Form No. 24

UPGRADE OF THE CMS DETECTOR

CODE NAME OF PROJECT OR COLLABORATION CMS

CODE OF THEME ТЕМЫ 02-0-1083-2009/2023

LIST OF AUTHORS IS APPENDED
(see next page)

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DATE OF SUBMISSION OF PROPOSAL OF PROJECT TO SOD ________

DATE OF THE LABORATORY STC 13.04.21

DOCUMENT NUMBER ________

STARTING DATE OF PROJECT ________
(FOR EXTENSION OF PROJECT — DATE OF ITS FIRST APPROVAL) ________

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EXTENDED ANNOTATION

The “Compact Muon Solenoid” (CMS) is the general-purpose experiment [1], designed to study physics of pp collisions at the Large Hadron Collider (LHC). The CMS provides extraordinary opportunities for particle physics based on its unprecedented collision energy and luminosity. The prime goals of CMS are to explore physics at the TeV scale and to confirm the mechanism of electroweak symmetry breaking through the studies of the Higgs particles discovered in 2012 and search for extra Higgs bosons beyond the Standard Model, or otherwise, search for supersymmetric partners of the SM particles, dark matter candidates, extra dimensions at TeV-energy scale, etc. Other important problem could be cleared with LHC which is looking for ways to unify the the fundamental interactions, for example via extended gauge models. Also, the CMS physics programme includes the tests of Standard Model itself in the new energy region, studies of EWK and QCD processes, search for quark-gluon plasma etc.

JINR physicists have been participating in the Compact Muon Solenoid (CMS project) for about 30 years since the CMS project was started. JINR contributes to the CMS Project in framework of the Russia and Dubna Member states CMS Collaboration (RDMS). The main effort of JINR in the CMS Project was concentrated on the design, construction, commissioning, operation and upgrade of the CMS inner Endcap detectors, where RDMS bears full responsibility on Endcap Hadron Calorimeter (HE) and First Forward Muon Station (ME1/1).

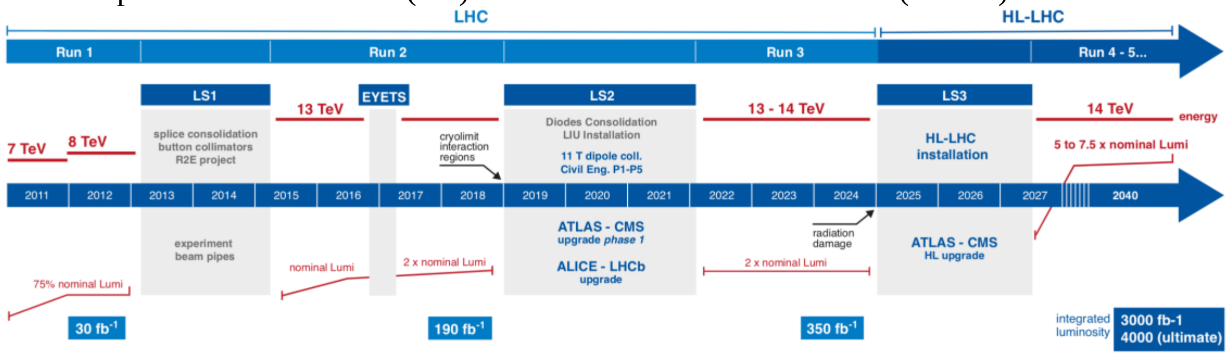

Figure 0. Timeline for LHC/HL-LHC operation.

