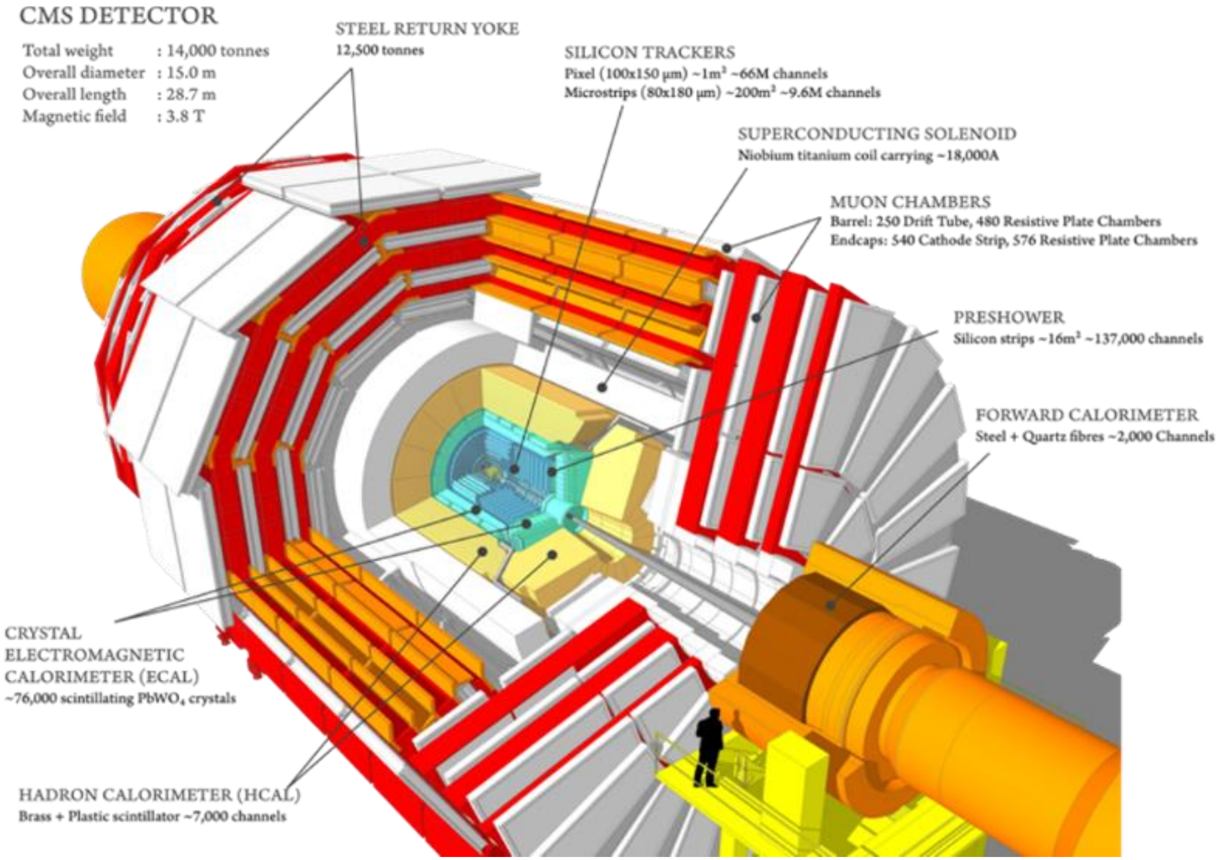
International Scientific Seminar dedicated to the memory of the Prof. I. A. Golutvin and his 90th Anniversary.

"Experimental Methods in Particle Physics"



RDMS contribution in construction of CMS Detector systems

Vladimir Karjavine

JINR Dubna, August 8, 2024

Timeline of the LHC Project Launching

CMS Letter of Intent → 1992

RDMS was founded → 1994

RDMS CMS Project → 1995

1984	Workshop on installing a Large Hadron Collider (LHC) in the LEP tunnel
1987	CERN’s long-range planning committee chaired by Carlo Rubbia recommends Large Hadron Collider as the right choice for CERN’s future
1989	LEP collider starts operation
1992	**First concepts for LHC Experiments, Evian les Bains**
1994	LHC Approved, ATLAS and CMS approved (**Technical Proposals**)
1995	
1998	**Construction begins**
2000	CMS assembly begins above ground; LEP Collider closes
2003	ATLAS underground cavern delivered, and assembly underground begins
2005	CMS experiment cavern delivered
2008	**LHC & Experiments ready for Beam. First proton-proton Collisions**

Historical Reference

ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ

ПРИКАЗ

10 августа 1994 года N 475

г. Дубна

В соответствии с решением Ученого совета ОИЯИ от 7-8 июня 1994г.

ПРИКАЗЫВАЮ:

1. Открыть с 1994 года сроком на четыре года новую тему "CMS - КОМПАКТНЫЙ СОЛЕНОИД" и присвоить ей шифр 02–7–1006–94/97, приоритет 1, руководитель темы Голутвин И.А.

2. Открыть с 1994 года сроком на четыре года новую тему "АТЛАС. pp - эксперимент общего назначения на LHC, присвоить ей шифр 02–2–1007-94/97, приоритет 1, руководитель темы Русакович Н.А.

Вице-директор ОИЯИ А.Н.Сисакян

08.08.94.

JINR order № 475 concerning opening new 1st priority Theme: “CMS - Compact Muon Solenoid“

Theme leader: Igor Golutvin

Exactly 30 years ago!

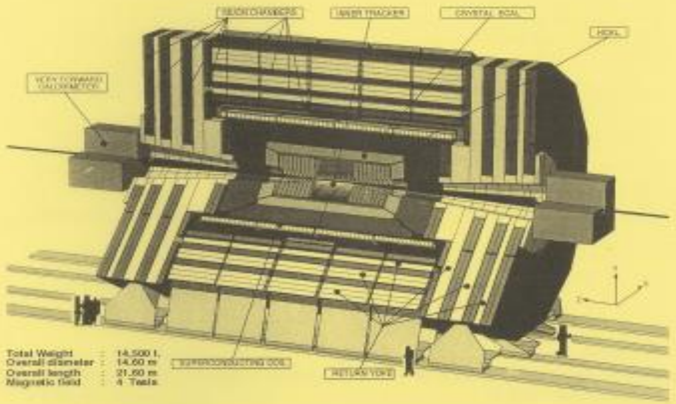
RDMS CMS Project

CMS Document 96-85, 1995

Study of Fundamental Properties of the Matter in Super High Energy Proton-Proton and Nucleus-Nucleus Interactions at CERN LHC. Participation in CMS Collaboration.

