EDMS NO.	REV.	VALIDITY
1568848	**1.0**	**VALID**

NOTE

HL-LHC CHALLENGES AND IMPACT IN A NUTSHELL

Abstract

The Large Hadron Collider (LHC) at CERN is the highest-energy collider in the world, dedicated to the study of particle physics. It has run successfully over the last few years, including the breakthrough discovery of the Higgs boson by the experiments ATLAS and CMS, which validates the Brout-Englert-Higgs (BEH) mechanism and marks the culmination of decades of effort by many people around the world.

The High Luminosity LHC (HL-LHC) is an upgrade of the LHC to achieve higher luminosity, which is planned over the next decade to increase the data sample for ATLAS and CMS by an order of magnitude. The full exploitation of the LHC, including the HL-LHC, was identified as the highest priority for European particle physics, in the update of the European Strategy for Particle Physics of 2013. For the physics programme to profit from this upgrade of the accelerator, the experiments will require upgrades to their detectors, such as the replacement of precision vertex detectors that will have reached the end of their useful lives, and the computing infrastructure will require to be upgraded to handle the increased data rates.

This document enumerates the physics goals, the technological, human and industrial challenges and the potential impact on the project on the society

This document is based on the proposal for inclusion of the HL-LHC upgrade in the ESFRI Roadmap CERN/3168/RA

TRACEABILITY

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Verified by: HL-LHC Project office	***Date:*** 2015-12-15
Approved by: L. Rossi	***Date:*** 2015-12-15
Distribution: Public	

Rev. No.	***Date***	***Description of Changes*** *(major changes only, minor changes in EDMS)*

1 INTRODUCTION

The Large Hadron Collider (LHC) at CERN is the highest-energy collider in the world, dedicated to the study of particle physics. It has run successfully over the last few years, including the breakthrough discovery of the Higgs boson by the experiments ATLAS and CMS, which validates the Brout-Englert-Higgs (BEH) mechanism and marks the culmination of decades of effort by many people around the world. The High Luminosity LHC (HL-LHC) is an upgrade of the LHC to achieve higher luminosity, which is planned over the next decade to increase the data sample for ATLAS and CMS by an order of magnitude. The full exploitation of the LHC, including the HL-LHC, was identified as the highest priority for European particle physics, in the update of the European Strategy for Particle Physics of 2013. For the physics programme to profit from this upgrade of the accelerator, the experiments will require upgrades to their detectors, such as the replacement of precision vertex detectors that will have reached the end of their useful lives, and the computing infrastructure will require to be upgraded to handle the increased data rates.

The funding commitment is:

- **Accelerator** – 830 MCHF from CERN budget (as agreed in Medium-Term Plan) and 200 MCHF from Japan and US in-kind contributions;
- **Experiments** – around 800 MCHF from Funding Agencies of collaborating institutes, of which CERN contributes 20%;
- **Computing** - 100 MCHF/year from the collaborating members of the World-wide LHC Computing Grid (WLCG).

2 GOALS AND CHALLENGES

2.1 Main physics goals

- Push further the validation of the Standard Model at the energy frontier, in particular by measuring the properties of the newly-discovered Higgs particle and of the longitudinal components of the massive vector bosons with the highest possible precision, and with the aim of establishing whether there are any deviations from the Standard Model predictions;
- Check whether the Higgs particle is accompanied by other new particles at the TeV scale, which could play a role in the global picture of electroweak symmetry-breaking or in the solution of the dark matter puzzle. As reflected in three of the four high-priority activities, both hadron and lepton colliders at the high-energy frontier can play essential and complementary roles in this quest.
- Provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

The LHC will push the limits of human knowledge

2.2 Technological challenges

- The HL-LHC accelerator depends on a number of innovative technologies, including high-field superconducting magnets, compact and ultraprecise superconducting radio-frequency cavities, high-power superconducting links, as well as vacuum, cryogenics, diagnostics and modelling.
- The success of particle physics experiments for the HL---LHC relies on innovative instrumentation, state-of-the-art infrastructures and large-scale data-intensive computing. Detector R&D programmes are supported strongly at CERN, national institutes, laboratories and universities. Infrastructure and engineering capabilities for the R&D programme and construction of large detectors, as well as infrastructures for data analysis, data preservation and distributed data-intensive computing will be maintained and further developed.
- Regarding computing, the expected increases in trigger rate, pile-up and detector complexity (number of channels) could increase the data rates by about a factor of 10 or more. This order of magnitude increase in storage and CPU requirements presents a new challenge for the computing infrastructure and the community will need time to prepare for it. The LHC community is beginning

to review their computing models as they make plans for the next decade. It is anticipated that the general design will be an evolution from the current models with the computing resources distributed at computing centres around the world.