In 2009–2012 LHC was running with proton beams colliding at $\sqrt{s}$ = 7 and 8 TeV (Run 1), as shown in Fig. 1. During Run 2 LHC has operated from 2015 until the end of 2018 with $\sqrt{s}$ = 13 TeV and its peak instantaneous luminosity ($\mathcal{L}$) at 2.1×10^{34} cm^{-2}s^{-1}. For this time the integrated luminosity ($\mathcal{L}_{\rm int}$) recorded by the CMS experiment has reached approximately $\mathcal{L}_{\rm int}$ = 190 fb^{-1}. It is expected that Run 3 will start in 2022 with $\sqrt{s}$ = 14 TeV and the value of $\mathcal{L}_{\rm int}$ will be ~ 350 fb^{-1} by the end of 2024. Starting from 2027 the LHC will be running at luminosity of $\mathcal{L} = 7.5\times10^{34}$ cm^{-2}c^{-1} (High Luminosity LHC, HL−LHC) that will allow increasing statistics by more than one order of magnitude ($\mathcal{L}_{\rm int}$ ~ 3000 fb^{-1}) by the LHC Phase 2 in 2038. Comparison of some key parameters for the nominal LHC and HL–LHC pp-collisions mode of operation is shown in Table 1.

The LHC Long Stops in 2013−2015 (LS1) and in 2018−2021 (LS2) were focused on the Phase 1 Upgrade of the CMS detector [2] to ensure effective operation at high luminosity of more than $\mathcal{L} = 10^{34}$ cm^{-2}s^{-1} in pp−collisions at the nominal LHC energy. The RDMS CMS Collaboration was responsible for forward muon station ME1/1 and endcap hadron calorimeter HE. After these upgrades CMS will collect data until 2025.

During the LS3 in 2025–2027 the major LHC upgrade to HL–LHC is planned. To ensure feasibility of the HL–LHC physics program a large scale modernization of detector systems is also required. The related CMPhase 2 Upgrade is scheduled for the LS3 [3].

The CMS detector systems have to be upgraded to be able to run at significantly rising levels of radiation. The detectors, the trigger system and the event reconstruction, data acquisition and analysis systems will be able to process essential experimental data in high pile-up environment.

The mean pile-up did not exceed 20–40 in Run 1 and Run 2, but it is expected to reach 60 in Run 3 and ≈ 140 in HL–LHC conditions. Thus, it will increase by about factor 5, what imposes additional requirements on the performance of the detector, the readout electronics and the data acquisition and analysis systems. It also requires the use of radiation-hard materials for detector elements and development of new methods for the experimental data analysis.

Table 1. LHC parameters in different operation modes.

Parameter	LHC nominal luminosity	HL–LHC high luminosity	HL–LHC ultimate luminosity
Peak luminosity (10^{34} $cm^{-2}s^{-1}$)	1.0	5.0	7.5
Integrated luminosity (fb^{-1})	300	3000	4000
Pileup	~30	~140	~200

The main goal of this project is contribution to the construction of the Highly Granularity Calorimeter (HGCal) [4] and an upgrade of the ME1/1 Cathode Strip Chambers (CSC) [5] of the CMS.

All work on the project is carried out within the framework of the obligations assumed in accordance with the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector between CERN and JINR, relevant Addenda (Addendum №10 [6], Addendum №13 [7], Addendum №14 [8], Addendum №15 [9]), and Memorandum of Understanding on participation of JINR in the CMS Phase-2 HGCal Project at CERN [10].

Participation in construction of the high granularity calorimeter

The HL-LHC will integrate ten times more luminosity than the LHC, posing significant challenges for radiation tolerance and event pileup on detectors, especially for calorimetry in the forward region. As part of its HL–LHC upgrade program, the CMS Collaboration is proposing to build a high granularity calorimeter (HGCal) to replace the existing endcap calorimeters. The existing forward calorimeters, the PbWO4-based electromagnetic calorimeter (EE) and the plastic scintillator-based hadron calorimeter (HE), were designed for an integrated luminosity of 500 fb^{-1}. The performance degradation much beyond this integrated luminosity leads to an unacceptable loss of physics performance.