Project

Russia and Dubna Member States CMS Collaboration



Chairman of Russia and Dubna Member States CMS Collaboration Board

Victor Matveev

Spokesman of Russia and Dubna Member States CMS Collaboration

Igor Golutvin

Согласовано

Директор Государственного научного центра
"Институт Физики Высоких Энергий"
Академик РАН А.А.Логунов
"25" июля 1995

Директор Государственного научного центра
"Институт Теоретической и Экспериментальной Физики"
Профессор И.В.Чувило
"15" сент. 1995

Директор Государственного научного центра
"Институт Ядерных Исследований РАН"
Академик РАН В.А.Матвеев
"21" июля 1995

Директор Государственного научного центра
"Институт Ядерной Физики им. Г.И. Будкера СО РАН"
Академик РАН А.Н.Скринский
"19" IX 1995

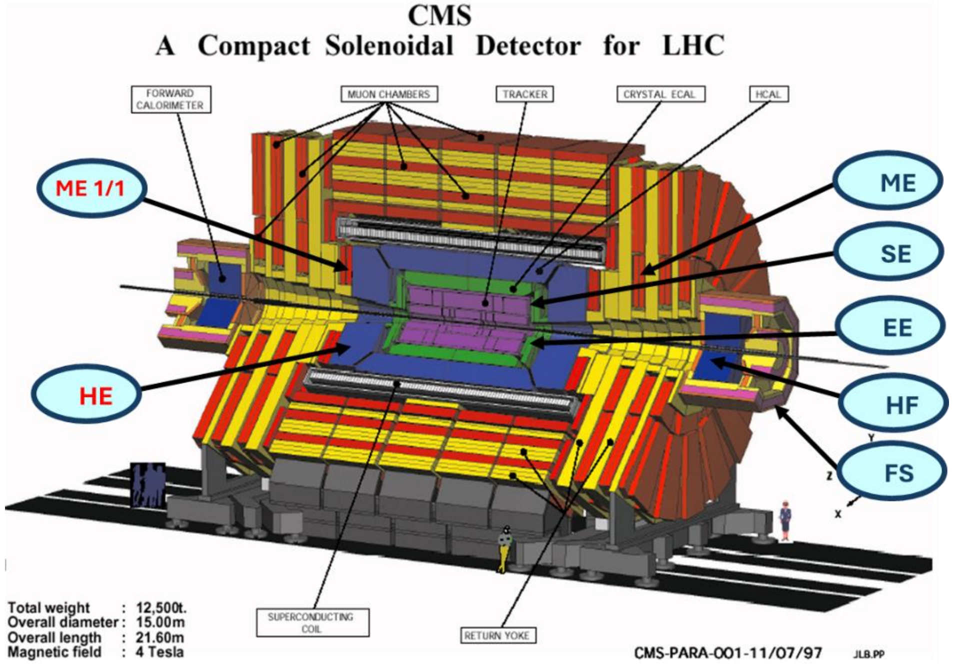
Директор Научно-Исследовательского Института Ядерной Физики
Государственного Московского Университета
Профессор М.И.Панасюк
"14" сент 1995

Директор Государственного научного центра
"Петербургский Институт Ядерной Физики им. Б.П. Константинова РАН"
Профессор В.А.Назаренко
"__" ______ 1995

Директор Отделения Ядерной Физики
Физического Института им. П.Н. Лебедева РАН
Член-корреспондент РАН С.И.Никольский
"22" сентября 1995

Директор Объединенного Института Ядерных Исследований
Член-корреспондент РАН В.Г.Кадышевский
"21" июля 1995

RDMS role in CMS Construction



The CMS RDMS Collaboration under leadership of Professor Igor Golutvin made outstanding contribution to the design and construction of the CMS endcap detectors and systems

RDMS Full responsibility:

Endcap Hadron Calorimeter, **HE**

Forward Muon Station, **ME1/1**

RDMS Participation:

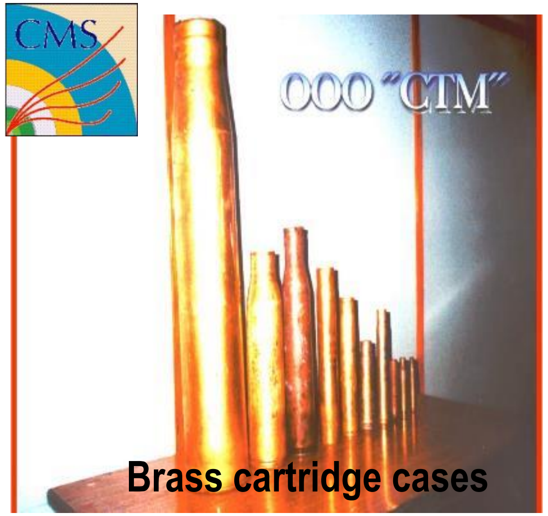
Forward Hadron Calorimeter, **HF**

Endcap Electromagnetic Calorimeter, **EE**

Preshower Detector of ECAL, **SE**

Endcap Muon System, **ME**

Forward Shielding, **FS**



Brass cartridge cases


Machining HE sectors at MZOR


Pre-assembly of HE disks at Minsk

Endcap Hadron Calorimeter, HE

JINR (Dubna), IHEP (Protvino)

In cooperation with NC PHEP (Minsk), NIKIET (Moscow), KIPT and Single Crystal Institute (Kharkov)


Rolling plates at Krasny Vyborzhets

Full responsibility for design, construction and commissioning of the CMS Hadron Endcap calorimeter.

Endcap nose with brass absorber plates and scintillator megatiles were designed, built, tested and installed by RDMS groups.

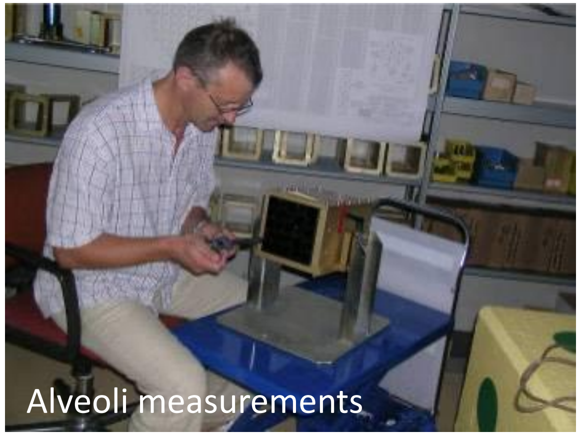
- Mechanical design by NIKIET
- Brass absorber plates were rolled in IZHORA of St. Petersburg
- Machined and pre-assembled in MZOR of Minsk
- Scintillator megatiles machined at Kharkov
- Megatiles assembled and tested in Protvino

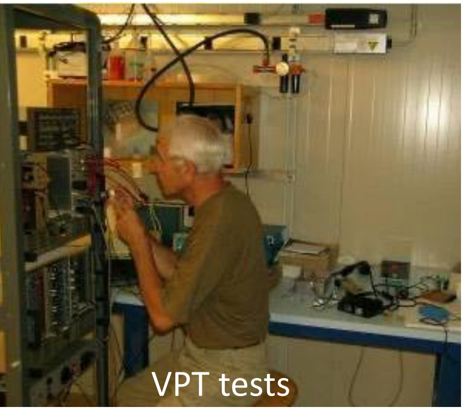
Endcap Hadron Calorimeter Installation at CERN

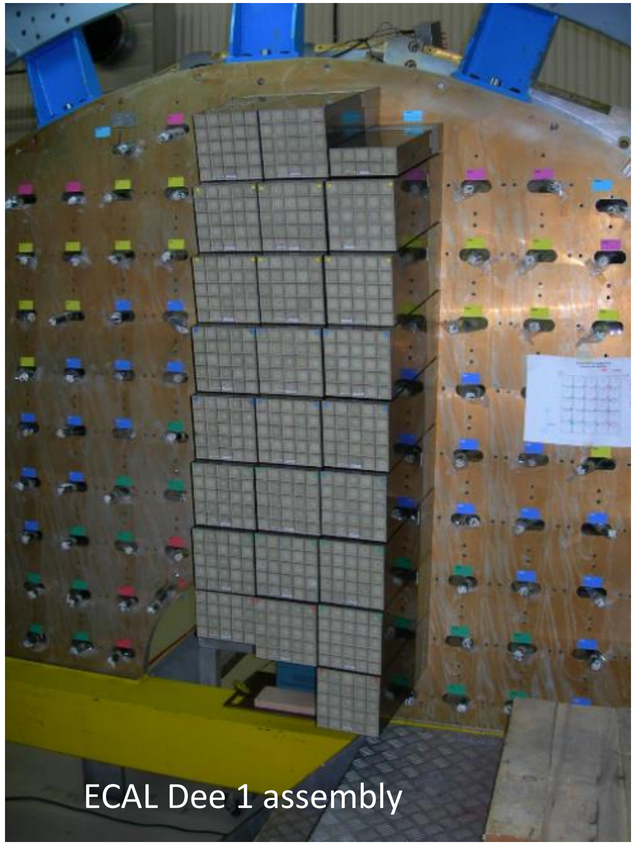
The HE installation was done by RDMS group with leadership of Vitali Kaftanov (ITEP)

