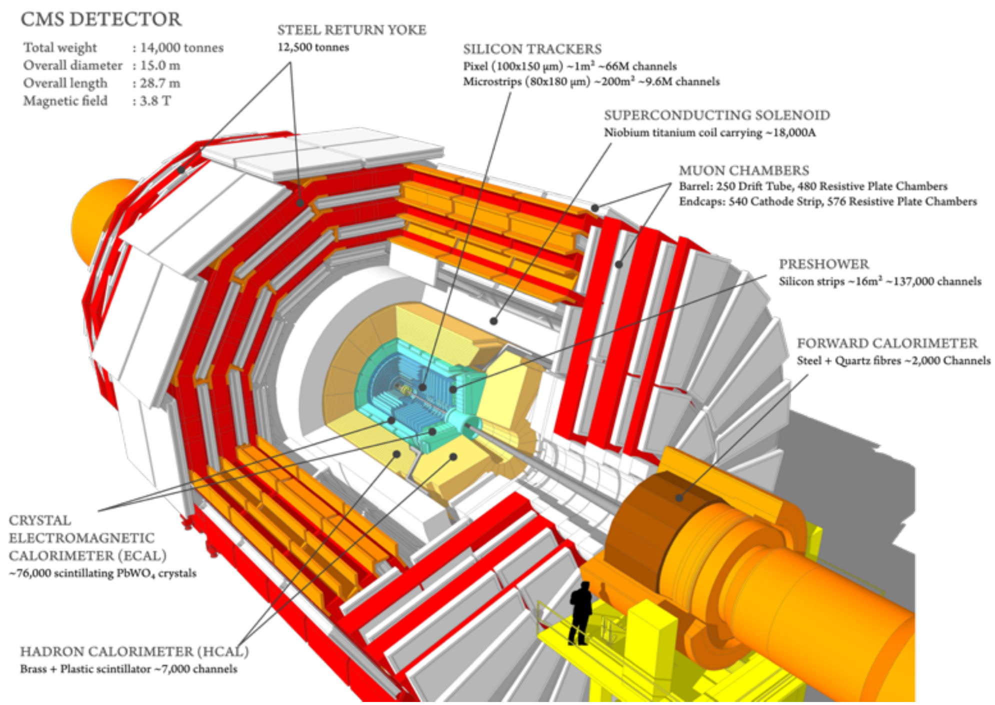
“Upgrade of the CMS Detector”

Project for 2022-2026

JINR Topic 02-0-1083-2009/2023
“CMS. Compact Muon Solenoid at the LHC”



Project leader: V.Yu. Karjavin

Scientific leader: I.A. Golutvin

8 апреля 2021 г. Физическая секция НТС ЛФВЭ

Outline

- ❑ Participants of Projects
- ❑ Motivations, goals and tasks
- ❑ Results expected for 2022-2026
  - ✓ HGCal
  - ✓ Muon System
- ❑ Funding for 2022-2026

The Report on Completion of the Project “Upgrade of CMS Detector through 2020” for 2013-2020 years was presented at the 54th meeting of the PAC for Particle Physics, 18 January 2021

Participants of Project

44 participants from JINR
23 participants from JINR member-states

Дирекция (0.1)
В.А. Матвеев (0.1)

Группа советников и консультантов
Б.С. Юлдашев (0,1)

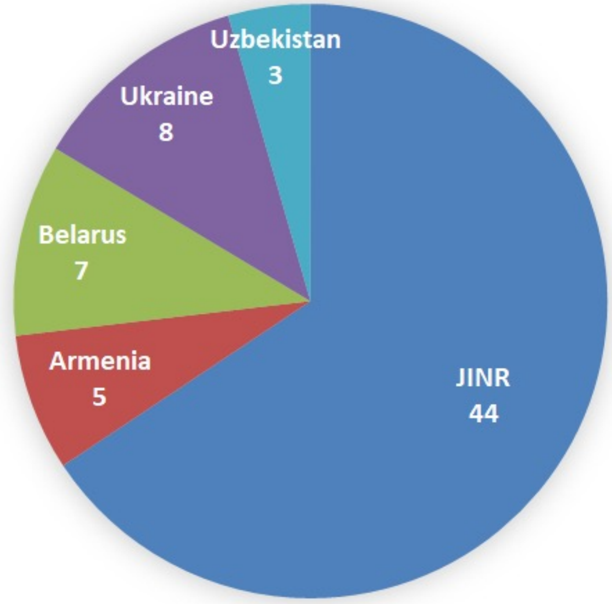
ЛФВЭ (27 участников, 15.3)
В.Ю. Алексахин (0.2), С.В. Афанасьев (0.3), Д.В. Будковский (0.2), П.Д. Бунин (1.0), М.Г. Гавриленко (0.4), А.О. Голунов (0.8), И.А. Голутвин (1.0), И.Н. Горбунов (0.2), Н.В. Горбунов (1.0), Н.Н. Евдокимов (1.0), Ю.В. Ершов (1.0), И.А. Жижин (0.2), Н.И. Замятин (0.1), А.В. Зарубин (1.0), А.Ю. Каменев (1.0), В.Ю. Каржавин (1.0), А.М. Куренков (1.0), А.В. Ланёв (0.1), А.И. Малахов (0.2), А.М. Маканькин (0.3), В.В. Перелыгин (1.0), В.А. Смирнов (0.9), Е.В. Сухов (0.5), О.В.Теряев (0.1), Е.В.Устинов (0.5), В.В. Шалаев (0.2), С.В. Шматов (0.1)

ЛИТ (13 участников, 5.5)
Н.Н. Войтишин (0.8), А.О. Голунов (0.5), В.В. Кореньков (0.4), В.В. Мицын (0.8), Д.А. Олейник (0.1), Г.А. Ососков (0.1), В.В. Пальчик (0.8), А.Ш. Петросян (0.1), Р.Н. Семенов (0.1), Т.А. Стриж (0.4), В.В. Трофимов (0.8), А. Хведелидзе (0.5), И.А.Филозова (0.1)

ЛЯП (2 участника, 0.5)
Г. Адамов (0.3), З. Цамалаидзе (0.2)

16 paid and 5 unpaid (4 PhD and 1 emeritus) authors from JINR

6 paid authors from JINR member-states



Laboratory	Number of Participants	FTE
JINR Directorate	1	0,1
JINR GA&C	1	0,1
LHEP	27	15,3
LIT	13	5,5
LNP	2	0,5
JINR	44	21,5

JINR in CMS Collaboration (Tasks)

Over 25 years JINR has been participated in the CMS experiment at the LHC, starting the very beginning of the detector concept development

- ✓ full responsibility within the RDMS Collaboration for the design, construction, commissioning, operation of the Endcap Hadron Calorimeters (HE) and First Forward Muon Stations (ME1/1)

JINR scientists play active role in the CMS Physics Programme. They contribute actively in data taking and processing, data analysis for the purpose of obtaining new physics results in the following fields:

- ✓ searches for physics beyond SM with the dimuon final states (low-energy gravity, dark matter, extended gauge models, etc)
- ✓ searches for physics beyond SM with missing energy final states (extended Higgs sector, dark matter, lepton-flavour violation)
- ✓ studies of Higgs boson properties and search for new scalar bosons beyond SM in the lepton decay channels
- ✓ studies of jet multiple production for searches of microscopic black holes and other BSM signals
- ✓ studies of muon pair production in Drell-Yan process to test SM at new energy scale, measurement of weak mixing angle and parton distribution functions (PDF)
- ✓ jet measurements for studies of hadronization, improvement of PDF and QCD coupling precision

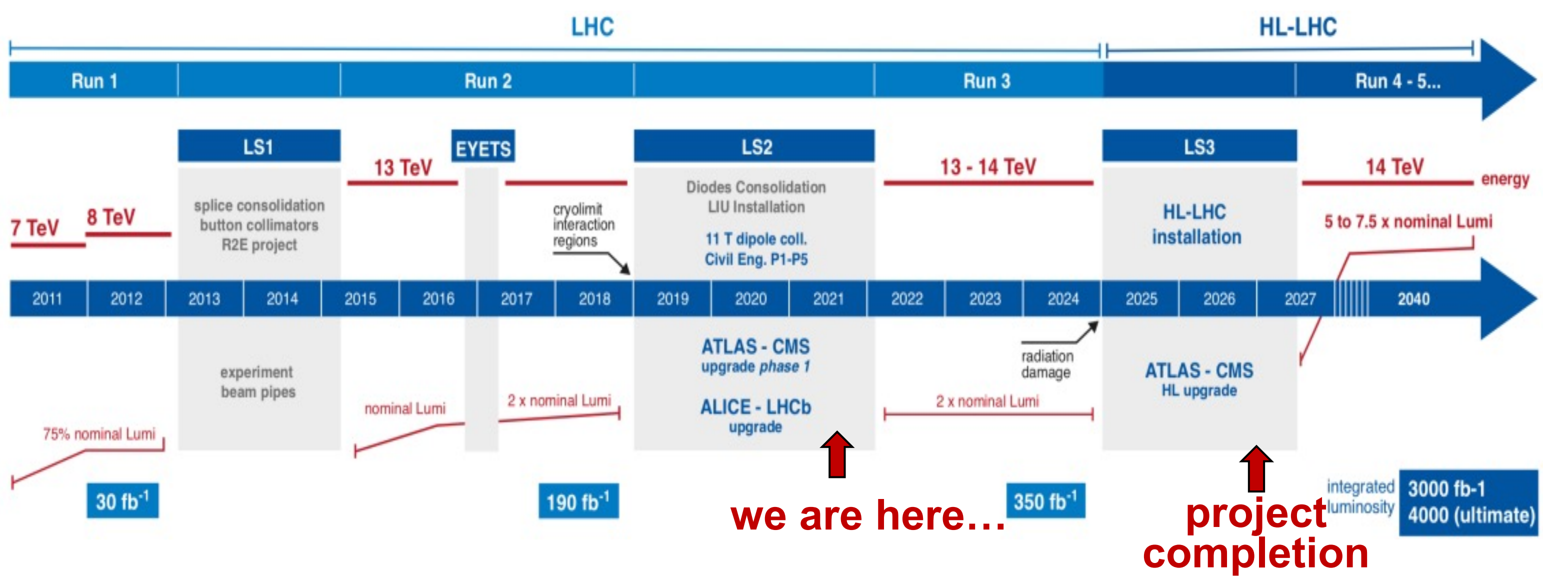
Since the beginning of the JINR Seven-Year Plan in 2017 up to now JINR physicists contributed in to

- ✓ 13 CMS public paper in scientific journals (of more than 510 CMS papers in total)
- ✓ 18 CMS notes with physics analysis
- ✓ 6 CMS operation and upgrade notes
- ✓ 22 paper in referred journals
- ✓ number of papers with CMS results review and future physics, and proceedings (35 papers in a total)
- ✓ more 70 talks were given by JINR physicists for the CMS project at the international conferences.