The HL-LHC will bring innovation to solve technological challenges

2.3 Human challenges

In 13 January 2015, the number of CERN Users (visiting scientists) exceeded 11 500, the significant majority of whom work on the LHC, and is expected to be similar for the HL-LHC.

The potential user community has been involved in the following areas of support and development of the projects:

- In the definition of the science case
- In the definition of the technical design specifications.
- In analysing costs versus benefits.
- In planning and financing parts of the infrastructure.

Full access to the HL-LHC will be open to participating national institutes, laboratories and universities.

The HL-LHC and particle physics research requires a wide range of skills and knowledge. Many young physicists, engineers and teachers are trained at CERN, in national laboratories and universities. They subsequently transfer their expertise to society and industry. Education and training in key technologies are also crucial for the needs of the field. CERN, together with national funding agencies, institutes, laboratories and universities, will continue supporting and further developing coordinated programmes for education and training.

The HL-LHC is a global human effort

The HL-LHC offers training opportunities on a global scale

2.4 Industrial challenges

The HL-LHC and its surrounding facilities will require a constant stream of supplies and services. These include civil engineering work and the systems and equipment needed to build and operate the particle accelerator, detectors and computing: power distribution, superconducting magnets, cryogenics, ultra-high vacuum, electronics, mechanical engineering, radiofrequency equipment and more. The HL-LHC will also require computing infrastructure to support the data analysis associated with the experiments. The HL-LHC will collaborate with many types of industries and businesses to pursue its goals.

The HL-LHC fostering R&D collaborations and pushing knowledge exchange between research institutes and companies

3 IMPACT

Knowledge and technology developed for particle physics research have made a lasting impact on society. These technologies are also being advanced by others, thus leading to mutual benefits. Knowledge and technology transfer is strongly promoted in most countries. Detailed studies have been made supporting the view of the high impact of particle physics, including studies by the OECD (http://www.oecd.org/sti/sci-tech/CERN-case-studies.pdf), by the Institute of Physics in the UK (http://www.stfc.ac.uk/resources/pdf/lrimpact_report_2013.pdf) and by the European Physical Society (http://www.eps.org/resource/resmgr/policy/EPS_economyReport2013.pdf). The technology transfer and technological learning through CERN's procurement activity has been documented in a study carried out during the LHC construction phase during 1997-2001 (https://cds.cern.ch/record/680242/files/CERN-2003-005.pdf).