Endcap Electromagnetic Calorimeter, EE

EE assembly, tests and quality control



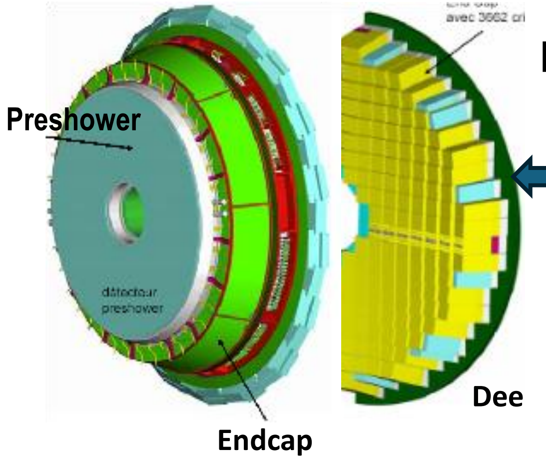




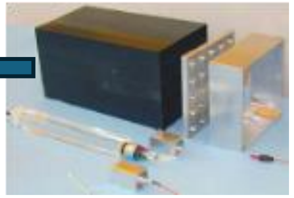
INR (Troitsk), IHEP (Protvino), PNPI St. Petersburg
LPI (Moscow), MSU(Moscow)

In cooperation with BTCP Bogoroditsk, RIE St. Petersburg, Myasishchev Design Bureau, Moscow

Electromagnetic calorimeter based on PWO crystals was proposed for the CMS by physicists from IHEP in 1994



Modular structure

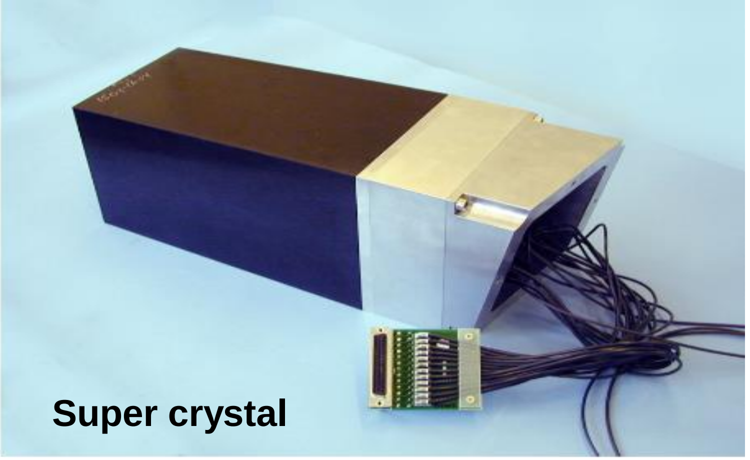


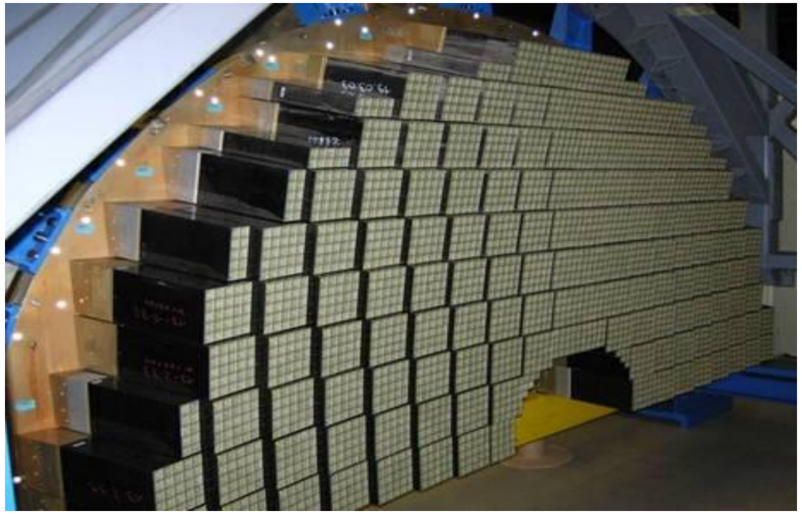
1 unit – Super-Crystal contains
25 crystals and vacuum photo triodes (VPT)
5x5 alveolar support unit

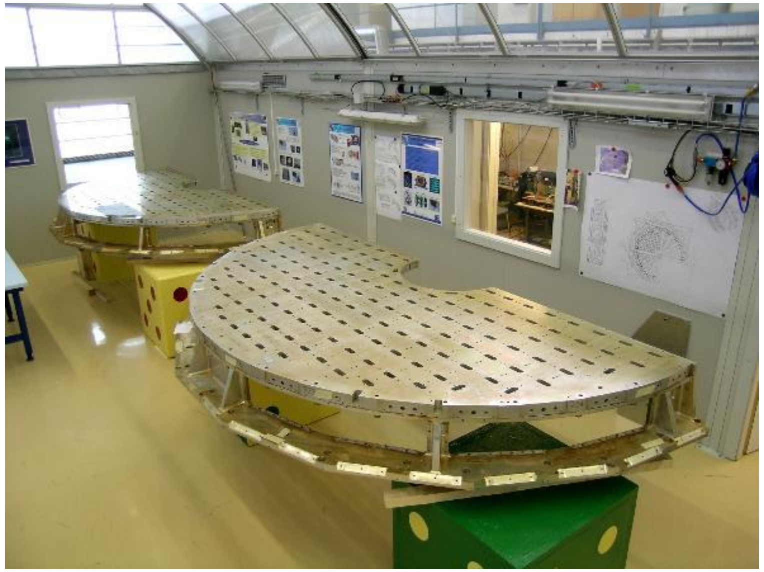
Endcap Electromagnetic Calorimeter, EE

Endcap Super crystal assembly (5x5 crystals each)

Assembly of EE Dee tests and quality control

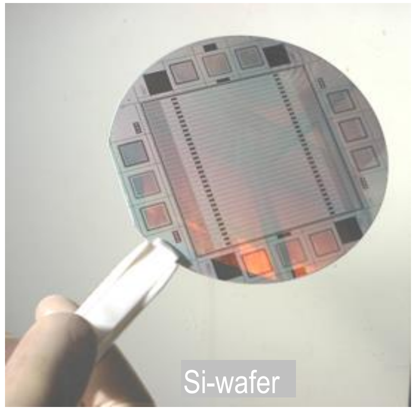






Preshower Detector, SE


Photolithography


Si-wafer


Ceramic PCB quality control

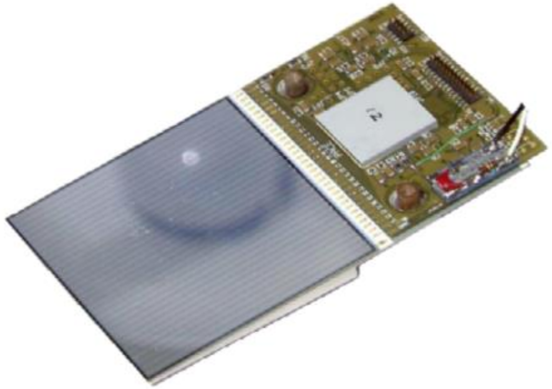

Si-detector quality control


Ultrasonic bonding of Si-detector


Si-detector modules assembly

JINR (Dubna), ANSL (Yerevan)
In cooperation with RIMS (Zelenograd)