LHC Schedule

The Large Hadron Collider (LHC) provided proton-proton collisions since 2009

- ✓ During Run 1 (2010–2012) LHC operated at 7 TeV first 2 years, delivering integrated luminosity ≈6 fb^{-1}, and in 2012 at 8 TeV, delivering ≈ 23 fb^{-1} (discovery of the Higgs boson)
- ✓ Run 2 started in 2015 at 13 TeV with instantaneous luminosity $1.7{\times}10^{34} cm^{-2}\, s^{-1}$, exceeded the design value. Physics tasks: detailed studies of the Higgs boson, standard model (SM) processes and searches for physics beyond the SM



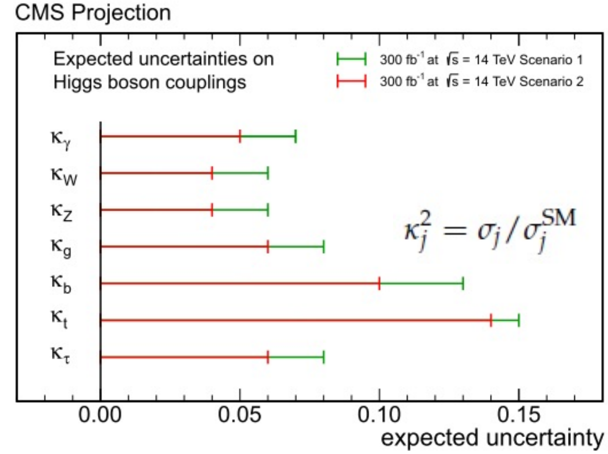
- ✓ After long shutdown LS3 the HL-LHC operational phase is scheduled to start in 2027. By the 2030 planned to have instantaneous luminosity $5{\times}10^{34} cm^{-2}\, s^{-1}$ with integrated luminosity ~3000 fb^{-1}.

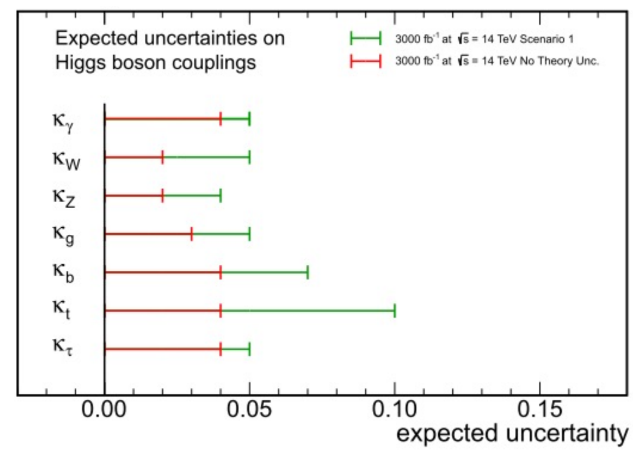
HL-LHC Physics Goals (1)

The main goal of the HL-LHC is to make New Discoveries

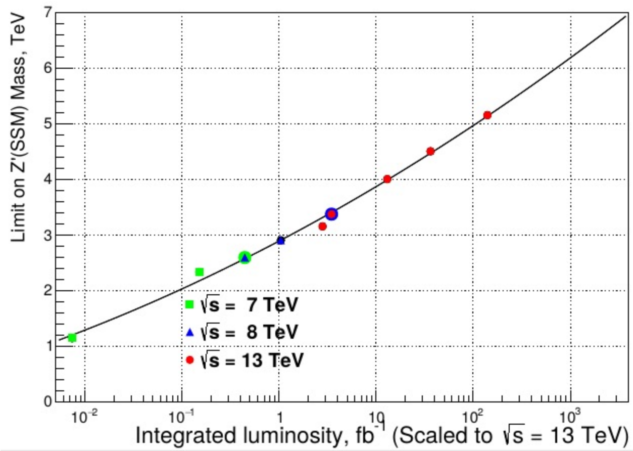
- ✓ Detailed study of the Higgs boson to show that it is indeed a SM Higgs boson (width, branchings, couplings, rare decays)
- ✓ Looking for new scalar states of extended Higgs sector
- ✓ Wide searches for physics beyond the SM (dark matter candidates, supersymmetry, TeV-scale gravity, extended gauge sector, etc.)
- ✓ Precision tests of the SM, including rare processes

Higgs Projections for 300 fb^{-1} and 3000 fb^{-1}

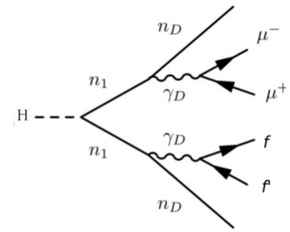


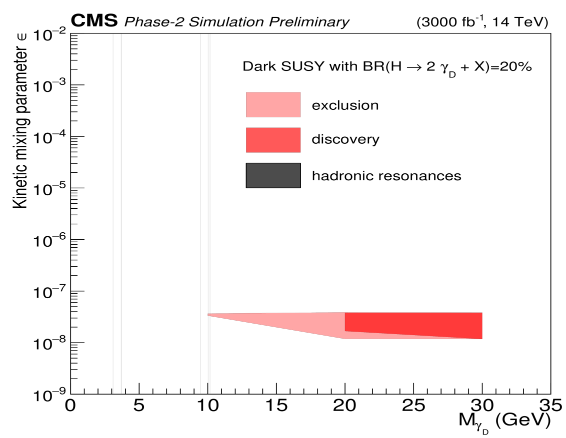


New resonances in Hi-mass Dilepton States



Dark photons decaying to displaced muons with CMS





The physics reach of the CMS achievable with HL-LHC will be increased, e. g. as

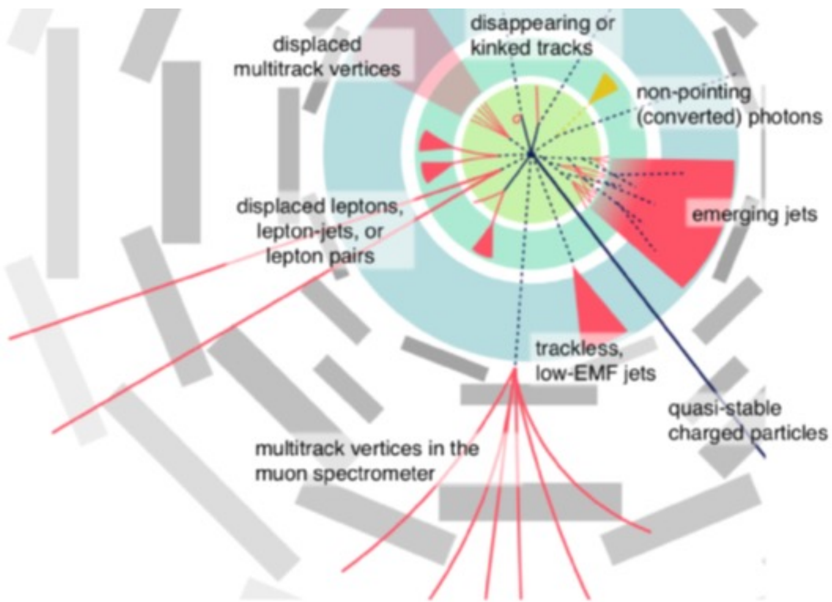
- ✓ for new resonances up to $m_{Z'}$ ~ 6.2-7 TeV (~ 4.56-5.15 TeV with RUN2 data)
- ✓ dark photon masses (1−30 GeV) and lifetimes (cτ = 0.01−10 m) in the context of Dark Supersymmetry models.

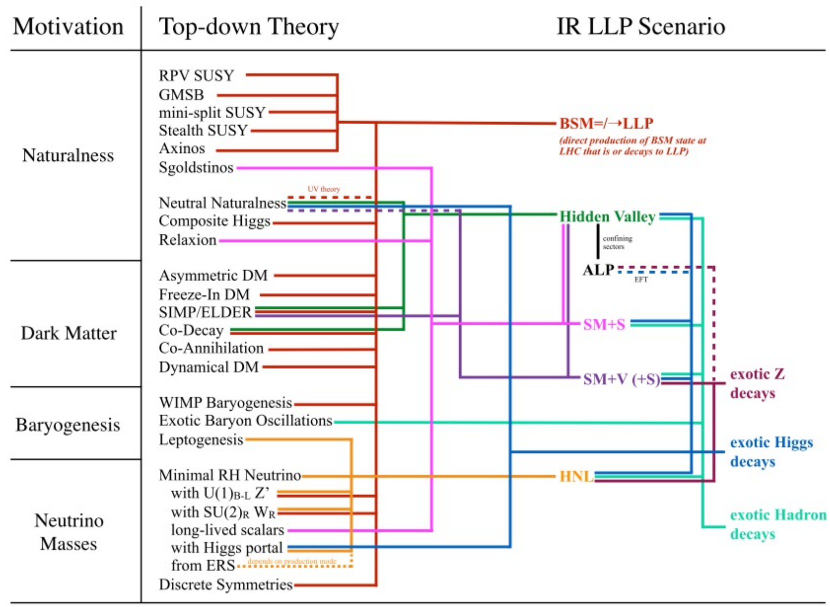
For the Higgs boson, the coupling constants to the SM particles will be measured with a precision of 5–14% and 2–10% given the integrated luminosities of 300 and 3000 fb^{-1}, respectively

HL-LHC Physics Goals (2)

HL-LHC physics aims at reactions initiated by vector boson fusion (VBF) and those involving boosted objects giving rise to narrow or merged jets (e. g. from hadronic decays of the W and Z bosons, the Higgs boson, new Higgs states, and possibly other new particles in the same mass range). A fine lateral and longitudinal granularity of the calorimeter is required for the observation of these narrow jets.

The LHC could produce many Long Lives Particles (LLP) with MeV - TeV masses that would lead to signatures involving displaced vertexes. These states can not be produced anywhere else, but with existing detectors can not discover (need to be reconstructed without tracker).

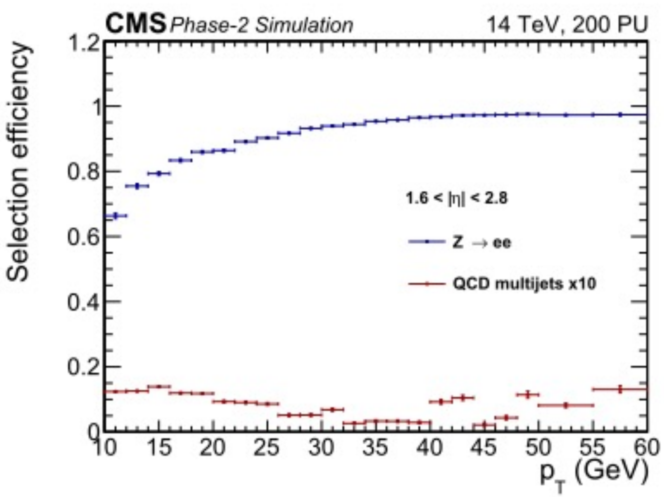




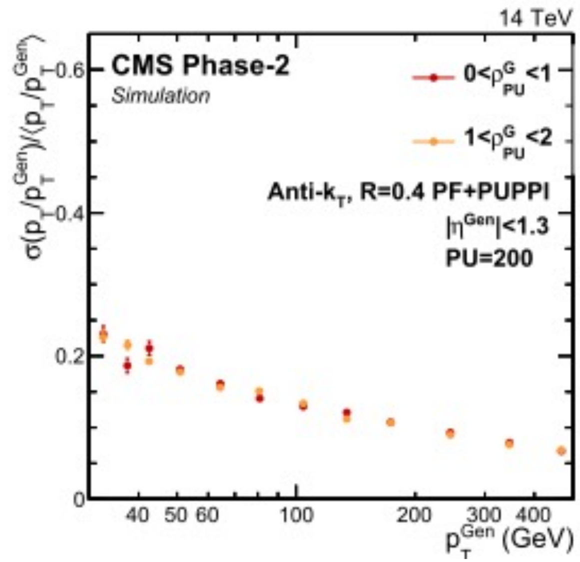
The capability of the upgraded detector has to extend the possibility of a dedicated triggering at Level-1 for displaced objects with a decay length, lifetime, larger than a few centimeters.

