Letter of Interest
The CMS Collaboration contribution to Snowmass 2021

CMS Collaboration

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The CMS Collaboration continues to work actively on developing the physics program for the High-Luminosity LHC (HL-LHC). The HL-LHC will extend the LHC program to the second half of the 2030s, with pp collisions at 14 TeV with an integrated luminosity of 3 ab^{-1} each for ATLAS and CMS experiments, and PbPb and pPb collisions with integrated luminosities of 13 nb^{-1} and 50 nb^{-1}, respectively. A factor of ten increase in the integrated luminosity compared to the initial LHC program, and new and improved detector components, open the door for refined studies of the properties of the Higgs boson, including its self-coupling, precision measurements of standard-model process, and further investigations of the flavour sector and the quark-gluon plasma. The success of the HL-LHC physics program strongly relies on the involvement of the US HEP community and can only be achieved by close cooperation with US Universities and laboratories. The CMS physics contributions to the Energy Frontier (EF) and to the Rare Processes and Precision Measurements (RF) groups of Snowmass 2021 will build on the studies that are summarized in the CERN Yellow Report on the Physics at the HL-LHC, and Perspectives for the HE-LHC [1], but many of the proposed contributions will be updated, and a few new studies will be added.

For the HL-LHC the CMS experiment is planning a significant modification of the detector, the so-called Phase-2 upgrade, that should allow for effective data taking and event reconstruction at increased luminosity and pileup (PU), with 200 additional interactions per bunch crossing. The triggering system will be replaced to be able to keep the trigger thresholds for objects similar to the current ones or even lower. The entire tracker system will be replaced. The geometrical coverage will provide efficient tracking up to pseudorapidities of about $|\eta| = 4$. The muon systems electronics will be upgraded, and new muon detectors will be installed to increase the geometrical coverage of the system up to about $|\eta| = 2.8$. The barrel electromagnetic and hadron calorimeters will be upgraded. The endcap electromagnetic and hadron calorimeters will be replaced with a new combined sampling calorimeter. The addition of a new timing detector for minimum ionizing particles in both barrel and endcap regions will provide the capability for 4-dimensional reconstruction of interaction vertices. A detailed overview of the CMS detector upgrade program is presented in Refs. [2–7], while the expected performance of the reconstruction algorithms and PU mitigation with the CMS detector is summarised in Ref. [8].

The HL-LHC program will extend the sensitivity of most physics analyses and considerable improvements are also expected for precision measurements. The HL-LHC program will also allow to extend the search for new physics to previously unexplored regions of masses, couplings, and phase space and to difficult signatures with large background. Thanks to the improvements of the upgraded trigger and timing system, the sensitivity for long-lived (LL) signatures will be greatly enhanced. One of the major goals of the program is the study of the properties of the Higgs boson, its mass and width, precision measurements of the Higgs boson couplings, double Higgs production and the Higgs trilinear coupling, study of Higgs production in the vector boson fusion (VBF) processes. Some results are also interpreted in the framework of the Standard Model (SM) Effective Field Theory (EFT). These analyses will contribute to the work of the first subgroup of the Energy Frontier group (**EF01**). The constraints on the rare decays of the Higgs boson, searches for charged and high/low mass Higgs boson, in particular in the framework of Higgs and Dark Matter (DM) models, constraints on light and non diagonal Higgs Yukawa couplings measurements will be presented in **EF02**.

Precision measurements of top quark properties present an important test of the SM. As the heaviest

particle in the SM, the top quark plays an important role in the electroweak symmetry breaking and is a sensitive probe for physics beyond the SM. The flavor physics program at the HL-LHC comprises many different probes with significant discovery potential. The heavy flavor and top quark-related topics will be presented in **EF03**. Rare decays of tau leptons will contribute to **RF05**. A few selected analyses can contribute to the future conventional and exotic Hadron Spectroscopy program in **RF07**.

The study of electroweak processes is a central topic of the SM tests. Given the small electroweak couplings, high luminosity provides a crucial handle for gaining precision in the measurements with relatively small cross sections like vector boson scattering (VBS) processes for multiboson production. Together with other SM-related measurements they will be presented in **EF04**, whereas the jet measurements will be discussed in **EF05**. The heavy-ion-related analyses will contribute to **EF07**.

Different approaches have been used to assess the sensitivity in searching for new physics (NP) at the HL-LHC: precise tests of the SM observables in the EW, QCD and in the flavour sectors, study of the properties of the Higgs boson, and direct search for new physics. Various models that predict NP are investigated like the top squarks (stops) in SUSY or vector-like fermions. Prospects for these measurements are presented in **EF08** and **EF09**, whereas proposals for DM searches will be presented in **EF10**.

The HL-LHC physics analyses use different techniques based on simulated MC samples. Some analyses use full simulation of the Phase-2 detector response, some use DELPHES [9], in some cases projections of existing Run 2 results are performed. The theoretical and experimental systematic, and statistical uncertainties assumtions are described in detail in Ref. [1].

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List of expected topics.