- The technology of radiation-hard silicon strip detectors was developed
- Mass-production of 1975 radiation-hard strip Si-detectors - in JINR-RIMS (Zelenograd) cooperation
- Regional center for Si-detector modules assembling was created at Dubna
- 1800 modules delivered to CERN



Forward Hadron Calorimeter, HF

ITEP (Moscow)
In cooperation with
VNIITF (Snezhinsk)


Absorbers production in Snezhinsk


Pre-assembly test
of HF wedges at CERN

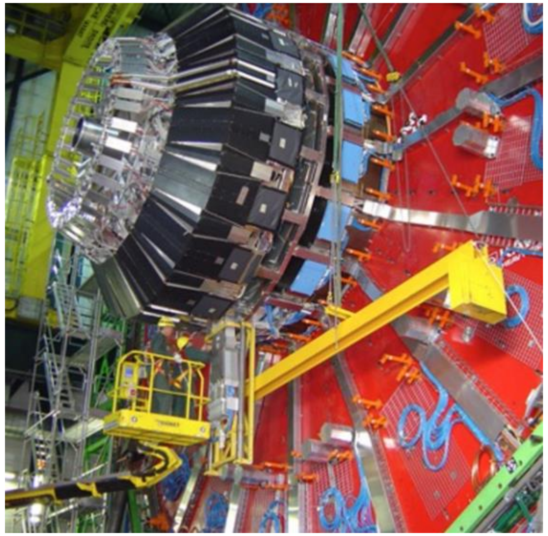
- **ITEP** scientists proposed a new type of radiation hard quartz fiber calorimeter for the CMS forward region.
- In cooperation with **VNIITF (Snezhinsk)** the technology of absorber manufacturing was developed.
- 36 absorber wedges were delivered to CERN and equipped with quartz fibers

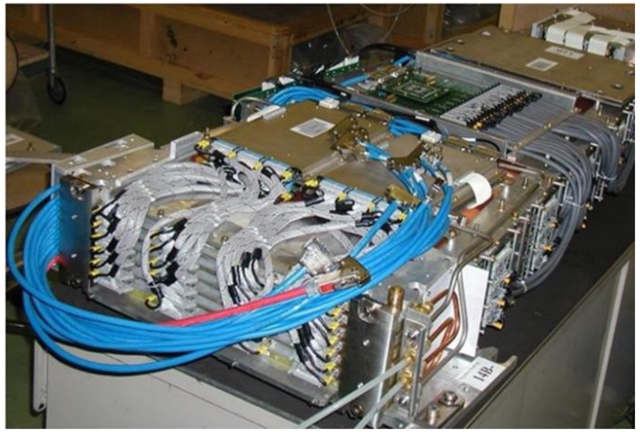
Forward Muon Station ME1/1

JINR (Dubna) in cooperation NC PHEP (Minsk), and INRNE (Sofia, Bulgaria)





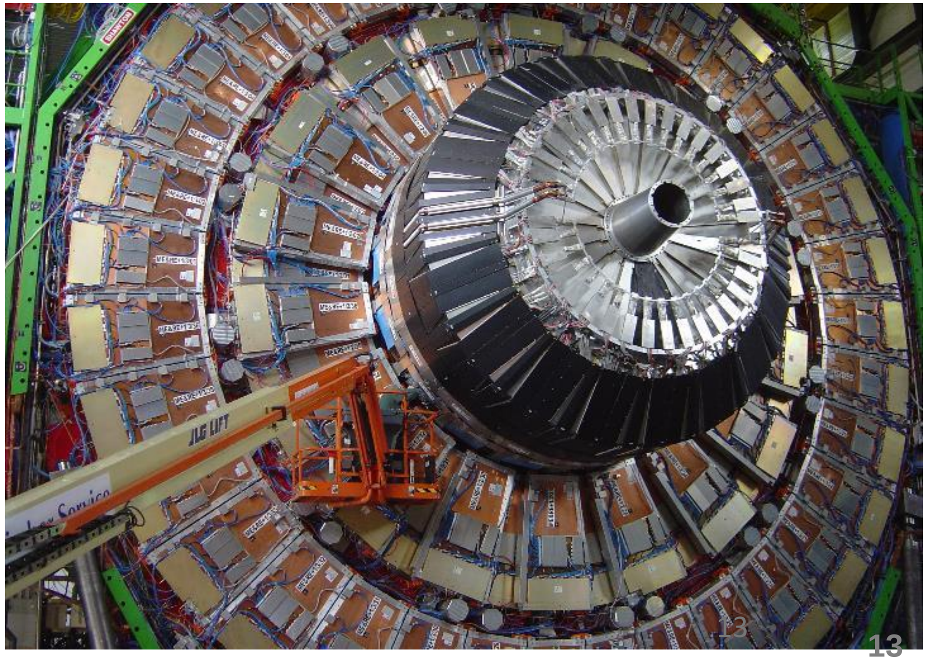


- Full responsibility in design, construction, installation, commissioning, maintenance and operation of ME1/1 detectors
- 76 cathode strip chambers with precise spatial and excellent timing resolution manufactured in Dubna and delivered to CERN and installed in CMS

CMS Endcap Muon System

PNPI (Gatchina) in collaboration with US CMS institutions

- Cathode-strip chamber production for ME1/2,3,4 rings of endcap muon stations



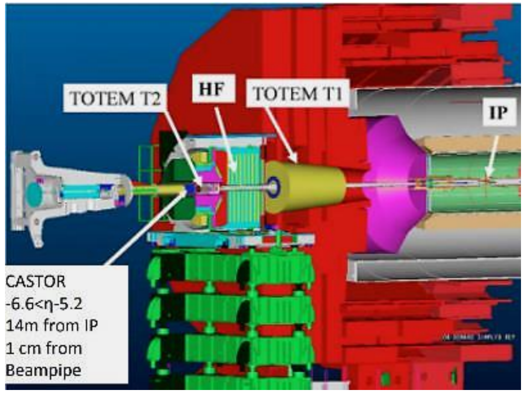
CMS Forward Shielding

IHEP (Protvino)
in cooperation with SMP (Savelovo)

- Manufacturing of Forward Shielding for the LHC machine and the CMS Rotating Shielding

CASTOR

"**C**entauro **A**nd **St**range **O**bject **R**esearch“

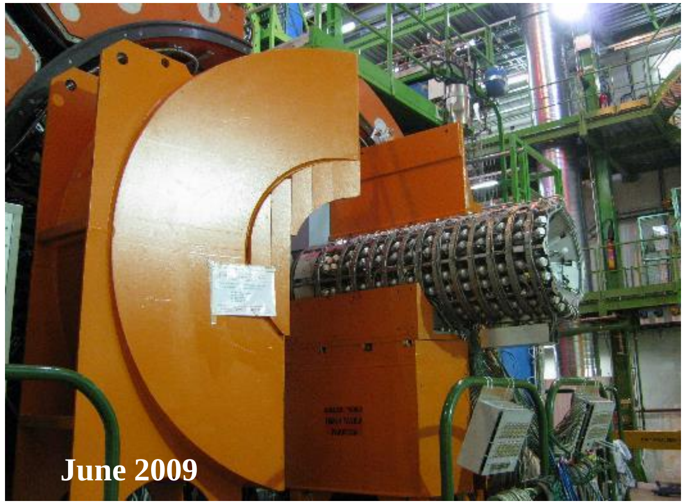


Electromagnetic and Hadronic tungsten-quartz calorimeter

JINR (Dubna), ITEP (Moscow),
INR (Troitsk), MSU(Moscow)

