, more than six months of contingency is available in at least four of the eight LHC sectors.

The issue of resource availability is initially assessed through PLAN, a centralised strategic tool providing a shutdown-wide view of activities across the CERN accelerator complex [13]. Its macroscopic level of granularity enables a preliminary assessment with the identification of workload peaks across years. The refinement of resource allocation relies instead on the detailed planning at facility level. This approach was essential, for instance, to resolve peaks in cabling demand arising from concurrent activities across the LHC and injectors. This optimisation was particularly critical given the scale of cabling activities (~1100 km of cables to be pulled in the LHC in multiple shifts [14]), which must occur prior to the installation of many pieces of equipment. The LS3 schedule has been further optimised by accounting for dose rate, which acts as a constraint on resource availability. While some activities have been shifted to periods characterised by lower radiological levels, other interventions that could not be postponed required the early removal of the most activated components from the tunnel to reduce the exposure of the personnel to radiation.

Logistics is a primary driver of the LS3 planning, as dismantling and installation activities, notably for HL-LHC, are governed by transport and storage capacity, resource availability, and involve inter-facility flows. Planning granularity was therefore refined to individual days and synchronised across adjacent infrastructures, with bulky transport preferentially scheduled during night shifts to limit interference with daytime works.

CHALLENGES ENVISAGED IN LS3 EXECUTION

The execution of LS3 within the LHC is characterised by a set of challenges that span from safety and coordination, to scheduling risks and uncertainties. From a safety perspective, co-activities require to carefully manage the hazards, particularly when cryogenic, electrical and radiological risks are present in the LHC, notably at the beginning and at the end of the shutdown (e.g. during warm-up/cool-down, individual system tests and machine recommissioning). In addition, the underground activities are limited by a maximum occupancy, defined by the safety department for each subsector of the LHC.

In parallel, HL-LHC activities must be coordinated with concurrent interventions in the LHC tunnel, including other major projects, regulatory and safety tests affecting project execution, maintenance of non-replaced systems, and activities requiring access to the same work areas.

Finally, schedule risks and uncertainties arise from the dependency of installation slots on equipment readiness (~330 major pieces of equipment to be installed), the lack of consolidated installation methodologies for new systems, and the possibility of non-conformities, which will need to be tackled as soon as they arise.

LS3 Execution and Follow-Up Framework

During LS3 execution, LHC general coordination is guaranteed by the Organisation and Scheduling LHC (OSL) team and the other areas of expertise within EN-ACE, with the primary goal of ensuring an effective co-activity management respecting the safety requirements. To reinforce safety and mitigate risks during critical phases the electrical safety management is centralised within the ESL team, which plays a key role in supporting CERN groups particularly at the beginning and at the end of LS3, managing lockout/unlockout requests and test permits. Responsibilities within the LHC

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general coordination are geographically distributed by areas, following the same approach adopted since LS1 [7]. Each coordinator is also designated as the reference contact for a subset of CERN groups and for the other large projects, such as Beam Screen Treatment [15] and the PSS-CONS programme [11]. EN-ACE retains full authority as the general coordination body, preserving a single point of overall oversight and final approval as occurred during LS2 [3, 8]. In parallel, HL-LHC project introduces also in execution an additional transversal layer in the form of technical coordination, through which it validates its own activities and ensures the consistency with project objectives at a finer level of granularity, while guaranteeing a strong on-site presence.

The LS3 progress follow-up is structured around a two-step approach [16]. The first step consists of regular information exchange between EN-ACE, the CERN groups, HL-LHC and the other main projects, enabling rapid re-profiling of activities in response to baseline deviations and limiting cascading resource impacts across facilities. This is supported by dedicated meetings handled by EN-ACE (LHC coordination meetings, ad-hoc and on-site meetings, weekly follow-up meetings with the main projects) ensuring alignment on overall execution progress and cross-facility implications, complemented by HL-LHC follow-up meetings, where the project progress is assessed at a higher level of technical detail. The second step establishes clear reporting lines towards the LS3 committee, project leaders, and department heads, supporting informed decision-making at higher organisational levels.