HGCal Impact on Physics

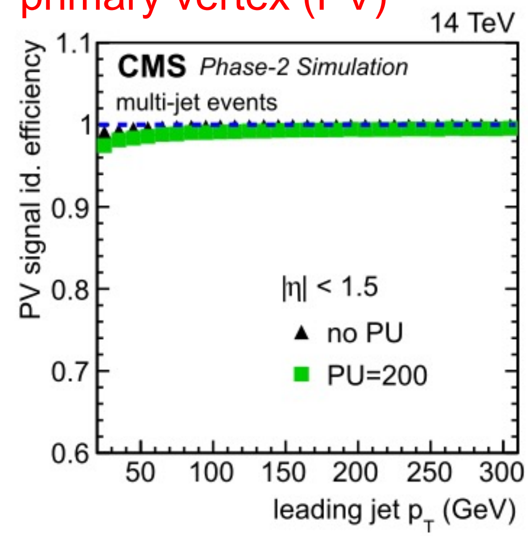
Electron Selection Efficiency (~100%)



Jet response resolution

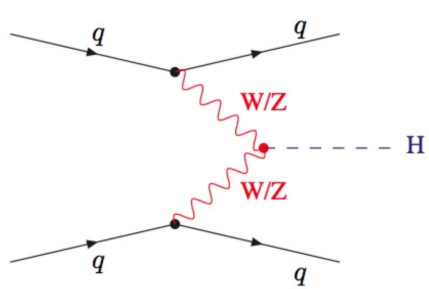


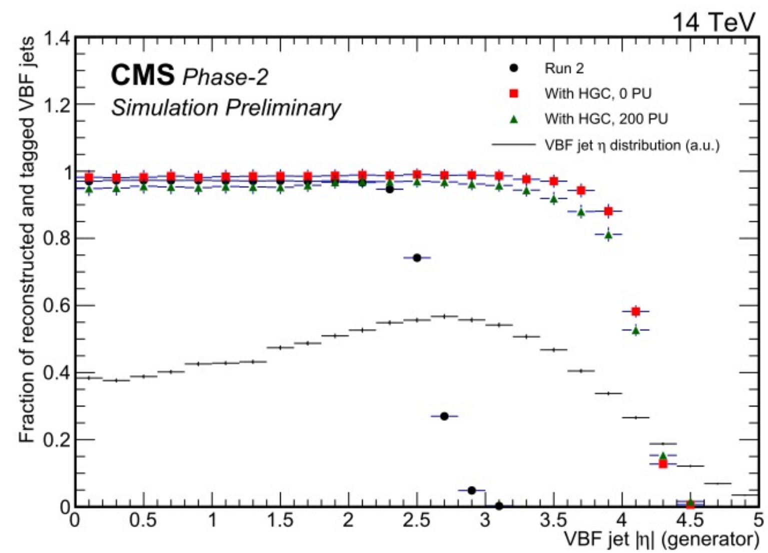
Efficiency to reconstruct the primary vertex (PV)



Vector Boson Fusion (VBF) jet reconstruction and tagging efficiency comparing Run 2 (pileup 25) simulation to the upgraded Phase-2 detector with 0 and 200 pileup events.

Higgs VBF Production





CERN-LHCC-2015-10
LHCC-P-008
CMS-TDR-15-02
ISBN 978-92-9083-417-5
1 June 2015

TECHNICAL PROPOSAL FOR THE PHASE-II UPGRADE OF THE COMPACT MUON SOLENOID

This Technical Proposal presents the upgrades foreseen to prepare the CMS experiment for the High Luminosity LHC. In this second phase of the LHC physics program, the accelerator will provide to CMS an additional integrated luminosity of about 2500 fb^{-1} over 10 years of operation, starting in 2025. This will substantially enlarge the mass reach in the search for new particles and will also greatly extend the potential to study the properties of the Higgs boson discovered at the LHC in 2012. In order to meet the experimental challenges of unprecedented p-p luminosity, the CMS collaboration will need to address the aging of the present detector and to improve the ability of the apparatus to isolate and precisely measure the products of the most interesting collisions. This document describes the conceptual designs and the expected performance of the upgrades, along with the plans to develop the appropriate experimental techniques. The infrastructure upgrades and the logistics of the installation in the experimental area are also discussed. Finally, the initial cost estimates of the upgrades are presented.

This Technical Proposal presents the upgrades foreseen to prepare the CMS experiment for the High Luminosity LHC. In this second phase of the LHC physics program, the accelerator will provide to CMS an additional integrated luminosity of about 2500 fb^{-1} over 10 years of operation, starting in 2025.

CERN-LHCC-2017-023
CMS-TDR-019
9 April 2018

The Phase-2 Upgrade

the CMS endcap calorimeter

Technical Design Report

CMS Collaboration

CERN-LHCC-2017-012
CMS-TDR-016
12 September 2017

The Phase-2 Upgrade

of the CMS Muon Detectors

Technical Design Report

CMS Collaboration

According to the Addendums to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector, JINR participate in

- ✓ Highly Granularity Calorimeter (HGCal) Project with total contribution of 2.2 MCHF
- ✓ upgrade of the Cathode Strip Chambers (CSC) muon chamber with total contribution of 76 kCHF

High-Granularity Calorimeter
HGCal

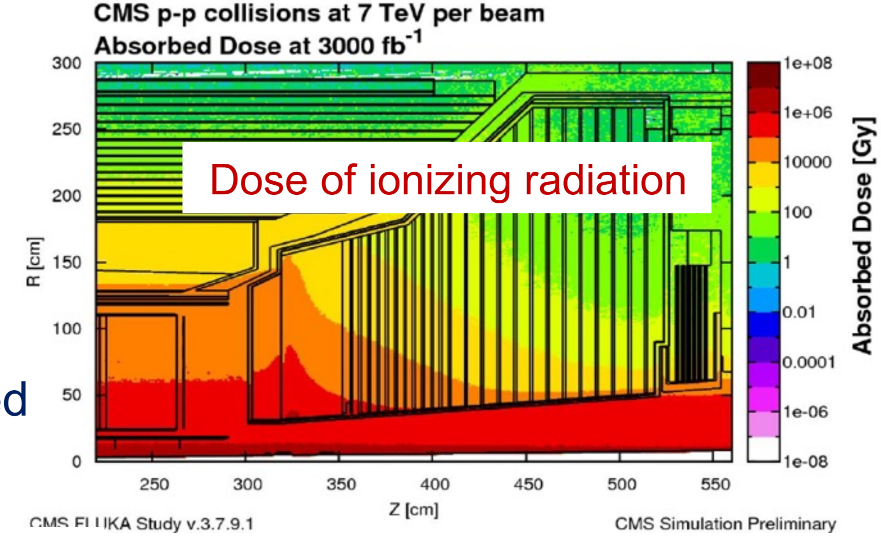
HL-LHC Requirements for Calorimeter Systems

The existing endcap calorimeters, the $PbWO_4$-based electromagnetic calorimeter (EE) and the plastic scintillator-based hadron calorimeter (HE), were designed for integrated luminosity of 500 fb^{-1}

HL-LHC integrated luminosity will became 10 times more - 3000 fb^{-1}, posing significant challenges to radiation tolerance of detectors and pileup

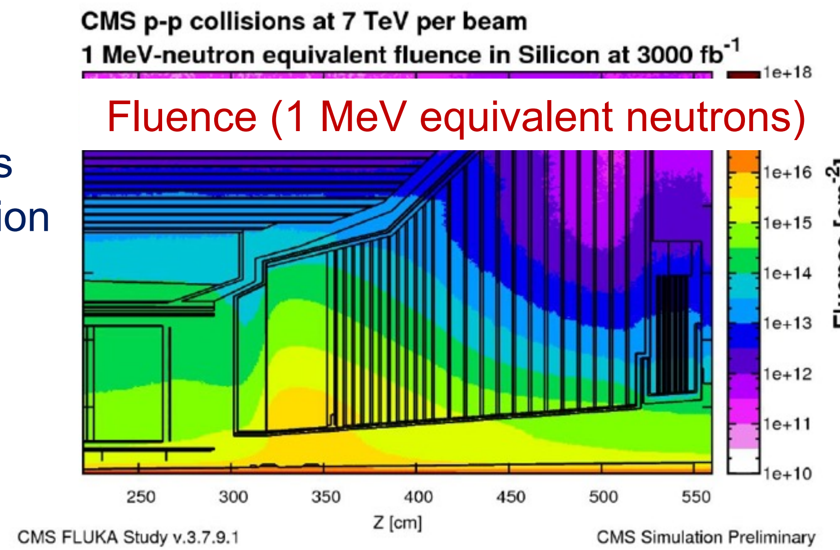
- Fluence ~10^{16} n/cm^2
- Integrated dose ~2 MGy

The **high granularity calorimeter** (**HGCal**) is designed to replace the existing endcap calorimeters



Main design requirements for HGCal :

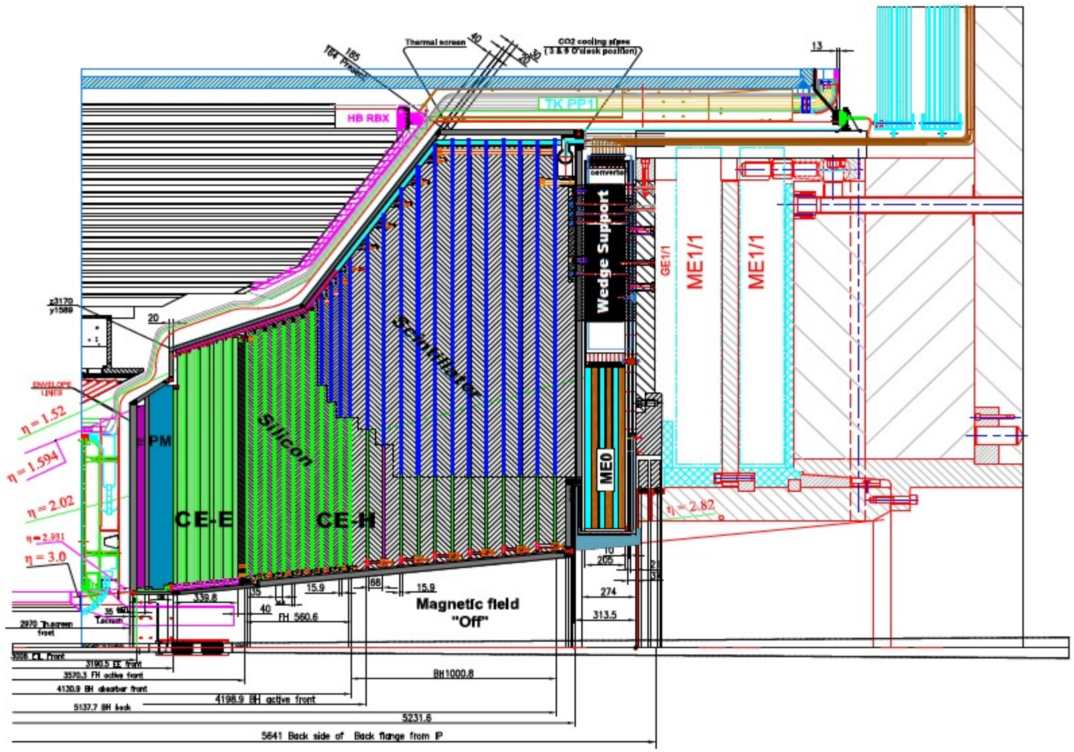
- radiation tolerance
- dense calorimeter structure to preserve lateral compactness in order to simplify two shower separation and the observation of narrow jets
- longitudinal granularity to provide a good electromagnetic energy resolution, pattern recognition and discrimination against pileup
- time precision measurement of high energy showers



Structure of the HGCal

Key Parameters (from TDR):

- HGCal covers $1.5 < \eta < 3.0$ (~640 m^2 of silicon sensors, ~370 m^2 of scintillators)
- full system maintained at -30°C
- 6.1M Si channels, 0.5 or 1.1 cm^2 cell size 240k scint.-tile channels ($\eta-\phi$)
- data readout from all layers
- trigger readout from alternate layers in CE-E and all in CE-H
- ~31000 Si modules (incl. spares)



Longitudinal structure of the HGCAL consists of three types of cassettes:

- **CE-E** cassetts,
- **CE-H** silicon sensor cassettes
- **CE-H** mixed silicon/scintillator cassettes.