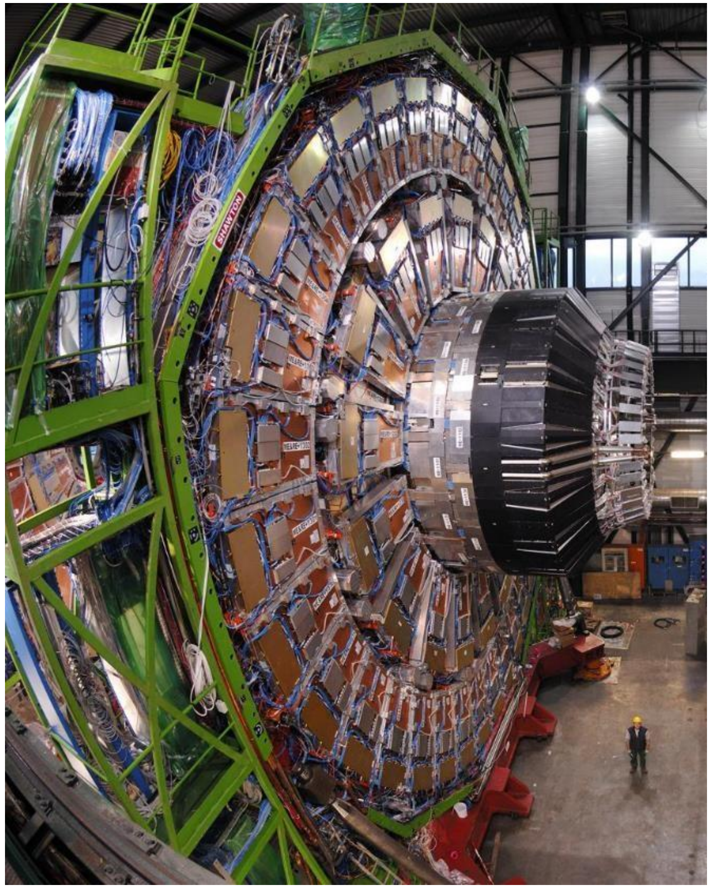
In cooperation with NIKIET (Moscow)

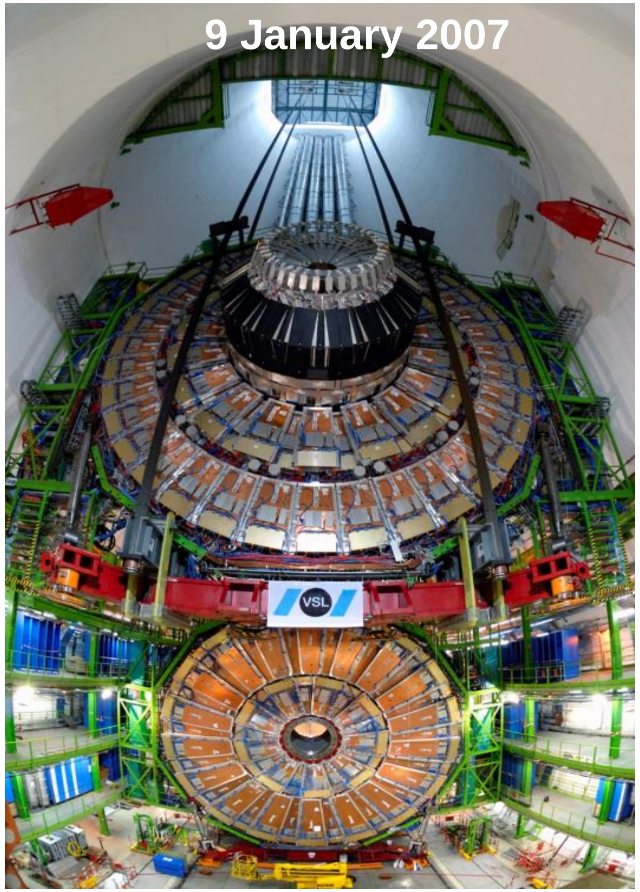
- Most forward at 14 m from interaction point.
- Extends the CMS acceptance: $5.2 \le \eta \le 6.6$
- Studying very forward particle production in heavy ion and pp collisions



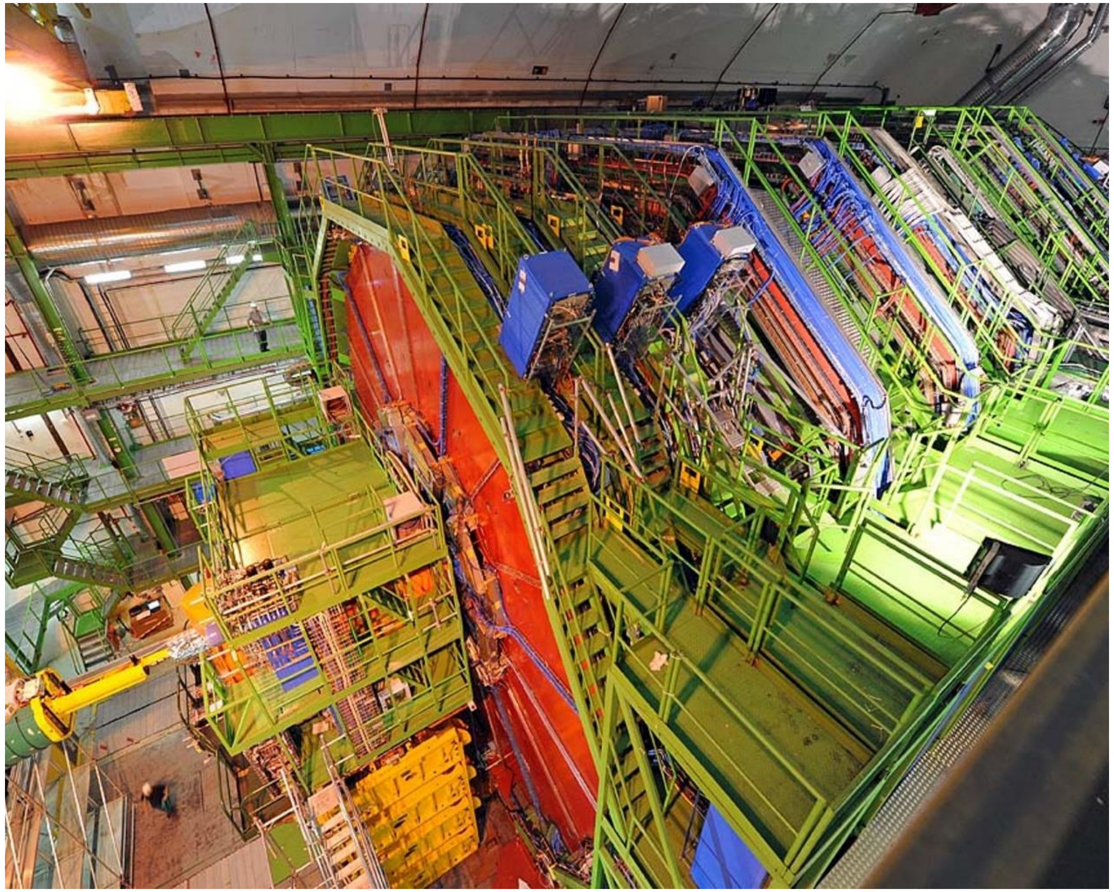
The CMS Detector assembled on the surface, tested, downloaded and reassembled in the underground hall

YE1 disks with **Inner Endcaps** - the most complicated area CMS integration includes all detectors built by RDMS.