HGCal is the calorimeter with high longitudinal and transverse segmentation facilitates for measurement of particle flux energy. The information from all HGCal subsystems is combining optimally. Construction of CMS HGCal takes into account that particle-flow will be the main reconstruction algorithm so energy flows of particles will be reconstructed. Therefore, the accuracy of the spatial reconstruction is of paramount importance. In particular, the transverse segmentation should be less than the Moliere radius in both the electromagnetic and hadronic parts. This allows good separation of double jets especially in high density HL–LHC conditions. The advantage of CMS HGCal is possibility to identify individual particles within jets as bubble chambers did in the early days of particle physics

This level of granularity also helps to mitigate event pileup, by associating jets/particles to particular primary vertices through pointing. This mitigation is improved further by including a precision-timing measurement of particle showers into the front-end electronics.

Precision timing represents a major addition to event reconstruction in the HL–LHC. For the HGCal, timing provides the ability to measure with high precision the time of electromagnetic and hadronic showers. Requiring the compatibility between the measured time of showers will provide a powerful tool to assist pileup rejection, and identification of the primary vertex of the triggered interaction. Results from beam tests have shown that the timing resolution obtained with silicon sensors does not vary significantly with sensor thickness when the resolution is measured as a function of signal-to-noise ratio S/N, nor does it vary as a result of irradiation up to fluences expected after 3000 fb^{-1} when measured as a function of S/N. For K_L^0 [1]of p_T > 5 GeV, the time of the reconstructed shower is measured with >90% efficiency, and with a resolution of < 30 ps.

The HGCal guarantees a high reconstruction and tagging efficiency for the signal VBF jets, and a sustainable rate of additional background jets in the forward region. The efficiency is found to be approximately 95% up to an |η| of 3.0 in the 200 pileup Phase-2 simulation, indicating good performance in the region covered by the HGCal. It is noted that at 200 pileup the efficiency is a few percent only lower than in the 0-pileup case.

The obligations for the construction of high granularity endcap calorimeters HGCal of CMS are defined in the Addendum No. 14 to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector (annexes 3 and 4) [8] and in the Memorandum of Understanding on participation of the Joint Institute for Nuclear Research in the Compact Muon Solenoid (CMS) Phase-2 High Granularity Calorimeter (HGCal) Project at CERN [10].

The total amount of JINR (RDMS–DMS) contribution to CORE[2] for these tasks is defined as 2 200 kCHF. JINR is responsible for:

- HGCal cooling plates production (assigned funding in CORE is 1210 kCHF);
- silicon sensors purchase (assigned funding in CORE is 700 kCHF);
- SiPM purchase (assigned funding in CORE is 200 kCHF);
- manufacturing of the cassette testing facility (assigned funding in CORE is 90 kCHF);
- testing of cassettes, assembly and commissioning of HGCal.

Within the framework of the agreement between JINR and CERN on participation in the development of high-granularity endcap calorimeters, the area of responsibility of JINR is participation in the development of the hadron part of HGCAL cassettes (mixed type CE-H) [10]. They include the following sections:

- production of low-temperature rooms for testing cassettes after assembly and transportation to CERN, 96 kUSD, including 90 kUSD of the JINR Directorate grant for 2021. Transportation of the cameras to CERN, installation and maintenance costs amount to 50 kUSD ;
- design and construction of trigger counters and related electronics for testing HGCAL active modules with cosmic rays in low-temperature rooms. This requires the design of scintillation counters and the mechanical design of the trigger system, the development of a high-voltage power supply system for photomultipliers and related register electronics, the estimated cost of materials and equipment is 20 kUSD. Maintenance and operation of the equipment directly during the test tests of the cassettes for 4 years is 42 kUSD;
- testing of CE-H cassettes before installation in the HGCal absorber. According to the schedule, the work will require the participation of specialists from JINR for 4 years, 264 kUSD ;
- Monte Carlo calculations of the response of calorimetric modules to an incoming minimally ionizing particle and developing algorithms for separation signals from particles against a noise background.