Active Elements:

- Si sensors (full and partial hexagons) in CE-E and high-radiation inner region of CE-H
- SiPM-on-Scintillating tiles in low-radiation region of CE-H

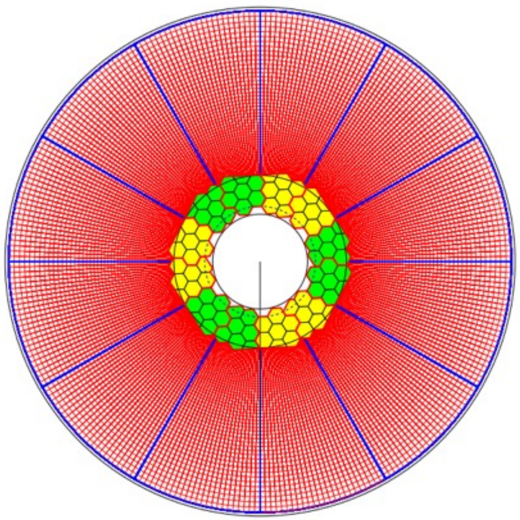
Electromagnetic calorimeter (**CE-E**): **Si**, Cu/CuW/Pb absorbers, 28 layers, 25.5 X_0 & ~1.7 λ

Hadronic calorimeter (**CE-H**): **Si & scintillator**, steel absorbers, 22 layers, ~9.5 λ (including CE-E)

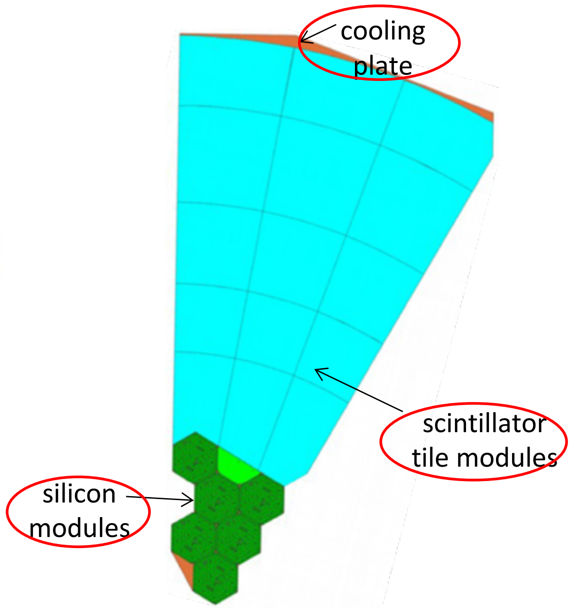
HGCal Active Elements

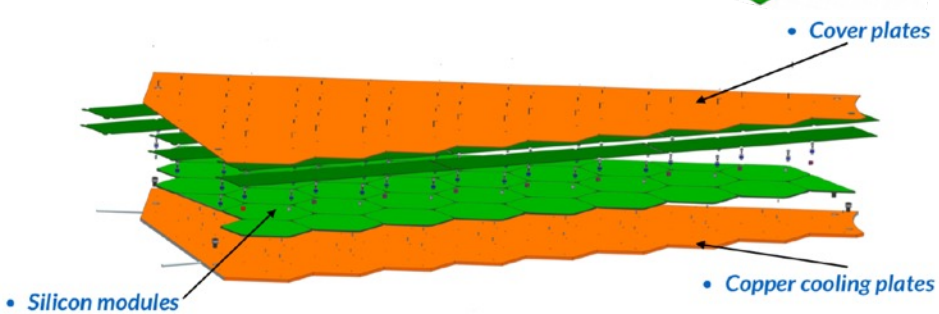
The active detector is formed into cassettes with cooling plate with silicon and scintillation modules

Layer with CE-H mixed silicon/scintillator cassettes



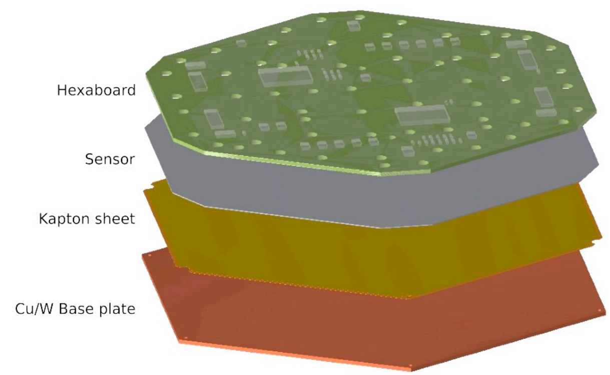
Half of mixed silicon-scintillator cassette





- ✓ Front-end electronics on the modules
- ✓ Readout and control through motherboards
- ✓ Powering via DCDC converters now located at the front-end

Silicon sensors in CE-E and CE-H



JINR Responsibility in the HGCal Project

The Full Cost of the CMS HGCal Project is 67.127 MCHF

According to the Addendum № 14 to the MoU (CERN-MoU-2019-009) JINR has contributed to

- ✓ production of CE-H cooling plates (1210 kCHF)
- ✓ purchase of silicon sensors (700 kCHF)
- ✓ purchase of SiPM photosensors (200 kCHF)

According to the MoU between CMS and JINR (CMS-2010-010) JINR obligations are:

- ✓ production of multi-cassette cold-room facility (90 kCHF)
- ✓ testing and diagnostic of CE-H cassette in 2022-2025
- ✓ assembly and commission of HGCal in 2023-2026

JINR has committed to participated in the HGCal project with total contribution of 2.2 MCHF in CORE

CMS COLLABORATION CERN-MoU-2019-009

ANNEX 4

Deliverables and Assigned Funding for the individual Items by Funding Agency

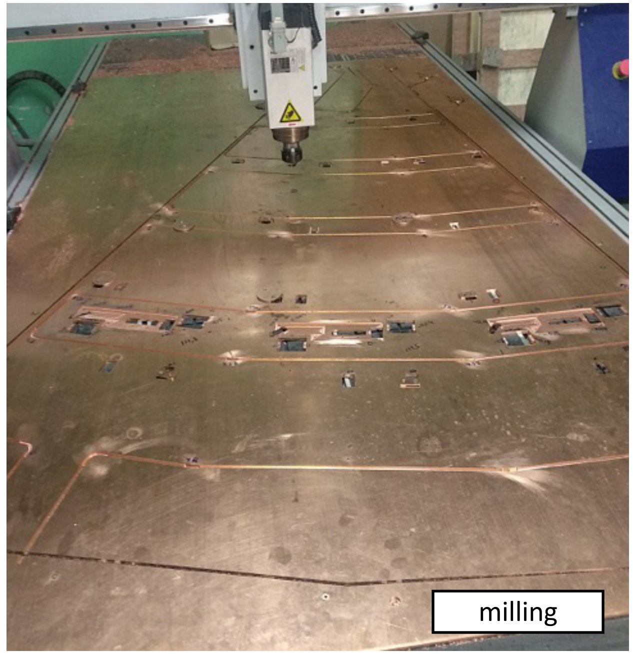
(including Estimated Costs)

Cost Book Items		Assigned Fund Sharing (all numbers in kCHF)																						Totals	
Item number	Item name	Austria	CERN	China	Croatia	France-CEA	France-IN2P3	Georgia	Germany-Helmholtz	Greece	India	Latvia	Malaysia	Montenegro	Pakistan	Portugal	RDMS-DMS	RDMS-Russia	Taipei	Thailand	Turkey	United Kingdom	USA-DOE	Total Assigned Funding	Estimated Cost
4.1.1	CE Electromagnetic Calorimeter (CE-E)						259																	259	258
4.1.2	CE Hadronic Calorimeter (FH+BH = CE-H)		2'324												1'100									3'424	3'424
4.1.3	Cooling		6'913				938	386																8'237	7'618
4.1.4	Dry Gas System		60																					60	60
4.1.5	Mechanical Assembly		80																					80	80
4.1	**Mechanical Systems**		**9'377**				**1'197**	**386**							**1'100**									**12'060**	**11'441**
4.2.1	CE-E Cassettes		221				622																	843	970
4.2.2	CE-H (Si-only) cassettes																295				68		7	370	413
4.2.3	CE-H (mixed) cassettes																915				215		26	1'156	1'324
4.2.4	Cassettes Assembly Centre and Tooling		100				49																149	298	298
4.2.5	Transport (assembly sites to CERN)																						22	22	22
4.2	**Cassettes**		**321**				**671**										**1'210**				**283**		**204**	**2'689**	**3'027**
4.3.1	Sensor Production	900	3'506	699	450	300	1'864			50	612	380	320	190		[illegible]9	700	1'610	1'698		638	1'000	6'459	21'435	21'513
4.3	**Silicon Sensors**	**900**	**3'506**	**699**	**450**	**300**	**1'864**			**50**	**612**	**380**	**320**	**190**		**[illegible]9**	**700**	**1'610**	**1'698**		**638**	**1'000**	**6'459**	**21'435**	**21'513**
4.4.1	Assembly Centre and Tooling			127							127								127				255	637	637
4.4.2	Sensor Module test stations			49							49								49		98			245	245
4.4.3	Silicon Module Components										163							2'859			281		29	3'332	3'331
4.4.4	Si Modules Production - Components on PCB		98	25							25								25				95	267	266
4.4	**Silicon Modules**		**98**	**201**							**364**							**2'859**	**201**		**379**		**379**	**4'481**	**4'479**
4.5.1	SiPM - Photosensors																200	667					851	1'718	1'718
4.5.2	Plastic scintillator																	832						832	832
4.5.3	Wrapping (ESR film)																						111	111	111
4.5.4	Assembly Centre and Tooling								100								90						90	280	270
4.5.5	Scintillator/SiPM Module Production																						3	3	14
4.5	**Scintillator/SiPM Modules**								**100**								**290**	**1'499**					**1'055**	**2'944**	**2'945**
4.6.1	Front-end System (Silicon sensors)		637		400	380	1'719				300		428						701	100			1'939	6'604	5'778
4.6.2	Front-end System (Scintillator/SiPM sensors)		150										122										386	658	872
4.6.3	Front-end System (Common to Silicon and SiPM)		1'821				322									3[illegible]1					128		1'973	4'605	4'164
4.6.4	Clock and Control					320																	180	500	500
4.6.5	Power Distribution		3'493																		468		1'525	5'486	4'448
4.6	**Electronics and Electrical Systems**		**6'101**		**400**	**700**	**2'041**				**300**		**550**			**3[illegible]1**			**701**	**100**	**596**		**6'003**	**17'853**	**15'762**
4.7.1	DAQ		1'183								177										198			1'558	2'447
4.7.2	Trigger		72		500		581				607											2'500		4'260	3'779
4.7	**Backend System (Trigger and DAQ)**		**1'255**		**500**		**581**				**784**										**198**	**2'500**		**5'818**	**6'226**
4.8.1	DCS		107							150														257	257
4.8.2	DSS		191							150														341	341
4.8	**Slow control**		**298**							**300**														**598**	**598**
4.9.1	Assembly Areas		294				46																315	655	655
4.9.2	CE-E Assembly		33															32						65	65
4.9.3	CE-H Assembly (at Point 5)		35																				35	70	70
4.9.4	CE-E-CE-H Integration		100					20																120	120
4.9	**Detector Assembly (on surface)**		**462**				**46**	**20**										**32**					**350**	**910**	**910**
4.10.1	CE installation in UXC		82					94															50	226	226
4.10	**Installation and Commissioning**		**82**					**94**															**50**	**226**	**226**
4	**Grand Total**	**900**	**21'500**	**900**	**1'350**	**1'000**	**6'400**	**500**	**100**	**350**	**2'060**	**380**	**870**	**190**	**1'100**	**4[illegible]0**	**2'200**	**6'000**	**2'600**	**100**	**2'094**	**3'500**	**14'500**	**69'014**	**67'127**