YE-1 downloading to the shaft – the heaviest endcap disk (1270 tons).



The CMS Detector ready for collisions

RDMS Participation in CMS Assembly and Installation

- RDMS team carried out most important mechanical work during CMS assembly including installation of detectors and services
- Thousands of electrical and optical cables were laid

RDMS physicists, engineers and technicians in SX5

RDMS Assembly Team in UX5

RDMS in Upgrade of Muon Endcap system in LS1 and LS2

CMS Phase-1 upgrade (LS1, LS2) task: reliable work of detectors in the **design LHC operating mode** at full energy up to $\sqrt{s}$ = 14 TeV and instantaneous luminosity L= $1 \div 2 \times 10^{34}$ $см^{-2}с^{-1}$

ME1/1 - JINR, dubna

ME4/2 - PNPI (Gatchina) in collaboration with US CMS institutions

LS1 period – restoring number of ME1/1 FE cards and ME4 station (were reduced on construction staging).

- 72 ME1/1 were disassembled, refurbished and reinstalled in CMS
- 72 new ME4/2 chambers constructed, installed and commissioned

Upgrade of 72 ME1/1 chambers

Installation of 72 new ME4/2 chambers

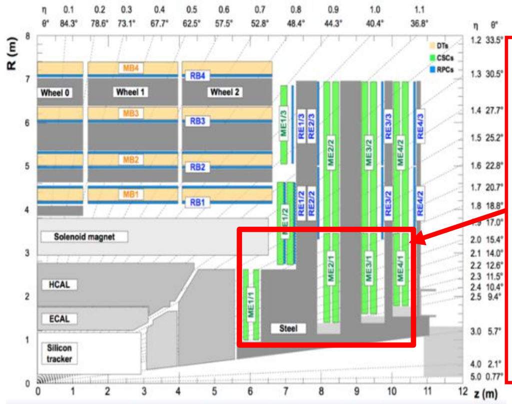
ME1/1 CSC installation

CSC upgrade infrastructure

ME4/2 CSC assembly

- Construction of a new CSC station ME4/2 - provide the redundancy in the region of 1.2 < |η| < 1.8.
- New digital FE boards (DCFEBs) installed on the ME1/1 station - minimize dead time
- 3 DCFEBs instead of 1 at the bottom part of ME1/1 CSCs - restores the trigger up to η =2.4

LS2 period - CSC electronics was replaced on detectors of the inner rings Endcap stations.

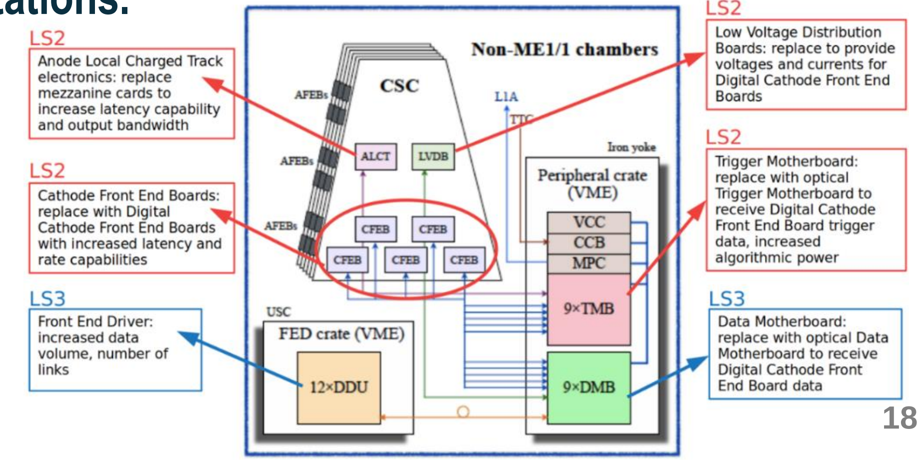


Inner rings stations:
ME1/1,
ME2/1,
ME3/1,
ME4/1

Total 180 CSCs

- 180 chambers of inner rings were upgraded with the **new electronics to sustain HL-LHC conditions**
- 72 ME1/1 CSCs were equipped with the new on-chamber cooling systems.

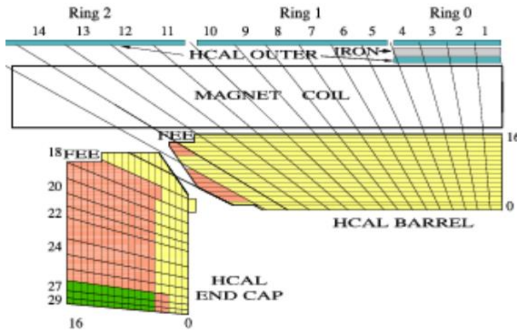
Major part of **CSC Phase-2 upgrade** was done in LS2.



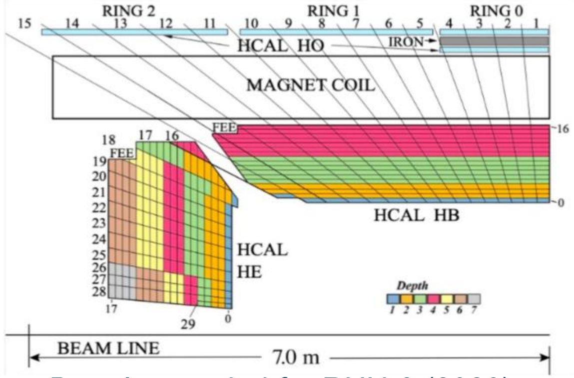
Participation in HCAL Upgrade

HCAL upgrades LS1, LS2 periods

- **Hybrid photodetectors(HPD) replaced with new silicon multipliers (SiPM)**
  - 3 times higher photon detection efficiency, 200 times higher gain
  - Increase dynamic range, rate capability, sub-ns timing, muon ID
- Finer depth segmentation 4 in barrel, up to 7 in endcap
  - Number of channels increase by factor ~2.5;
  - Depth dependent calibration.
- New front-end and back-end electronics
  - increase Particle Flow capability and 1-level trigger.
  - Enable new triggers (e. g. long lived particles).
  - Better timing information (0.5ns resolution);
  - Encoding an energy value into 8 bits instead of 6 bits as now;
  - Increase a bandwidth of data transfer from 1.6 Gbit/s to 4.8 Gbit/s.