Upgrade of the ME1/1 Cathode Strip Chambers (CSC)

An increase in the luminosity by a factor of 5, an increase in the trigger frequency by a factor of 7.5, and an increase in the delay of the low-level trigger by a factor of 4 impose additional requirements for the detectors and electronics efficiency, which requires the modernization of the CSC readout and trigger electronics (Table 2.1). The detectors located on the inner rings of the four muon stations: ME1/1, ME2/1, ME3/1 and ME4/1 (generically: MEx/1) are instrumented with faster electronic modules that meet the requirements for operation in high luminosity LHC

[1] K_L^0 do not convert or interact in the tracker material.
[2] Cost of Resource Exchange

conditions: trigger delay 12.5 μs and maximum trigger frequency 750 kHz. Most of the updates have been planned to be carried out during the LS3 period. However, since the LS3 period assumed to be extremely busy, it was decided to replace the on-chamber electronics on 108 MEx/1 detectors during the LS2 long shutdown period.

Table 2.1. Muon system characteristics for the high luminosity LHC conditions.

	Parameter	LHC	HL–LHC	Increase factor
LHC	Peak luminosity ($cm^{-2}s^{-1}$)	10^{34}	5×10^{34}	5
	Pile-up	30	150	5
	Integral luminosity (fb^{-1})	300	3000	10
CMS	Trigger frequency L1 (kHz)	100	750	7.5
	Trigger delay L1 (μs)	3.2	12.5	3.9
	DAQ muon system bandwidth		×10	×10

To provide low-voltage power supply for the electronics of MEx/1 chambers, an electronic LVDB5 low-voltage power distribution module was designed and manufactured in the amount of 120 pieces. The chambers of the ME1/1 muon station are equipped with new increased performance xDCFEB boards. To replace the electronics in the peripheral racks during the LS3 period, new electronic trigger and readout control modules (OTMB, ODMB) are being developed. In addition, the existing fiber optic cables connecting the CSC readout electronics to the DAQMB modules in the peripheral racks will be replaced with higher bandwidth fiber optic cables during the LS3 period.

In conditions of HL–LHC the radiation effect on the detectors and electronics significantly increases. It leads to the effects of "aging" of the CSC structural elements and radiation damage to the components of electronic modules. The total radiation dose will increase by 5 times (the required safety factor is 3), as well as frequency of events and background loading. In this regard it is necessary to check and certify the detectors and readout electronics for operation under high luminosity conditions HL–LHC. A comprehensive study of the detectors aging is carried out at the GIF++ facility at CERN [15,16]. Irradiation of electronic modules is carried out at various installations: CERN (CHARM), UC Davis (cyclotron) and TAMU (reactor).

The main task of ME CSC modernization during LS2 period is upgrade of CSC electronics of the inner rings of CMS Muon Endcap stations MEx/1 (180 chambers).

LS3 period is dedicated to substantial modernization of ME system by installation of new detectors: ME0 station based on GEM detectors, High-Granularity Calorimeter (HGCal) and Endcap Timing Layer (ETL). Integration of their services implies considerable redesign and reintegration of the whole YE1 disk cables and services routing. Current YE1 radial cable trays are not able to accommodate all the HGCal, ME1/1, ME0, RE services and cables. The redesign also concerns the ME1/1 patch panels height reduction to free space for HGCal cables routed above ME1/1.

The main directions and tasks of JINR group participation in modernization of the endcap muon system CMS are as follows:

- Electronics upgrade during LS2 period and preparation to LS3 period
  - design and construction of 120 new Low Voltage Distribution boards (LVDB-5);
  - manufacturing of the 120 reference voltage cables;
  - design and construction of the test stand for LVDB boards;
  - design and production of 72 ME1/1 high voltage filters - to be installed during LS3;
  - design and production of 36 ME1/1 patch panels - to be installed during LS3.
- MEx/1 CSC refurbishing, testing, assembly, and installation during LS2 period
  - design and construction of the Endcap Muon System upgrade infrastructure (area and test stands);
  - ME1/1 CSCs extraction;
  - installation and tests of HV filters for ME1/1 CSCs;

- replacement and tests of the ME1/1 optical fibers (planned for LS3 period);
- modernization of the ME1/1 cooling system;
- production and installation of the new ME1/1 CSC cables and services;
- refurbishment, installation, and commissioning of MEx/1 muon chambers.