CE-H Cooling Plates (1)

Production steps:

- Copper sheets quality control
- Copper sheet milling from both sides
  - Vacuum table with rotation and transportation system
- Tube electroplating
- Tube bending
- Tube/fitting orbital welding
- Tube and groove tinning
- Ultrasonic cleaning
- Soldering - using preheating table
- Final plate polishing
- Cooling Plates quality control (geometry, pressure, welding)
- Packaging and transportation

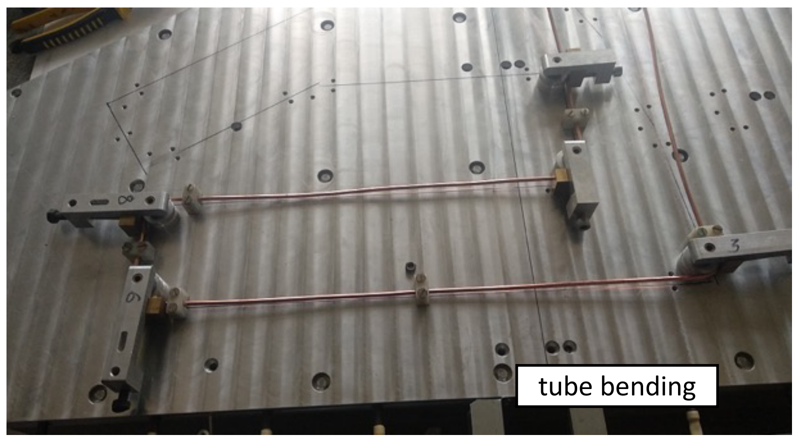


milling

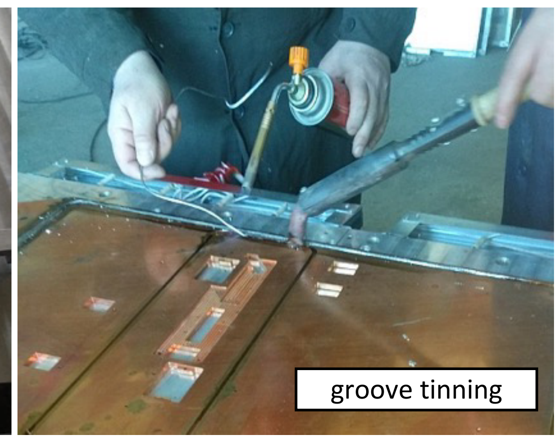
Material:

Oxygen-free copper plates
- thickness 6 mm
- from 1300x900 to 2300x1300

Cooling tube
- 4 mm stainless steel tube
- length from 6m to 13m



tube bending



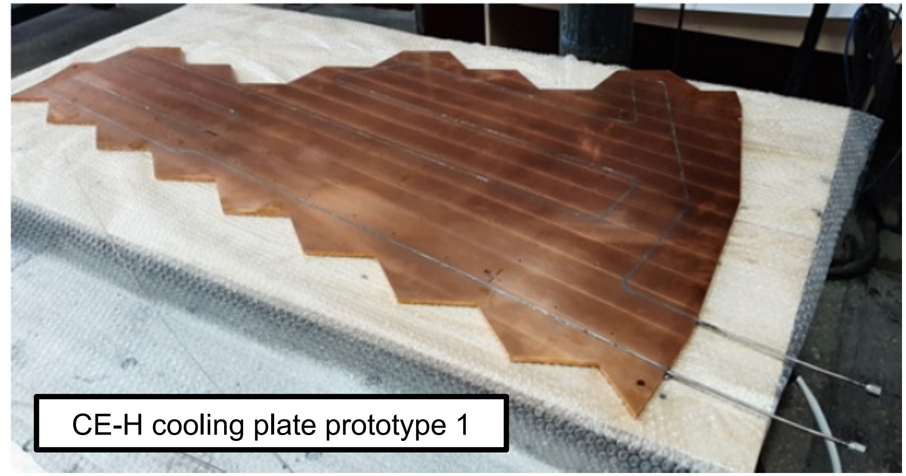
groove tinning

CE-H Cooling Plates (2)

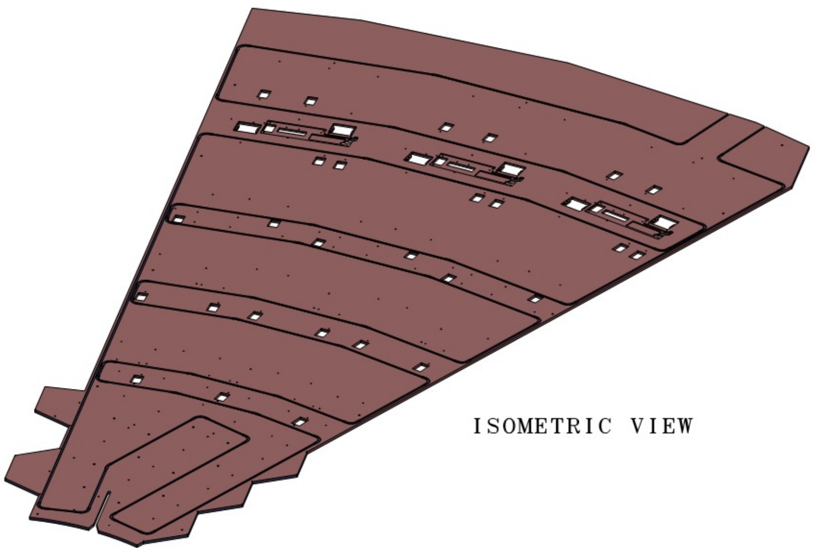
Two prototypes were produced

✓1st prototype delivered in 2020
- −CE-H (Si) plate of minimum size
- −simplified geometry
- −Iterative surface milling: from 8 mm sheet to 6 mm plate
- −milling precision cross-checked by FNAL

✓2nd prototype ready in 2021
- −CE-H (mixed) plate of maximum size
- −using 6-mm copper sheets



CE-H cooling plate prototype 1



Plans for late 2021 & early 2022

✓two adjacent prototypes to test a 60^{o} segment

✓search for different manufacturers

Plans for mass production

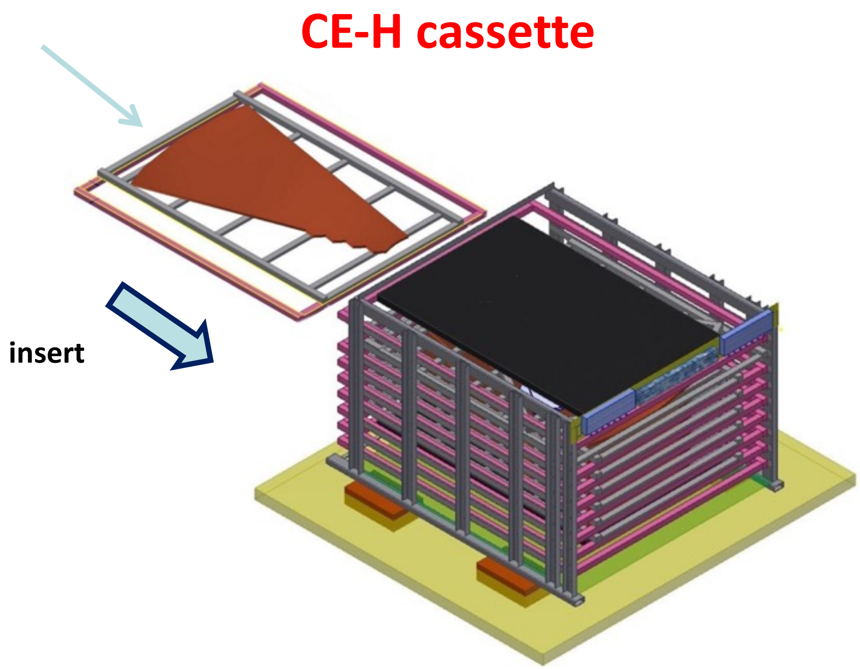
✓tender to be held in 2022

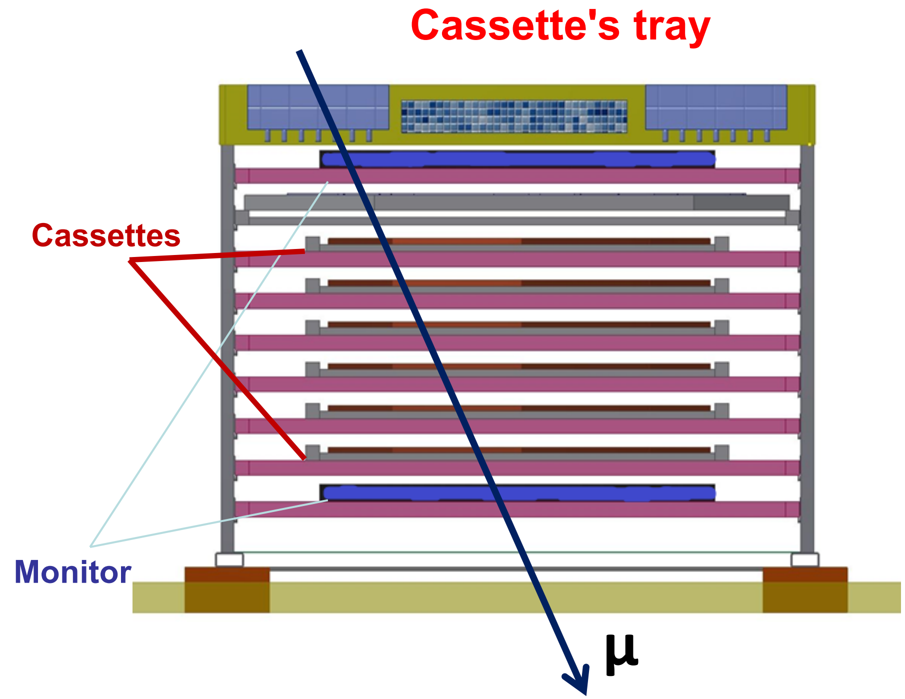
✓546 plates to be delivered at CERN in 2022–2024

