Preface

The high-luminosity phase of the LHC (HL-LHC) will extend the LHC programme to the second half of the 2030's, with a major increase in the statistics relative to what has been collected so far. As approved, the HL-LHC project will deliver (a) pp collisions at 14 TeV with an integrated luminosity of 3 ab^{-1} each for ATLAS and CMS and 50 fb^{-1} for LHCb, and (b) PbPb and pPb collisions with integrated luminosities of 13 nb^{-1} and 50 nb^{-1}, respectively. With the newly proposed upgrades of the detector, the LHCb experiment could increase its target luminosity to 300 fb^{-1}, and an extension of the heavy ion programme could lead to 1.2 pb^{-1} of integrated luminosity for pPb collisions, with the addition of collisions of other nuclear species.

A large effort has taken place over the last few years, to define the detector upgrades required to sustain the HL-LHC event rates while maintaining, and often significantly improving, the detectors' physics performance. This work, accompanied by the experience gained with the data analyses so far, has made it possible to explore the HL-LHC physics potential in a realistic, concrete and reliable way. Building on this groundwork, and on the theoretical progress stimulated by the interpretation of the data from the first two runs of the LHC, the Workshop documented in this Yellow Report carried out an extensive review of the HL-LHC prospects. Five working groups covered a broad range of topics:

1. Standard Model measurements
2. Studies of the properties of the Higgs boson
3. Searches for phenomena beyond the Standard Model
4. Flavor physics of heavy quarks and leptons
5. Studies of QCD matter at high density and temperature.

This Report has a companion Volume, collecting the ATLAS and CMS notes that provide additional details on all reported analyses.

A rich picture has emerged, defining new ambitious targets for critical measurements ranging from the Higgs couplings and self-coupling, to the W mass, flavor properties, and more. New opportunities have been considered in the search of new physics, with emphasis on the class of models that lead to the most challenging and elusive signatures, and which could have evaded detection so far. The goals of precise Quark-Gluon Plasma studies and the new questions raised by current LHC data have led to the confirmation of the programme of runs with Pb nuclei and a proposal to collide lighter nuclei in Run 5.

The workshop has made it clear that physics at the HL-LHC will not be just a bare rerun of previous analysis strategies and techniques. The immense statistics will open the way to new ideas, stimulating creativity and original thinking, leading to better ways to control the experimental and theoretical systematics, and ultimately to improve the precision of the measurements and the sensitivity to new physics. It will be the task of the coming generations of young physicists to uncover and fully exploit the fantastic opportunities created by the HL-LHC!

The possibility of increasing the LHC energy to 27 TeV, by using the 16 T dipoles under development in the context of the Future Circular Collider project, expanded the scope of the Workshop. Each working group analyzed the reach of this possible future project (the high-energy LHC, HE-LHC), documenting its findings in parallel with the presentation of the HL-LHC results.

The HL-LHC projections presented in this Report set a new and very challenging reference benchmark to assess the added value, and required performance, of future colliders. This was stressed on several occasions

during the 2019 CERN Council Open Symposium on the update of the European Strategy for Particle Physics, in Granada. We therefore trust that these HL-LHC projections, together with the studies of the HE-LHC physics potential, will be useful to the ongoing strategy update process.

The Workshop engaged the LHC experimental and theoretical communities, through a year-long world-wide effort. We are deeply grateful to the working group conveners for successfully leading this big effort, and to all participants, for their commitment and substantial contributions. We also thank Angela Ricci, who provided administrative support and assistance.

The workshop steering committee has been constituted by:

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The working groups were convened by:

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WG4: Opportunities in flavour physics at the HL-LHC and HE-LHC
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WG5: Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams
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