- Continue development and test of an algorithm for track segments reconstruction in the CSC chambers.
- Continue participation in CMS CSC ageing study at GIF++, CERN
  - study of CSC characteristics in HL LHC conditions with uncorrelated background;
  - study of methods for eliminating the Malter current in CSC.
- Participation in the new gas mixture studies for endcap CSC.

The obligations of JINR in the CMS Muon system Phase-I Upgrade fulfilled in LS2 period. The responsibilities of JINR together with DMS countries (RDMS-DMS) in construction of the Phase-2 Muon System: “On-detector electronics and OTMBs” and “RE3/1 RE4/1 Chambers” is defined in Annex 3 of Addendum №13 to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector (CERN-MoU-2019-008) [9]. The total CORE JINR contribution (Annex 4 to MoU) accounted as 151 kCHF (76 kCHF – from JINR budget, 75 kCHF – from Georgia Technical University and Tbilisi State University budget).

In addition, the unexpected/extra JINR expenditures of 63 kCHF related to the manufacturing of the new cooling circuits and monitoring of the water leaks will be acknowledged as an advanced contribution in the M&O-B budget of the Muon System from 2021 in 2019.

1. CMS Collaboration, CMS, the Compact Muon Solenoid: Technical Proposal, CERN/LHCC 1994-038 (1994).
2. CMS Collaboration, Technical proposal for the upgrade of the CMS detector through 2020, CERN-LHCC-2011-006; CMS-UG-TP-1; LHCC-P-004. – Geneva, CERN, 2011.
3. CMS Collaboration, Technical Proposal for the Phase-II Upgrade of the CMS Detector, CERN-LHCC-2015-010; LHCC-P-008; CMS-TDR-15-02. – Geneva, CERN, 2015.
4. CMS Collaboration, The Phase-2 Upgrade of the CMS endcap calorimeter Technical Design Report, CERN-LHCC-2017-023, CMS-TDR-019. – Geneva, CERN, 2019.
5. CMS Collaboration, The Phase-2 Upgrade of the CMS Muon Detectors, CERN-LHCC-2017-012; CMS-TDR-016. – Geneva, CERN, 2017.
6. Addendum No. 10 to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector Common Items for the Phase II Upgrade of the CMS Detector, CERN-RRB-2017-060.
7. Addendum No. 13 to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector (comprising an Upgrade of the Muon Subsystem), CERN-MoU-2019-008.
8. Addendum No. 14 to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector (comprising an Upgrade to the HGCal Subsystem), CERN-MoU-2019-009.
9. Addendum No. 15 to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector, CERN-MoU-2019-036.
10. Memorandum of Understanding (MoU) on participation of the Joint Institute for Nuclear Research in the Compact Muon Solenoid (CMS) Phase-2 High Granularity Calorimeter (HGCal) Project at CERN, CMS-2020-010.

ESTIMATION OF HUMAN RESOURCES

JINR's contribution to the CMS experiment has been well known since the foundation of the CMS. JINR's participants in CMS made a significant contribution to the design, creation and modernization of the endcap muon system and the endcap hadron calorimeter system.

The authors of the project have extensive scientific experience. The list of participants includes 2 Full Members of the National Academies of Sciences of the Russian Federation and Uzbekistan (V.A. Matveev and B.S. Yuldashev), 8 doctors of science (I.A. Golutvin, V.Yu. Karjavine, V.V. Korenkov, A.I. Malakhov, G.A. Ososkov, V.A. Smirnov, O.V. Teryaev, S.V. Shmatov), 11 candidates of sciences (V.Yu. Alexakhin, S.V. Afanasiev, N.I. Zamiatin, A.V. Zarubin, I.N. Gorbunov, N.V. Gorbunov, A.V. Lanoyv, V.V. Palichik, T.A. Strizh, A. Khvedelidze, Z. Tsamalaidze). The share of young employees under the age of 35 exceeds 20%. All young employees are actively working on the preparation of PhD theses.