Multi-cassette cold-room facility

Testing and diagnostic of dual use multi-cassettes (CE-E and CE-H)

- Up to 7 cassettes testing in cold environment (room cooled to -35^0 C) simultaneously
- The duration of tests of one cassettes batch is ~2 weeks including test with cosmic muons





Will be set up in 2021-2022 and operate in 2022-2025

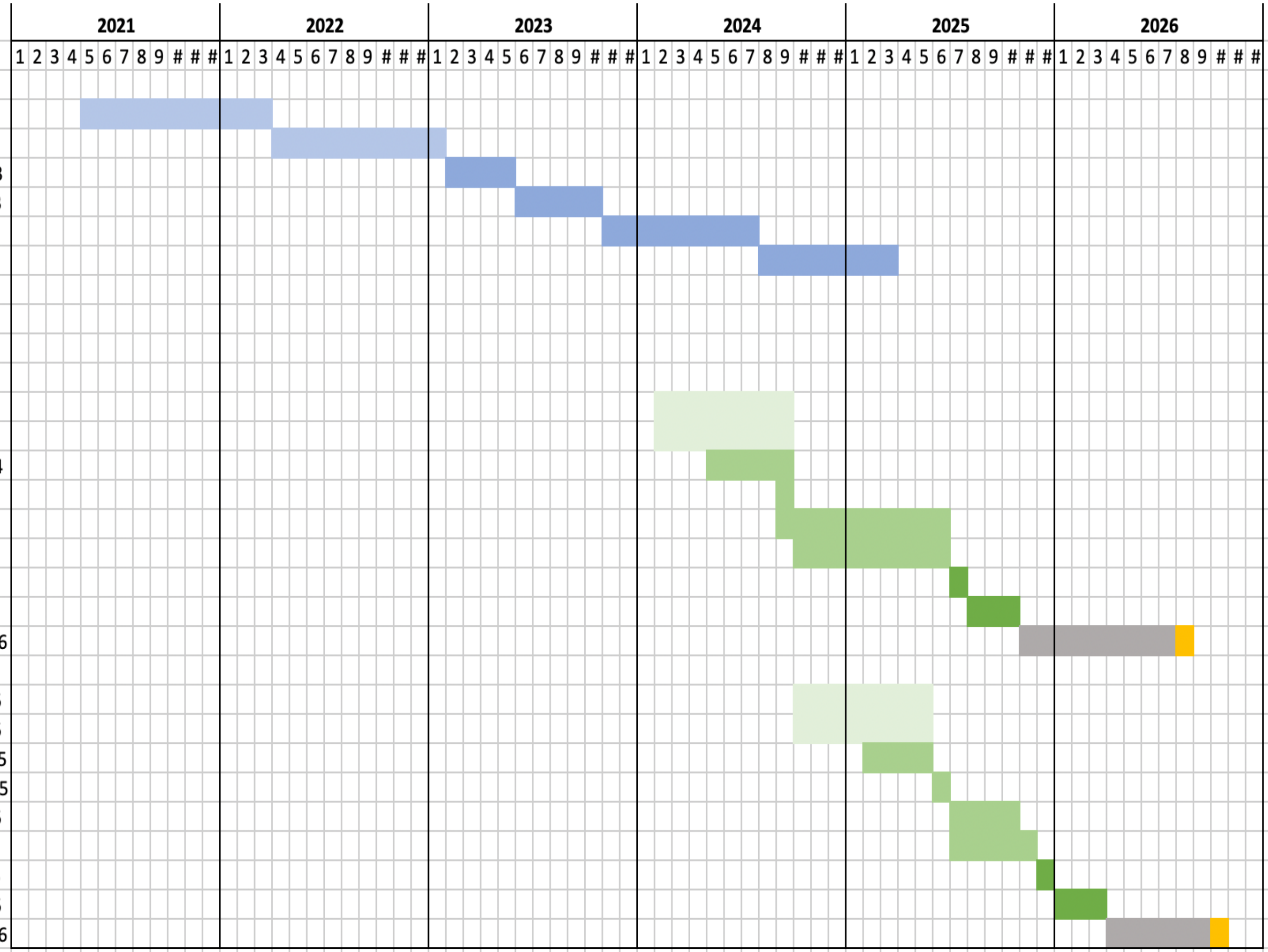
To be done: production of multi-cassette cold-room facility (design, mechanical assembly, services and cables preparation)

Development of cosmic test setup, DAQ, trigger and detector control

HGCal Project Schedule

Cassettte and Detector assembly and commissioning

cassette production	
prepare cassette assembly site at CERN	11-May-21 to 7-Mar-22
develop assembly and testing procedures	7-Mar-22 to 24-Feb-23
1st cassette with final elements assembled	24-Feb-23 to 25-May-23
cassette preproduciton (5%)	25-May-23 to 22-Oct-23
cassette production (first 50%)	22-Oct-23 to 15-Jul-24
cassette production (100%)	19-Aug-24 to 16-Apr-25
detector assembly	
CE-E1 stacking of cassettes	19-Feb-24 to 16-Sep-24
CE-H1 insertion of cassettes	19-Feb-24 to 16-Sep-24
integration of CE-H1 (sector by sector)	13-May-24 to 16-Sep-24
CE-E1 mechanical assembly on CE-H	16-Sep-24 to 30-Sep-24
integration of CE-E1 part and finishing	30-Sep-24 to 09-Jun-25
Sector tests of full CE1 (at room temperature)	30-Oct-24 to 11-Jun-25
HGCAL1 thermal screen installation	11-Jun-25 to 11-Jul-25
HGCAL1 cold tests	11-Jul-25 to 09-Oct-25
HGCAL1 lowering to UX5	26.Jul.26
CE-E2 stacking of cassettes	18-Oct-24 to 16-May-25
CE-H2 insertion of cassettes	18-Oct-24 to 16-May-25
integration of CE-H2 (sector by sector)	21-Feb-25 to 16-May-25
CE-E2 mechanical assembly on CE-H	16-May-25 to 30-May-25
integration of CE-E2 part and finishing	30-May-25 to 31-Oct-25
Sector tests of full CE2 (at room temperature)	20-Jun-25 to 21-Nov-25
HGCAL2 thermal screen installation	21-Nov-25 to 21-Dec-25
HGCAL2 cold tests	21-Dec-25 to 21-Mar-25
HGCAL2 lowering to UX5	06.Sep.26



- CE-E cassette preparations
- CE-E cassette production
- stacking of CE-E cassettes, insertion of CE-H cassettes
- integration of CE-E and CE-H, warm tests
- themal screen installation and cold tests of fully assembled endcaps
- contingency
- lowering of endcaps

based on EDMS 2276592
Oct-30-2020

Upgrade of the Endcap Muon System

Motivations/Benefits for Muon Upgrade

HL-LHC conditions

Instantaneous luminosity	x 5
Integrated luminosity	x 10
Pileup	x 5

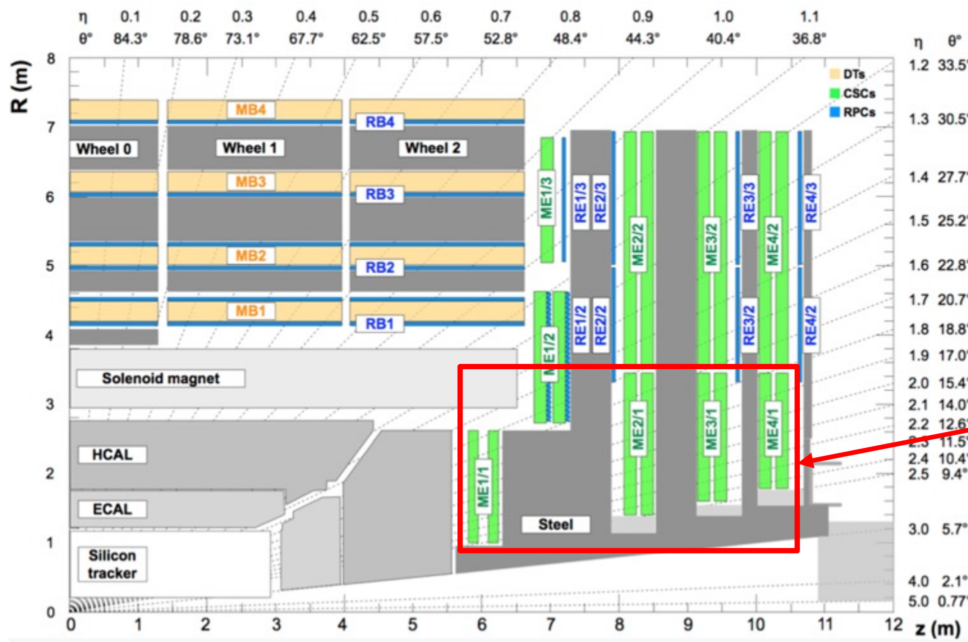
HL-LHC at detector level

L1 trigger rate	x 7.5
L1 trigger latency	x 10
DAQ bandtwidth	x 10

Additional requirements to sustain work at high rates

to detectors, readout, DAQ and trigger electronics.

The main task of ME CSC Phase 2 upgrade: modernization of CSC electronics on the inner rings Muon stations (Mex/1), where the rates is higher with respect to the outer stations



MEx/1 ststions: ME1/1, ME2/1, ME3/1,ME4/1

Total 180 CSCs

Contribution of RDMS-JINR in Muon System upgrade during LS2 period :

- Design and construction of 120 new Low Voltage Distribution boards (LVDB-5)
- Assembly, installation and commissioning of the 180 inner muon chambers
- Modernization of the ME1/1 cooling system
- Endcap Muon System upgrade infrastructure

JINR Responsibility in the Muon Upgrade

The Full Cost of the CMS Muon Upgrade is 21.437 MCHF

According to the Addendums 13 to the MoU (CERN-MoU-2019-008) JINR contribute to CORE:

- ✓ upgrade of the CSC electronics (76 kCHF)
- ✓ RPC Upgrade Project (75 kCHF paid by Georgia Institutions)

Also, JINR group participates in R&D works:

- ✓ CMS CSC ageing study at GIF++
- ✓ study of CSC characteristics in HL-LHC conditions with uncorrelated background.
- ✓ study of methods for eliminating the Malter current in a cathode strip chamber.
- ✓ participation in the new gas mixture studies
- ✓ development and test of an algorithms for track segments reconstruction in the CSC chambers.