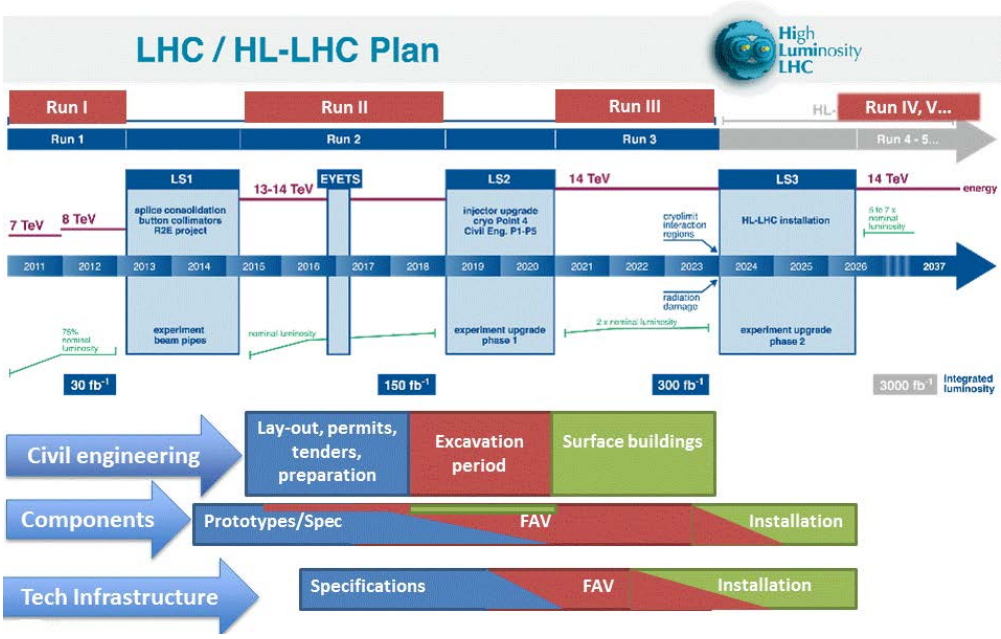
Particle physics research requires a wide range of skills and knowledge. Many young physicists, engineers and teachers are trained at CERN, in national laboratories and universities. They subsequently transfer their expertise to society and industry. Education and training in key technologies are also crucial for the needs of the field.

The HL-LHC will train the scientist and technologists of the future

The HL-LHC R&D will create new opportunities for the European Industry

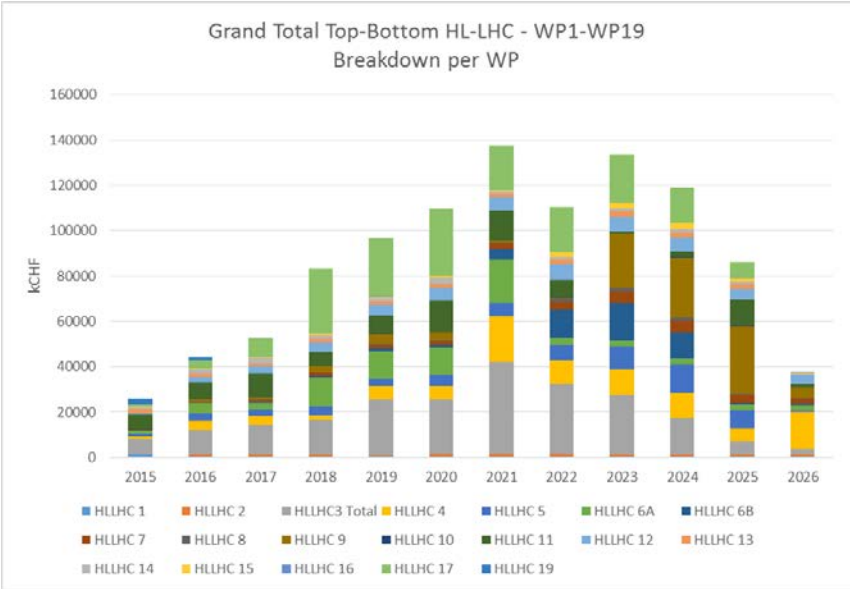
4 TIMESCALE FOR THE HL-LHC (ACCELERATOR)

Construction of the HL-LHC is planned to be completed in 2026 and will be followed by at least 10 years of physics exploitation. The HL-LHC construction and operation schedule is shown below.



5 BUDGET FOR THE HL-LHC (ACCELERATOR)

Components requiring the following technologies will be needed for the HL-LHC completion. The project is committed to source from CERN member and associate states and work together with industry to meet the present technological challenges



Cryogenics Systems	WP9
Magnets components and assemblies	WP3, WP11
Electrical equipment, Electronics and instrumentation for accelerators	WP4, WP5, WP6A, WP6B, WP7, WP13
Ultra vacuum components and systems	WP12
Collimators and new material resistants to high temperatures	WP5
Cryostats and subcomponents for cryogenic equipment	WP3, WP4, WP6A, WP9, WP11
High precission Assembling and manufacturing technologies	WP4, WP5, WP8, WP14
Others	WP6A, WP10, WP15, WP16
Raw Materials	WP3, WP4, WP5, WP8, WP11, WP12, WP14
Civil Engineering and Technical Infrastructures	WP17