The total number of participants from JINR is 44 employees, 21.5 FTE.

Employment for participants of the JINR Project "Upgrade of the CMS Detector"

	Name	FTE in Upgrade Project	Activity	Other activities in CMS topic	Total FTE in CMS Topic
JINR Directorate					
1	V.A. Matveev	0,1	overall direction		0,1
JINR GA&C					
2	B.S. Yuldashev	0,2	upgrade works		0,2
VBLHEP					
3	V.Yu.Alexakhin	0,2	data processing and analysis	physics analysis (0,7)	0,9
4	S.V.Afanasiev	0,3	upgrade works		0,3
5	D.Budkovsky	0,2	data processing and analysis	physics analysis (0,8)	1,0
6	P.D.Bunin	1,0	upgrade works and detector operations		1,0
7	M.G. Gavrilenko	0,4	upgrade works and detector operations	physics analysis (0,6)	1,0
8	A.O. Golunov	0,8	upgrade works and detector operations	computing (0,2)	1,0
9	I.A. Golutvin	1,0	overall direction		1,0
10	I.N. Gorbunov	0,2	data processing and analysis	physics analysis (0,8)	1,0
11	N.V. Gorbunov	1,0	upgrade works and detector operations		1,0
12	N.N.Evdokimov	1,0	upgrade works and detector operations		1,0
13	Yu.V.Ershov	1,0	upgrade works and detector operations		1,0
14	A.Yu. Kamenev	1,0	upgrade works and detector operations		1,0
15	V.Yu. Karjavin	1,0	O verall direction		1,0
16	A.M. Kurenkov	1,0	upgrade works and detector operations		1,0

17	A.V. Lanev	0,1	data processing and analysis	physics analysis (0,9)	1,0
18	A.M.Makan'kin	0,3	upgrade works and detector operations		0,3
19	A.I. Malakhov	0,2	upgrade works and detector operations		0,2
20	V.V. Perelygin	1,0	upgrade works and detector operations		1,0
21	V.A.Smirnov	0,9	upgrade works and detector operations		0,9
22	E.V.Sukhov	0,5	upgrade works and detector operations		0,5
23	O.V.Teryaev	0,1	physics analysis (0,1)		0,1
24	V.V. Ustinov	0,5	upgrade works and detector operations		0,5
25	V.V. Shalaev	0,2	data processing and analysis	physics analysis (0,8)	1,0
26	S.V. Shmatov	0,1	data processing and analysis	physics analysis (0,8), computing (0,1)	1,0
27	N.I. Zamyatin	0,1	upgrade works and detector operations		0,1
28	A.V. Zarubin	1,0	upgrade works and detector operations		1,0
29	I.A. Zhizhin	0,2	data processing and analysis	physics analysis (0,8)	1,0
LIT					
30	A.O. Golunov		computing (0,5)		0,5
31	I.A. Filozova		computing (0,1)		0,1
32	A.Khvedelidze	0,5	upgrade works and detector operations		0,5
33	V.V.Korenkov	0,4	computing (0,4)		0,4
34	V. Mitsyn	0,8	computing (0,8)		0,8
35	D.A. Oleynik	0,1	computing (0,1)		0,1
36	G.A. Osokov	0,1	data processing and analysis		0,1
37	V.V.Palchik	0,8	data processing and analysis		0,8
38	A. Petrosyan	0,1	computing (0,1)		0,1
39	R.N. Semenov	0,1	computing (0,1)		0,1
40	T.A. Strizh	0,1	computing (0,1)		0,1
41	V. Trofimov	0,8	computing (0,8)		0,8
42	N.N.Voytishin	0,8	data processing and analysis		0,8
DLNP					
43	G. Adamov	0,3	upgrade works and detector operations		0,3
44	Z. Tsamalaidze	0,2	upgrade works and detector operations		0,2
Total		21,5			31,8*

*) A number of CMS participants from JINR are missed in this list since they are not involved in the CMS Upgrade Project.