CMS COLLABORATION CERN-MoU-2019-008

ANNEX 4

Deliverables and Assigned Funding for the individual Items by Funding Agency

(including Estimated Costs)

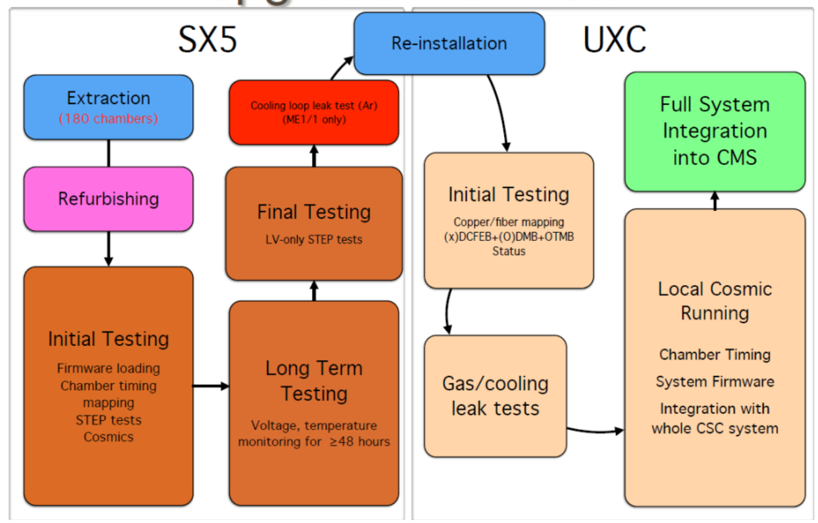
Cost Book Items		Assigned Fund Sharing *(all numbers in kCHF)*																				Totals	
Item number	Item name	Bulgaria	CERN	China	Colombia	Egypt	France-IN2P3	Germany-BMBF	Hungary	India	Iran	Italy	Korea	Mexico	Qatar	RDMS-Russia	RDMS-DMS	Spain	Sri Lanka	USA-DOE	USA-NSF	Total Proposed Funding	Estimated Cost
2.2.1	Minicrate System							948	100			1'472						769				3'289	3'289
2.2.2	DT Back-end electronics							499				545		112				453				1'609	1'609
2.2.3	OPTOLINKS							223				283						278				784	784
2.2	**DT Electronics**							**1'670**	**100**			**2'300**		**112**				**1'500**				**5'682**	**5'682**
2.3.1	On-detector electronics and OTMBs															11	76			2614		2'800	2'690
2.3.2	FED system and ODBMs															10					887	994	887
2.3.3	High Voltage System															20						209	209
2.3	**CSC Electronics**															**42**	**76**			**2614**	**887**	**4'003**	**3'785**
2.4.1	RE3/1 RE4/1 Chambers	73			48	50						100	340	509			75					1'195	1'170
2.4.2	RE3/1 RE4/1 Front-end electronics						600					50		189								839	749
2.4.3	RE3/1 RE4/1 Power System											150		190								340	335
2.4.4	Back-end electronics			400							1'390											1'790	1'380
2.4	**RPC Upgrade Project**	**73**		**400**	**48**	**50**	**600**				**1'390**	**300**	**340**	**888**			**75**					**4'164**	**3'634**
2.5.2.1	GE2/1 Chambers	89		157				50	60	434		405	433		240				319			2'187	2'002
2.5.2.2	GE2/1 Front-end Electronics		148									170										318	272
2.5.2.3	GE2/1 DAQ and Back end electronics			264												5					531	847	884
2.5.2.4	GE2/1 Power System		452			50						435										937	937
2.5.2	**GE2/1 Detector System**	**89**	**600**	**421**		**50**		**50**	**60**	**434**		**1'010**	**433**		**240**	**5**			**319**		**531**	**4'289**	**4'095**
2.5.3.1	ME0 Chambers	148		143				100	65	445		30	633		60				354			1'978	1'732
2.5.3.2	ME0 Front End Electronics		92									231							87			410	411
2.5.3.3	ME0 DAQ and Backend Electronics			186																	721	907	959
2.5.3.4	ME0 Power System		608			50						479										1'137	1'139
2.5.3	**ME0 Detector System**	**148**	**700**	**329**		**50**		**100**	**65**	**445**		**740**	**633**		**60**				**441**		**721**	**4'432**	**4'241**
2	Grand Total	310	1'300	1'150	48	150	600	1'820	225	879	1'390	4'350	1'406	1'000	300	47	151	1'500	760	2'614	2'139	22'570	21'437

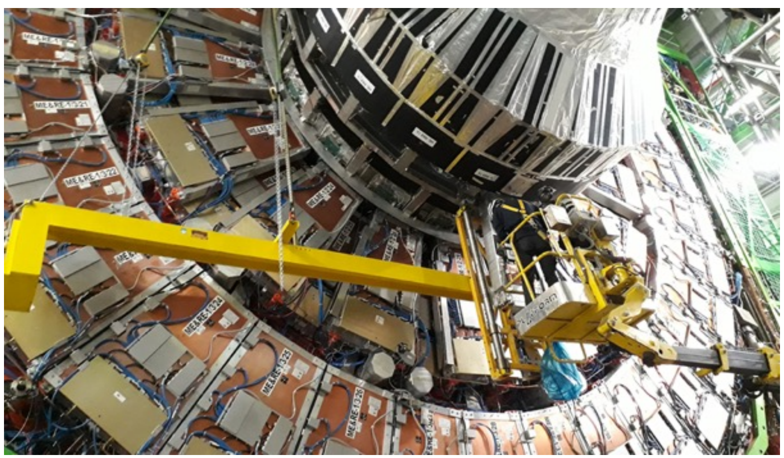
JINR team participation in LS2 CSC upgrade

On-chamber electronics on MEx/1 chambers upgrade done in LS2 shutdown instead of initially planned LS3 due to the LS3 shutdown will be extremely busy

CSC upgrade infrastructure

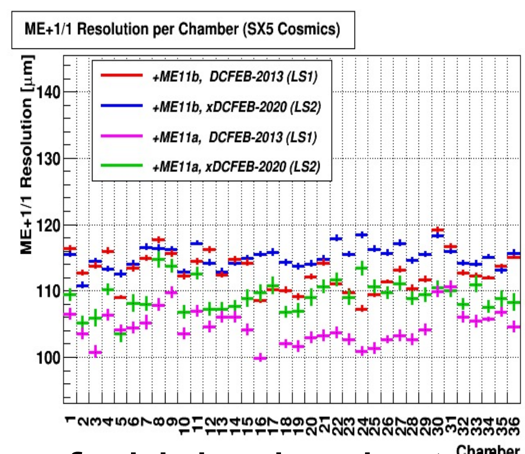
Upgrade Workflow

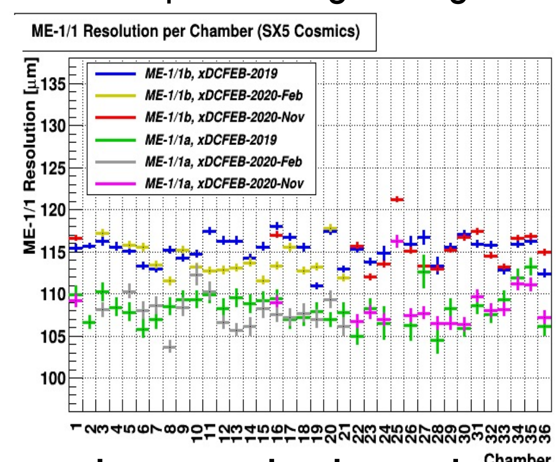




ME1/1 installation with Loading Machine

LS2 CSC cosmic test data for both Endcaps are in good agreement





180 CSC chambers successfully refurbished, reinstalled and commissioned

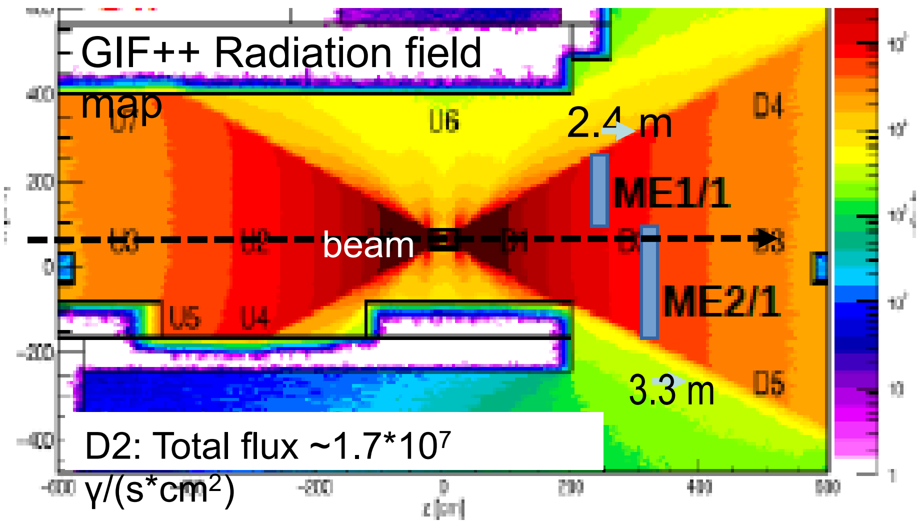
CSC ageing study R&D at GIF++

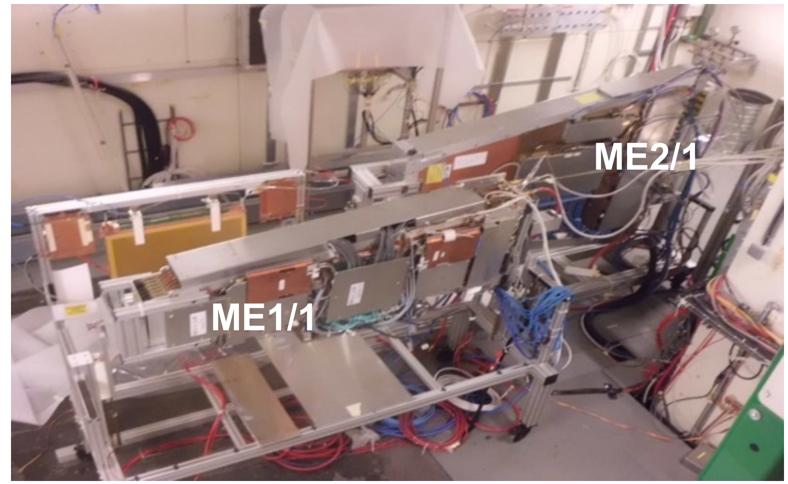
Main goals of tests at Gamma Irradiation Facility GiF++ :

1. CSC Ageing study.
2. CSC characteristics degradation with the background rate increase study.
3. Study of methods for Malter current eliminating.

Will CSCs survive at HL-LHC of L_{int}=3000 fb-1?