Public results are given with citations, new or modified analyses are indicated in italic font.

EF01: EW Physics: Higgs Boson properties and couplings

1. Non resonant gluon-gluon fusion HH production [10]
2. Sensitivity projections for Higgs boson properties measurements [11]
3. Search for invisible decays of a Higgs boson in VBF [12]
4. *Non resonant ttHH production and constraints on the Higgs boson self-coupling from ttH* [13]
5. *H mass and width measurements* [11]
6. *Non resonant VBF HH production*
7. *Rare decays of the Higgs boson*
8. *Measurement of differential VBF Higgs boson cross sections*
9. *HHH and quartic couplings*
10. *Higgs EFT studies*

EF02: EW Physics: Higgs Boson as a portal to new physics

1. Search for MSSM H$\to \tau\tau$ [14]
2. Search for high mass second Higgs-like boson [15]
3. *Search for resonant and non-resonant VBF HH$\to bbbb$* [16]
4. *Search for exotic Higgs boson, H$\to aa$* [17]
5. *Search for Lepton Flavor Violation in H$\to \mu\tau$, eτ*
6. *Search for charged Higgs boson, H$\to \tau\nu$*
7. *Search for H$\to$MM' and H$\to$Z/γM, where M,M'=J/Ψ or ϕ*

EF03: EW Physics: Heavy flavor and top quark physics

1. Differential $t\bar{t}$ cross section in full kinematic range, resolved and boosted [18]
2. 4-top quark production with same-sign and trilepton final states [19]
3. Measurement of the rare B decays and combination of Bs measurements [20]
4. CPV in Bs$\to$J/$\Psi\phi$ [21]
5. Study of the expected sensitivity to the P'_5 in the $B^0 \to K^{*0}\mu^+\mu^-$ decay [22]
6. *Measurement of $t\bar{t}V$ and constraints on anomalous couplings* [23]
7. *Searches for LFV, FCNC and FCNH in EWK and QCD top-quark production* [24]
8. *Measurement of the top Yukawa coupling in $t\bar{t}$*

9. *Study of $t\bar{t}XX$ and $t\bar{t}XX/t\bar{t}$ ratio in different final states*
10. *Measurement of tV production, inclusive and differential*
11. *Measurement of top quark spin correlation and polarization*
12. *Measurements of the top EFT parameters*

EF04: EW Physics: EW Precision Physics and constraining new physics

1. Projects for measuring weak mixing angle [25]
2. VBS diboson measurements [26], [27], [28]
3. *Multiboson measurements*
4. *Measurement of W-production in different helicity states*

EF05: QCD and strong interactions: Precision QCD

1. *High-p_{T} and forward jet measurements* [29]
2. *Double Parton Scattering in 4-jet and Z+jets events*
3. *Measurements of V+jets including VBF production*
4. *Measurement of jet substructure variables in quark and gluon jets*
5. *α_S measurements and PDF extraction*

EF07: QCD and strong interactions: Heavy Ions

1. Open heavy flavor and quarkonia in heavy ion collisions [30]
2. Jet quenching measurements in heavy ion collisions [31]
3. Small system flow measurements in heavy ion collisions [32]
4. Constraining nPDF with heavy ion collisions [33]
5. *Projection for $t\bar{t}$ analysis in heavy ion collisions*
6. *Measurement of $gg \to \tau\tau$ in PbPb collisions*

EF08: BSM: Model specific explorations

1. Leptoquark search [34], [35]
2. Search for gluinos and top squarks in final states with boosted objects [36]
3. Chargino-neutralino search with same-charge dilepton final states [5]
4. Search for compressed Higgsinos [37]
5. Search for stau pair production in the $\tau\tau$ channels [38]
6. *SUSY search in top squark decays to taus*
7. *Search for compressed staus (in EWK gaugino or stau production) using final states with soft taus*
8. *Search for VBF production of compressed SUSY in 0, 1, or 2 leptons final states*

EF09: BSM: More general explorations

1. Heavy composite Majorana neutrinos [39]
2. Search for RS gluons decaying to $t\bar{t}$ final states [40]
3. Search for W'$\to \tau\nu$ [41]
4. Search for excited leptons [42]
5. Heavy stable charged particles with time of flight [6]
6. *Search for high- or low-mass exotics in 4 lepton final states* [15]
7. *Search for new dilepton resonances*
8. *Search for vector-like quark pairs decaying to SM quarks and bosons*
9. *Search for heavy, neutral LL particles in decays to delayed jets*
10. *Exploring exotic final states with unconventional track signatures*
11. *Searches with disappearing tracks*

EF10: BSM: Dark Matter at colliders

1. Search for DM produced in association with a Z boson [43]
2. LL dark photon decays into displaced muons [44]

RF05: Charged Lepton Flavor Violation (electrons, muons and taus)

1. *Tau leptons rare decays*

RF07: Hadron Spectroscopy

1. *Precision studies of production of heavy mesons and baryons*
2. *Searches of exotic heavy hadronic states*

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