The number of participants from the JINR member countries:

5 people from the A. Alikhanyan National Science Laboratory (Yerevan, Armenia), 7 people from the Institute of Nuclear Problems of the Belarusian State University (Minsk, Belarus), 4 people from the Institute of Scintillation Materials of the National Academy of Sciences of Ukraine (Kharkiv, Ukraine), 4 people from the Kharkiv Institute of Physics and Technology (Kharkiv, Ukraine), 3 people from the Institute of Nuclear Physics of the Uzbek Academy of Sciences (Tashkent, Uzbekistan).It is also planned to involve students and postgraduates of Dubna University and other educational centers in the modernization work.

SWOT ANALYSIS

Project benefits

After the modernization of the detector systems, the experiment at the LHC discovery machine has a high potential to make a world-class discovery, as was done during the first stage of work (the discovery of the Higgs boson). LHC experiments are attractive to scientists all over the world, useful for popularizing science and for involving the younger generation in science.

CMS is one of the largest international innovation projects in the field of technology for the design and creation of equipment for experimental research in the field of high-energy physics.

International cooperation within the framework of the CMS collaboration with a large number of research centers leading in the field of high-energy physics makes it possible to transfer modern technologies to a home institute. Good examples of such cooperation are:

- transfer of GEM (Gas Electron Multiplier) detector technology to JINR to study the properties of baryonic matter in the experiment (BM@N) at JINR;
- implementation of the track reconstruction algorithm for the BM@N experiment at JINR.

TIER-1 computing center at JINR is built on the basis of modern Grid technologies and is provided with a proper computing infrastructure for receiving, processing and storing experimental information from the CMS experiment at JINR and in Russian institutes.

The experiment has one of the highest publications ranking in high-energy physics. In 2020, more than 100 articles were published with high citation index.

JINR contribution to the CMS experiment has been well known since the formation of the CMS. JINR participants in CMS made a significant contribution to the design, construction and modernization of the muon endcap system. At the same time, JINR scientists are actively involved in physics analysis, reconstruction and selection of events, data quality control, and development of basic software. As part of the research and optimization of the parameters of the endcap muon system detectors, JINR physicists have made a significant contribution to the development and implementation of the algorithm for the reconstruction of physics objects. The development of CMS projects for the modernization of detector systems was carried out with the active participation of JINR employees.

Project weaknesses and risks

Due to the inadmissibility of violating the delivery time of cooling plates for the timely installation of detector elements, as well as a large volume of parallel technological processes at the mass production stage, strict control of all stages of work performed at the manufacturer is required. Reserve production facilities should also be prepared for the case of force majeure at the main manufacturer.

The costs do not take into account the possible increase in the price of materials and components, as well as fluctuations in the exchange rate. The cost estimate may need to be adjusted to reflect these circumstances. At the time of submission of the project, there are no final drawings of all the required cooling plates, as the final specification for the manufacture of plates. At the same time, the party responsible for the development of design documentation (FNAL) promises not to make significant changes to the project. The estimated deadline for receiving the final documentation is the summer of 2021.

An unplanned shortfall in project funding may affect the implementation of JINR's obligations under the project, as well as to limit the possibility of involving project participants in solving additional tasks.

Due to the global coronavirus pandemic and the introduction of severe restrictions on commercial activities by a number of countries, which led to a slowdown in production processes and disruption of logistics chains, there is a risk of increasing the time period allocated for the implementation of the project.