LS3 Reporting Dashboards

During LS2, progress monitoring relied on dashboards based on group- and project-level schedules and Key Performance Indicators (KPIs), periodically reported to the LS2 committee. Although central schedules from the general coordination were available, dashboards were partially aligned with them, as they were developed from group- and project-owned data sources not anchored to the global planning. For LS3, this limitation is addressed by reinforcing the link between dashboards and the EN-ACE central schedules, established as the single source of truth. This is achieved through their integration within a unified platform managed at LS3 committee level, thereby preventing data fragmentation and ensuring reliable reporting.

The monitoring platform is implemented in Microsoft Power BI [17], enabling data aggregation and online dissemination. It is structured around the EN-ACE central schedules, while allowing the integration of complementary inputs from the groups. The platform offers a facility-based view with a variety of filtering options. Progress curves are the primary monitoring feature and show direct comparison between actual progress and the baseline. Additional and more detailed KPIs, e.g. the number of vacuum sectors opened or kilometres of cabling pulled, also provide useful insights to coordination and the groups. This framework supports a data-driven decision-making and fosters a greater collective awareness of the progress throughout the LS3 period. For the LHC, the focus will be put on key aspects such as equipment readiness and installation (Fig. 1), and critical path, enabling the visualisation of progress against the baseline, and allowing delays and bottlenecks to be promptly identified. Another key dashboard is the estimation of LHC underground occupancy (Fig. 2), counting the number of personnel assigned to tasks and visualising these resources across time and space. This allows for the identification of potential over-occupancies and subsequent actions to avoid reaching maximum tunnel capacity. They include adjusting personnel usage for relevant tasks or reallocating the task in the planning.

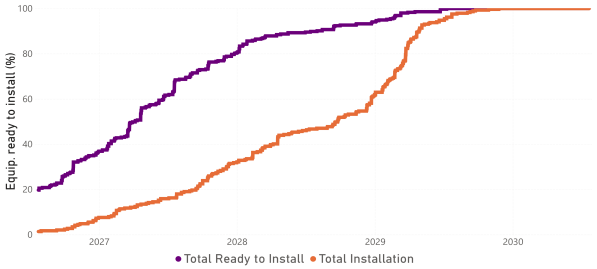


Figure 1: LS3 LHC equipment readiness and installation progress curves.

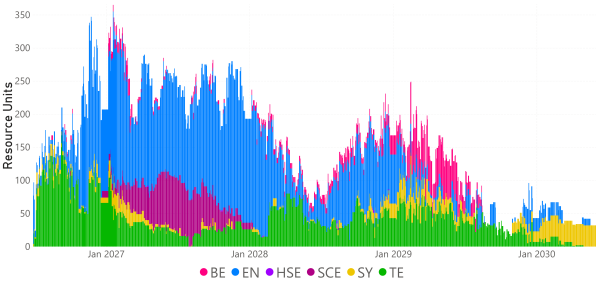


Figure 2: LS3 LHC resource units vs. time.

CONCLUSION

The methodology developed by EN-ACE with its evolutions has demonstrated its robustness in addressing the preparation of LS3, successfully integrating a major project such as the HL-LHC upgrade within a coherent and unified 47-month schedule that includes other projects, maintenance, and consolidation activities. The conditions exist to establish a consolidated and optimised LS3 LHC schedule baseline, with risks and uncertainties identified and assessed. Contingencies have been incorporated wherever feasible, and the teams must be able to react in case of planning deviations and shifts of the critical path. At the same time, a comprehensive execution and follow-up framework has been jointly developed, ensuring an iterative and structured alignment between EN-ACE, HL-LHC, projects and groups, as well as management throughout LS3. Finally, the implementation of a unified environment for LS3 progress monitoring provides a concrete response to data fragmentation and reporting reliability. It enhances global awareness of the LS3 execution status, supports informed decision-making in the presence of issues, and facilitates the identification of optimisation opportunities across the shutdown.

ISBN: 978-3-95450-252-3 ISSN: 2673-5350 doi: 10.18429/JACoW-IPAC2026-MOP1091

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