Endcap upgrade before 2018



Barrel upgraded for RUN-3 (2023)

JINR, dubna
IHEP (Protvino)
ITEP (Moscow)
MSU (Moscow)

Commissioning of HCAL electronics

Participation in CMS Phase 2 Upgrade (LS3)

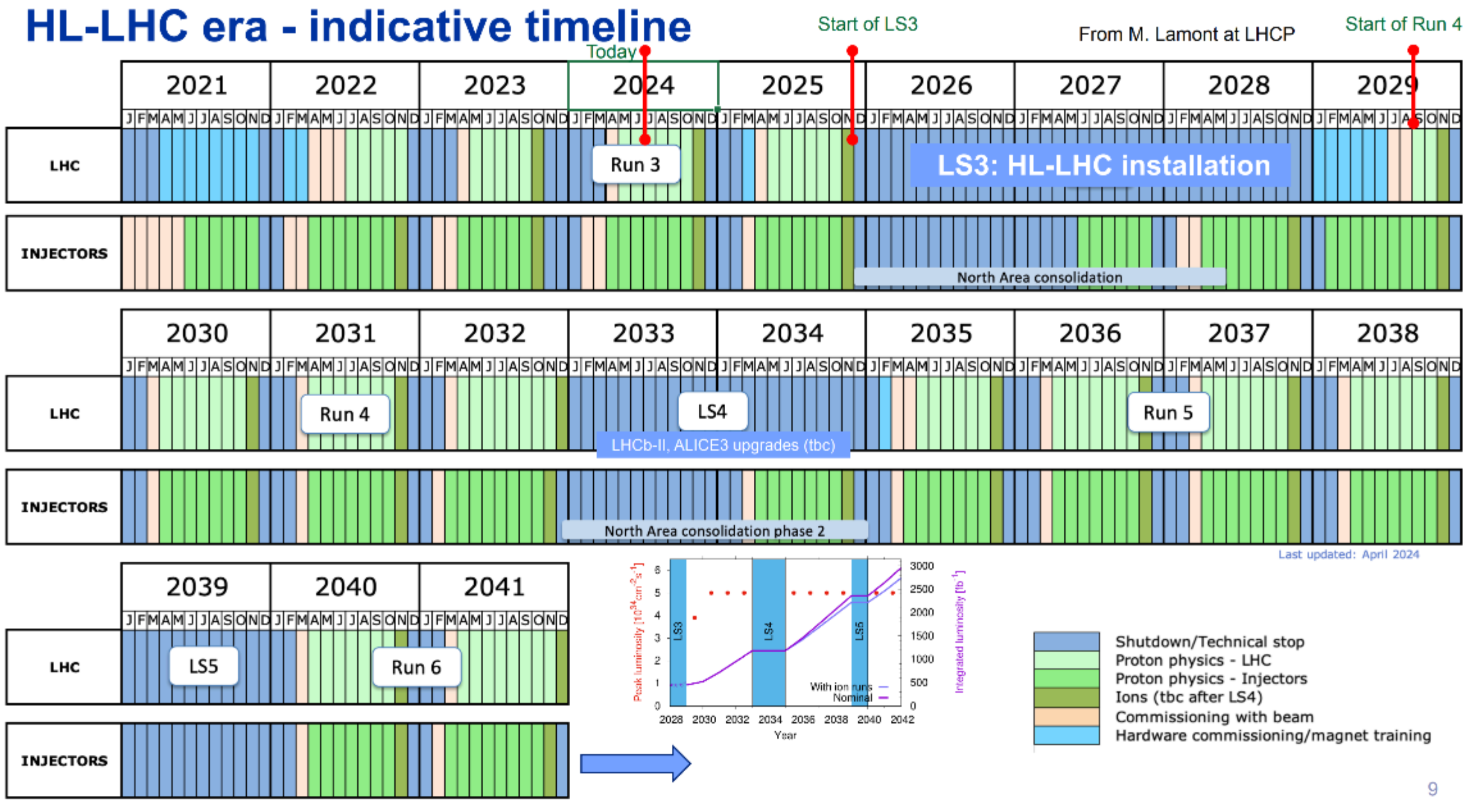
CMS Phase-2 upgrade (LS2) is aimed to provide reliable work of detectors in the **High Luminosity LHC operation mode (HL-LHC)** at energy **√s = 14 TeV** and instantaneous luminosity **L= 5÷7x10^{34}cm^{-2}c^{-1}**

HL-LHC challenging conditions

	LHC	HL-LHC
Instantaneous lumi (cm^{-2}s^{-1})	10^{34}	**(5-7.5) x 10^{34}**
Integrated Lumi (fb^{-1})	300	**3000 (4000)**
Pile Up	30	**140 (200)**

	CMS Phase1	CMS Phase2
L1 trigger (kHz)	100	**750**
L1 latency (μs)	3.6	**12.4**

- **Participation in High Granularity Calorimeter (HGCal) project.**
  - Cooling plate of HGCal cassettes design - **JINR (Dubna), НИИ ЯП БГУ (Minsk).**
  - Design and construction of the HGCAL cassettes test facility - **JINR (Dubna).**
- **Participation in the Endcap Muon system upgrade - JINR (Dubna).**
  - CSC longevity study and searches for eco friendly gas mixtures R&D.
  - ME1/1 CSCs cables and services layout in the new Endcap detectors configuration.
  - Design and construction of the new ME1/1 Patch Panel.
  - Design and construction of new tooling for ME1/1 CSC assembly and installation.

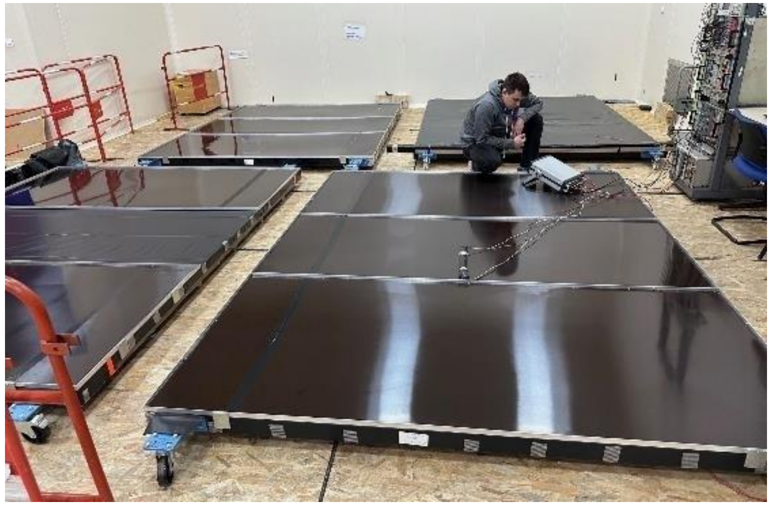


Setup for HGCaL Cassettes Testing

2 Cold rooms were assembled at SX5 CERN

Test of the cassette insertion in the

Cassette on the supporting frame



Commissioning of the scintillation trigger planes.

Test setup consists of:

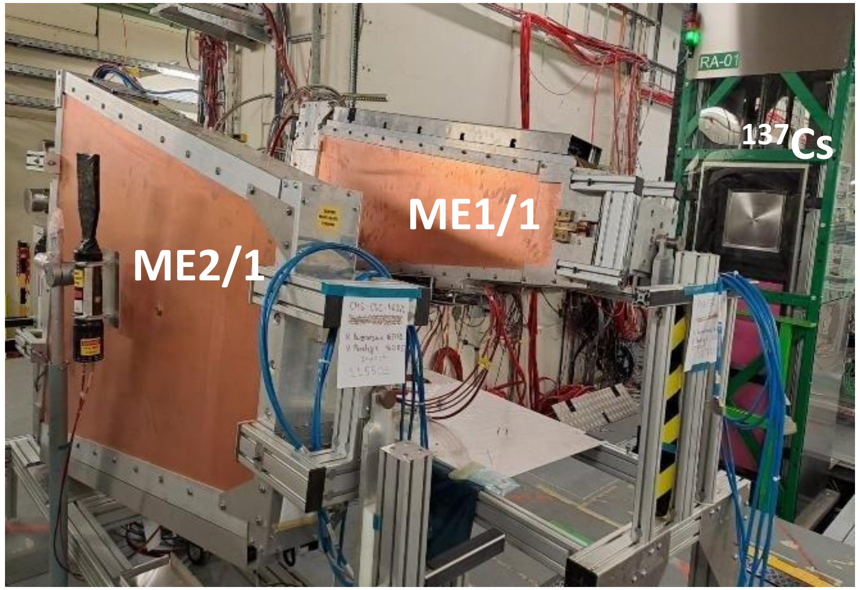
- Racks for cassettes (inside cold rooms).
- Supporting frames for cassettes.
- Scintillation trigger planes (on top and bottom of cold room)
- Readout electronics