ESTIMATION OF BUDGETS

The cost estimate and pattern of charges are related to the official obligations of JINR to participate in the experiment in accordance with the Memorandum of Understanding for the Creation of the CMS detector between CERN and JINR (Memorandum of Understanding for Collaboration in the Construction of the CMS Detector), the relevant Annexes (Addendum No. 10 [6], Addendum No. 13 [7], Addendum No. 14 [8], Addendum No. 15[9]), the Memorandum of Understanding on the participation of JINR in the project HGCal CMS [9]:

- Common Fund expenditures on CMS Phase II Upgrade (CORE contribution is 289.855 kCHF according to Addendum №10 [6], total amount for 2020–2025 is 434.783 kCHF[3]);
- the cost of HGCal cooling plates (CORE contribution – 1210 kCHF according to the Addendum №14 [8]);
- the cost of purchasing silicon sensors (CORE contribution – 700 kCHF according to the Addendum №14 [8]);
- the cost of purchasing SiPM (CORE contribution – 200 kCHF according to the Addendum №14 [8]);
- the cost of creating a stand for testing cassettes (CORE contribution – 90 kCHF according to the Addendum №14 [8] and Memorandum [9]);
- expenditures for testing cassettes, assembly and commissioning of HGCal (according to Addendum №14 [8] and Memorandum [9]);
- expenses for the upgrade of muon CSC stations (CORE contribution – 76 kCHF according to the Addendum №13 [7]);
- costs for testing and commissioning of ME1/1, carrying out of R&D;
- operating expenses for the maintenance of the facility under the responsibility of JINR and its personnel, in accordance with the Memorandum on the Maintenance and Operation of the experimental complex (M&O category B) on the HGCal project (179 kCHF in 2022–2026)[4].

The total amount of the contribution to CORE is 2276 kCHF, including Common Fund of 2565.855 kCHF.

The proposed schedule, required resources, and cost estimates for the “CMS DETECTOR UPGRADE” project are provided in Forms 26 and 29. The results of tenders for the purchase of materials and manufacturing may lead to a change in the total cost of work.

[3] In 2020-2021, a contribution of 144,928 kCHF.

[4] In 2020-2021, a contribution of 5.9 kCHF was made. Currently, the cost of M&O category B expenses is estimated based on the amount of the contribution to CORE. The collaboration discusses the transition to a calculation formula based on the number of project participants (PhD), which will entail a change in the cost price for this category.

Form No. 26

Schedule proposal and resources required for the implementation of the Project UPGRADE OF THE CMS DETECTOR

Expenditures, resources, financing sources			Costs (kUSD) Resource requirements	Proposals of the Laboratory on the distribution of finances and resources				
				2022 (1st year)	2023 (2nd year)	2024 (3rd year)	2025 (4th year)	2026 (5th year)
Expenditures		Materials and Equipment	2407	940	865	590	7	5
		CMS Maintenance and Operation	507	98	109	118	130	52
		Travel allowance	575	65	119	136	128	127
Requiredr esources	Standard hour	Resources of – Laboratory design bureau; – JINR Experimental Workshop; – Laboratory experimental facilities division; – accelerator; – computer. Operating costs	LHC	LHC	LHC	LHC	LHC	LHC
Financing sources	Budgetary resources	Budget expenditures including foreign-currency resources.	3489	1103	1093	844	265	184
	External resources	Contributions by collaborators – reimbursement of in-kind contribution to CMS Grants. Contributions by sponsors. Contracts. Other financial resources, etc.						

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Form No. 29

Estimated expenditures for the Project
UPGRADE OF THE CMS DETECTOR

	Expenditure items	Full cost, k$	2022 (1st year)	2023 (2nd year)	2024 (3rd year)	2025 (4th year)	2026 (5th year)
	Direct expenses for the Project						
1.	Materials and Equipment	2407	940	865	590	7	5
2.	CMS Maintenance and Operation	507	98	109	118	130	52
3.	Travel allowance, including: a) non-rouble zone countries b) rouble zone countries	575	65	119	136	128	127
	Total direct expenses	3489	1103	1093	844	265	184

Comments:

All the values include expenses on upgrade of the CMS detector systems in accordance with MoU, payments of Upgrade Common Funds, operation expenses on technical maintenance of the HGCal according M&O_B, R&D for upgrade, visit expenses.

PROJECT LEADER V.Yu. Karjavine

LABORATORY DIRECTOR R. Lednicky

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