Referee report

on the "Upgrade of the CMS detector" project for 2022-2026

CMS is one of four major experiments at the LHC. It is a general-purpose particle physics experiment run by an international collaboration and designed to exploit the full discovery potential and the huge range of physics opportunities that the LHC provides. After the discovery of the Higgs boson, the last missing piece in the Standard Model (SM), at the LHC in 2012, the leading experiments in particle physics are focused on precision tests of the SM and searches for new phenomena beyond the Standard Model (BSM).

In 1994, JINR physicists and engineers initiated the formation of the RDMS CMS Collaboration, which together with colleagues from the JINR member-states was aimed at the construction and exploitation of the CMS Detector. Since then, the team's obligations have been focused on the construction and maintenance of the forward parts of the muon spectrometer and hadronic calorimeter endcaps. During the Run 2 (2016-2018), the LHC provided 13 TeV center-of-mass energy of proton-proton collisions at the instantaneous luminosity of $1.7\text{-}2.2\times10^{34}$ $cm^{-2}s^{-1}$, which exceeded the design value of 1×10^{34} $cm^{-2}s^{-1}$. Detailed studies are being carried out for the Higgs boson and other SM processes, as well as for the BSM searches. The plan is to accumulate a dataset corresponding to 300 fb^{-1} by the end of the LHC Run 3 (2023). After the third long shutdown (LS3), the HL-LHC operational phase will start in 2026 with the instantaneous luminosity of 5×10^{34} cm^{-2} s^{-1} with the goal to collect 3000 fb^{-1} by the mid-2030s. The corresponding mean number of pileup collisions per bunch crossing will increase from 60 to 140. However, the LHC has an ability to deliver 50% higher values for both the instantaneous and integrated luminosities. The number of interactions per bunch crossing will increase further to 200. To withstand such a harsh environment, many systems of the CMS detector must be upgraded. The detector performance should not deteriorate under these conditions.

The HL-LHC will bring ten times more integrated luminosity than the LHC, posing significant challenges for the radiation tolerance of the detectors and their occupancy, especially for calorimetry in the forward region. As part of its Phase-II upgrade programme, the CMS Collaboration is proposing to build a high granularity calorimeter (HGCal) that will replace the existing endcap calorimeter. It was decided that the new hadronic calorimeter would be based on silicon detectors suitable for intense fluxes of neutrons and ionizing particles. The part of the HGCal, where the radiation fluxes are significantly relaxed, is proposed to be made of plastic scintillators equipped with silicon photomultipliers. According to the MoU, JINR will be responsible for:

- Production of cooling panels.
- Purchase of silicon sensors and SiPM's.
- Facility development for testing of cassettes (sensors holders), cassettes tests, their assembling and commissioning.

The CSC Muon Stations will be upgraded as well. The upgrade of the Endcap Muon System focuses on replacing the detector electronics of the innermost ring chambers of all four Muon stations (called MEx/1) in order to meet the new HL-LHC requirements. During the LS2 period (2019-2022), ME1/1 chambers were equipped with new cathode readout electronics with increased response speed, which allowed efficient track reconstruction and triggering in the high rates area. For the HL-LHC, the following should be done:

- Refurbishment of Muon Stations, testing, assembly and installation.
- Electronics upgrade.

— Development of an algorithm for track segments reconstruction in CSC.
— Ageing study for CSC at CERN gamma-irradiation facility GIF++.
— Study of new gas mixtures.

The proposed upgrade project is a continuation of the work of the JINR team in the CMS project since the start of its construction. Although the main efforts of the JINR team are concentrated on the development and construction of important hardware, JINR scientists actively participate in physics analyses, reconstruction and selection of events, data validation, development of core software and computing. While participating in the detector performance group (DPG) of the Muon Endcap system, JINR physicists made a substantial contribution to the design and implementation of the track reconstruction algorithm. This algorithm is a part of the official CMS software package and is used by default for the reconstruction of experimental and simulated data, as well as for R&D tasks.

On the “dark side”:

The proposal is overloaded with a description of many technical features of the detector, although some important details are omitted. Namely, it is not clear what timing resolution will be achieved in HGCal and how it will affect the L1 trigger efficiency. No results of the performance study are presented, which demonstrate the advantages of the HGCal implementation.

The SWOT analysis contains a list of remaining uncertainties in the status of the project that may affect the starting date, it would be interesting to see a list of corresponding measures as well.

In addition to the FTE, it would be appropriate to show the list of responsibilities for all team members, indicating also their involvement in the realization of the CMS physics program. It will demonstrate the balance and synergy between the detector- and analysis-oriented participants.

In conclusion:

The scientific value of the project and its competitiveness are very high. The qualification of the authors is well known, and the participation of a very experienced group of experimentalists in this project makes it feasible. The realization of the project will provide a promising opportunity for attracting the next generation of young talented physicists to modern physics. It is worth noting the involvement into the project of physicists from many JINR Laboratories: VBLHEP, BLTP, LIT, DLNP, as well as many JINR member-states: Armenia, Belarus, Georgia, and Ukraine. So far, only 5% of the expected statistics have been recorded, there are many discoveries ahead of us.

In general, the project "Upgrade of the CMS detector" deserves a positive assessment, the requested funding looks reasonable, and I recommend the project to be adopted for the period of 2022-2026 with the first priority.

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