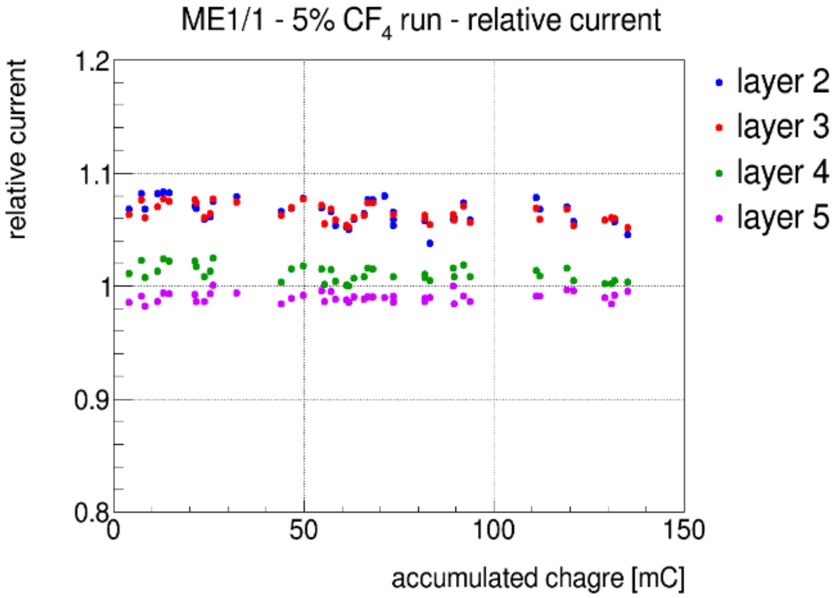
Cathode Strip Chamber Longevity Study @ GIF++

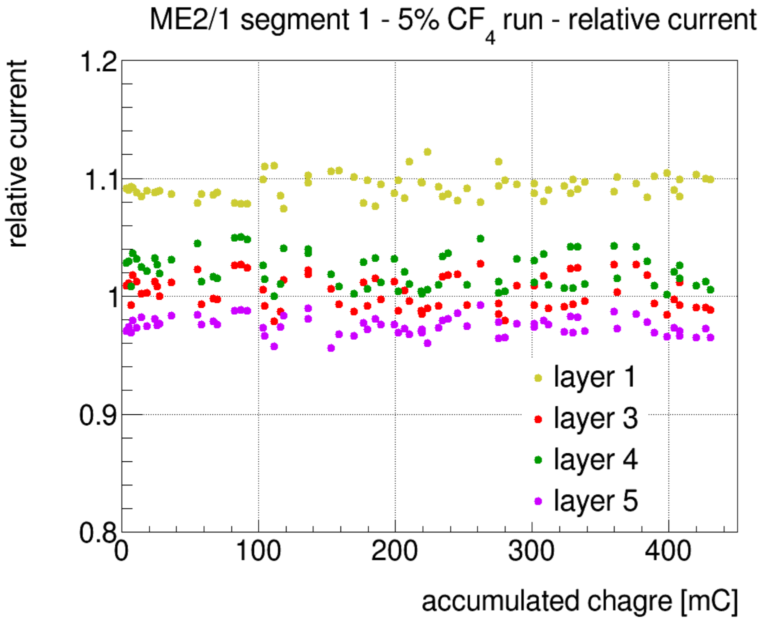
Irradiation setup: ME1/1 and ME2/1 CSCs exposed with the 12 TBq ^{137}Cs gamma source at the GIF++ Facility (HV-ON on 4 layers and HV-OFF on 2 layers kept as reference).

CSC	HL-LHC Expected (3000 fb-1) mC/cm	Accumulated charge Q (mC/cm)						
		Before 2018	Nov. 2021	Oct. 2022	May 2023	19.07.23	25.08.23	30.04.24
ME1/1	200	330 (10% CF_4)	700 (2% CF_4)	725 (5% CF_4)	770	790	800	845
ME2/1	130	310 (10% CF_4)		420 (5% CF_4)	530	570	620	745

Relative current ($I_{Layer}/\langle I_{referencs\ Layers}\rangle$) vs charge – for mixture with 5% CF4







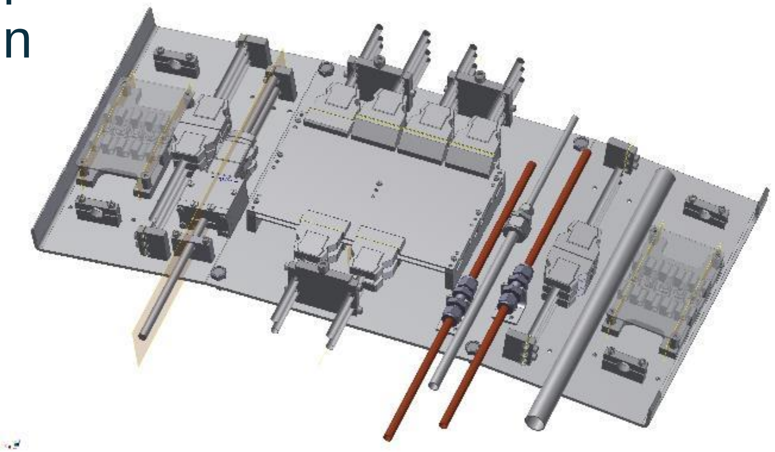
Relative current is stable → no CSC performance degradation observed so far

ME1/1 CSC Preparation to the Phase-2 Upgrade

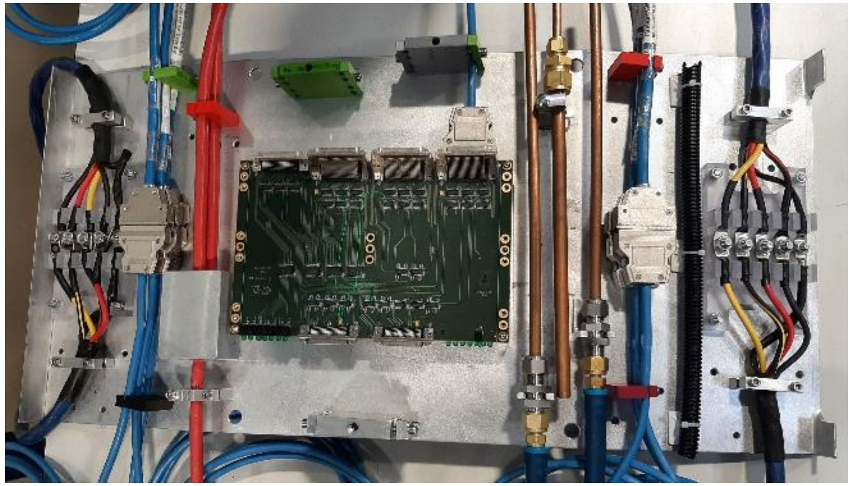
- ✓ **ME1/1 Patch Panel** redesigned to fit more rigid envelope for endcap detectors cables and services in the CMS Phase-2 configuration
  - 36 new ME1/1 PP should be
  - constructed before LS3

ME1/1 Patch panel

3d model



Prototype



Loading machines

- ✓ **ME1/1 two loading machines** were constructed for extraction/installation of ME1/1 CSC detectors).

CONCLUSION

- **RDMS's role in the creation of the CMS detector is very significant, and we are proud of it !**
- **Igor Golutvin made the great contribution to success of the RDMS CMS collaboration !**