14 TBq Cs137 source (Eγ = 662 keV)





Irradiation:

4 inner layers (L2-L5) have HV = on, I_{layer} ~300μA

L1 and L6 Ireference layers - (HV=0)

Equivalent to 3×HL-LHC of L=3×3000 fb^{-1}

the integrated charge to be:

ME1/1 - 0.33 C/cm

ME2/1(sect.1) - 0.24 C/cm

Longevity tests- monitoring CSC performance:

- Dark rate/currents
- Relative currents
- Strip-strip resistance
- Test beam measurements:

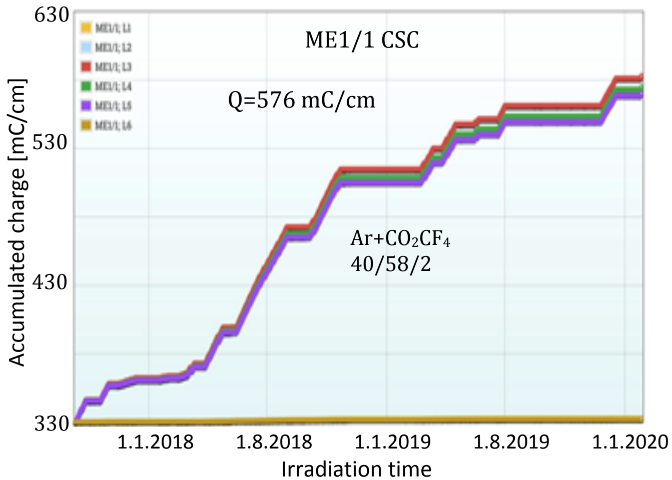
✓ Efficiency

✓ Spatial resolution

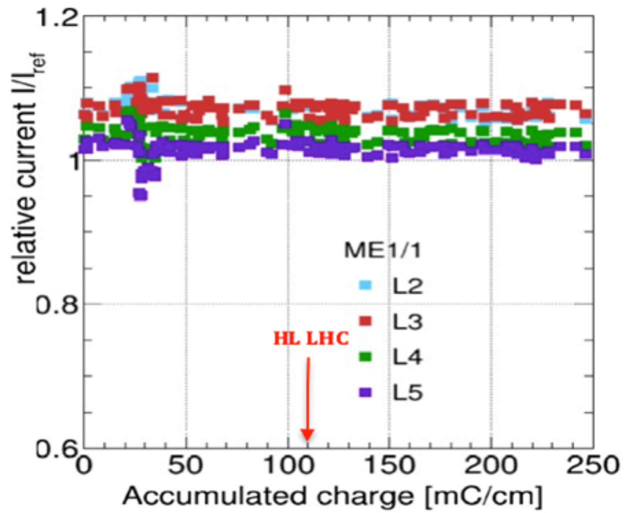
✓ Gas gain

Recent CSC ageing study results

ME1/1 with the accumulated charge



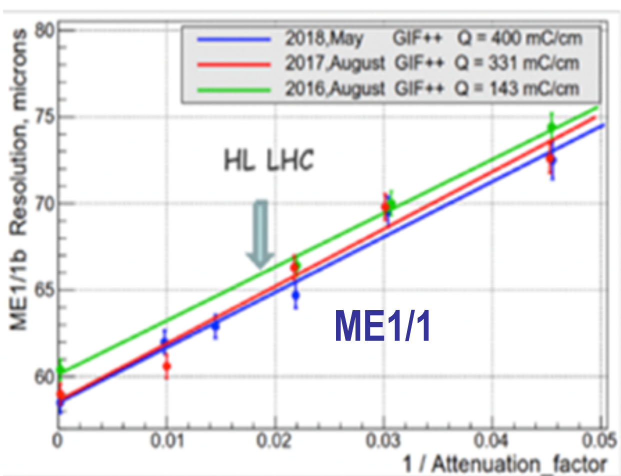
ME1/1 accumulated charge in time

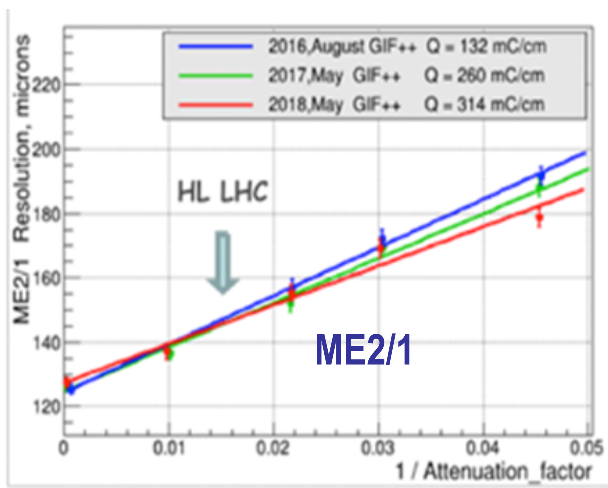


ME1/1 Relative current I_{layer}/I_{ref}.

No degradation observed

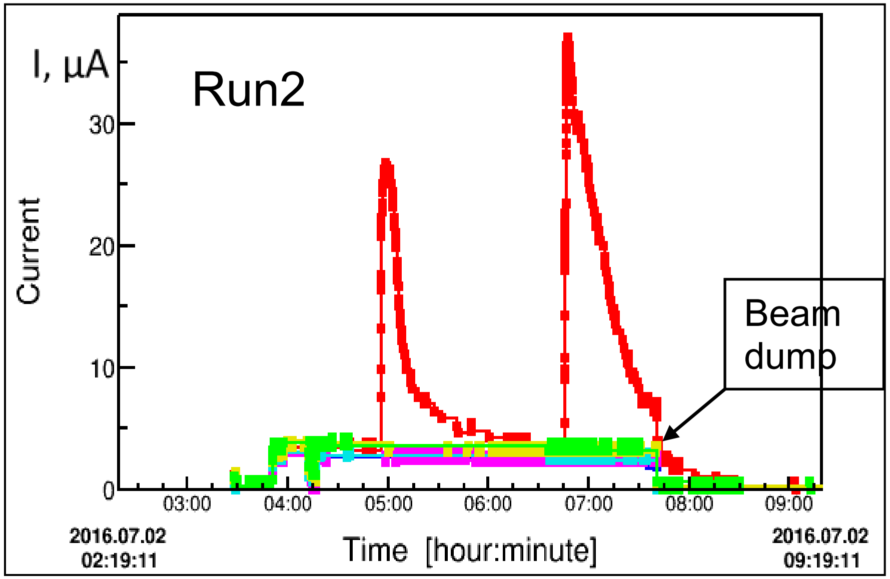
CSC spatial resolution vs GIF++ Source intensity for different values of accumulated charge

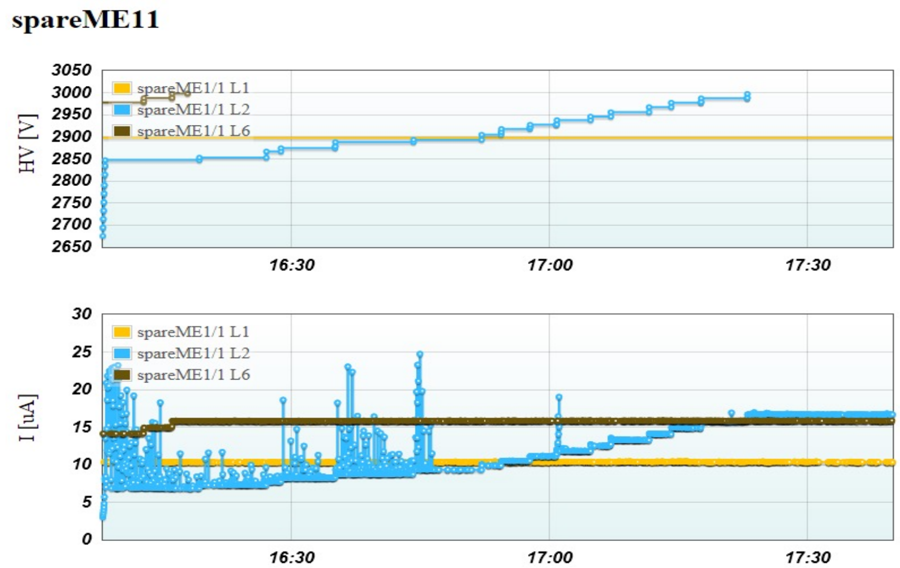




With the HL LHC conditions at L= 5×10^{34} Hz/cm^2 the spatial resolution degradation:
10% for ME1/1
16% for ME2/1

Malter currents at CMS and GIF++





CMS p-p collisions:

One of the 6 CSC ME1/1 layers shows a current spike exceeding 30 µA followed by a long-time discharge. The current persists even after the LHC beams are dumped. The other layers show stable currents around 3 µA.

HV training of the Spare ME1/1 layer 2 (blue) at GIF++.

The current is produced by Cs-137 gamma source. As soon as the current disappeared, the voltage is raised manually by 5-10V. At some point Malter current disappears and no seen even at HV=3.0kV.

Upgrade Cost Summary

The CMS Phase II Upgrade Cost is 285 MCHF in terms of CORE value

The Phase II Upgrade Common Fund is established at the level of 25’000’000 CHF (twenty-five million Swiss Francs)

According to the Addendums to the Memorandum of Understanding for Collaboration in the Construction of the CMS Detector, JINR has following commitments in CORE (2020-2026):

- ✓ participation in the Highly Granularity Calorimeter (HGCal) Project with total contribution of 2.2 MCHF
- ✓ upgrade of the Endcap Muon system Cathode Strip Chambers (CSC) with total contribution of 76 kCHF (these obligations is nearly fulfilled, have to be accounted)

The payments also needed for:

- ✓ contribution to Upgrade Common Funds of 289,855 kCHF in 2022-2026 (468.855 kCHF is in a total, 144.928 kCHF is already accounted for 2020-201)
- ✓ 179 kCHF of operation expenses on technical maintenance of the HGCal in 2022-2026 according M&O_B

The R&D for Muon System are foreseen for study CSC performance at HL-LHC conditions

Funding Requested for 2022–2026

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

LABORATORY CHIEF ENGINEER-ECONOMIST G.G. Volkova

We ask VBLHEP Scientific Council to support prolongation of our Project

aimed to Upgrade of the CMS Detectors ongoing activities for the LHC Phase 2 (HGCal and Muon System)

for 2022-2026

Thank you for your attention!!!

CERN

Memorandum of Understanding (MoU)
on participation of
the Joint Institute for Nuclear Research (JINR)
in the the Compact Muon Solenoid (CMS)
Phase-2 High Granularity Calorimeter (HGCal) Project
at CERN

According to the Annex 4 of the Addendum No. 14 to the Memorandum of Understanding (ref. CMS-MoU-2019-009), the Joint Institute for Nuclear Research (JINR) in Dubna, Russian Federation has committed to participate in the HGCal Project with total contribution of 2.2 MCHF. Within this project, JINR has agreed to provide CORE financing of 90'000 CHF (ninety thousand swiss francs) to the task 4.5.4 (Assembly Centre and Tooling).

Following the review of the production and assembly process, mutually done by JINR and CERN scientists, it has been decided that Tilemodule Assembly Centre facility, to be placed either in Dubna or in CERN, is no longer needed. JINR will instead provide financing of 90'000 CHF to the task 4.2.4 (Cassettes Assembly Centre and Tooling) and assume lead responsibility for sub-task 4.2.4.2 (Test/Burn-in Stands including CO2 cooling) at CERN. JINR Group will in addition participate in cassette activities and in detector assembly and commissioning at CERN.

With respect to Annex 3 of the above-mentioned Addendum 14, the JINR Group will participate in the following tasks using none-core funds in addition to 90'0000 CHF core funds defined in 4.2.4.2:

1) design, construction, commissioning and operation of the dual use (CE-E and CE-H), multi-cassette cold-room test facility. This facility will be set up in 2021-22 at CERN SXA5 building at the Point 5 site in Cessy, France. The facility will be operated in 2022-25;
2) reception testing and diagnostics of CE-H cassettes arriving from the Fermi National Accelerator Laboratory (FNAL) in Batavia, USA to CERN. This activity will take place in the period 2022-25 at CERN Building SXA5 at the Point 5 site in Cessy, France;
3) assembly and commissioning of HGCal detectors, including installation of CE-H cassettes into absorber, integration of CE-H sections and cold-tests of fully assembled HGCal endcaps. These activities are scheduled to take place in the period 2023-26 at CERN Building SX5 at the Point 5 site in Cessy, France.

The expenses for the travel and staying at CERN for the JINR Group to carry out above mentioned tasks are under responsibilities of JINR. Other non-core funding for the above projects will be subject of further discussion between CMS and JINR.

In two copies:

Signed in Dubna	Signed in Geneva, Switzerland
on 30 October 2020	on 22 October 2020
For JINR	For CMS Collaboration
Prof. Viktor Matveev Director of JINR	Dr. Karl Gill CMS HGCal Project Manager
	Mr. Andrzej Charkiewicz CMS Resources Manager