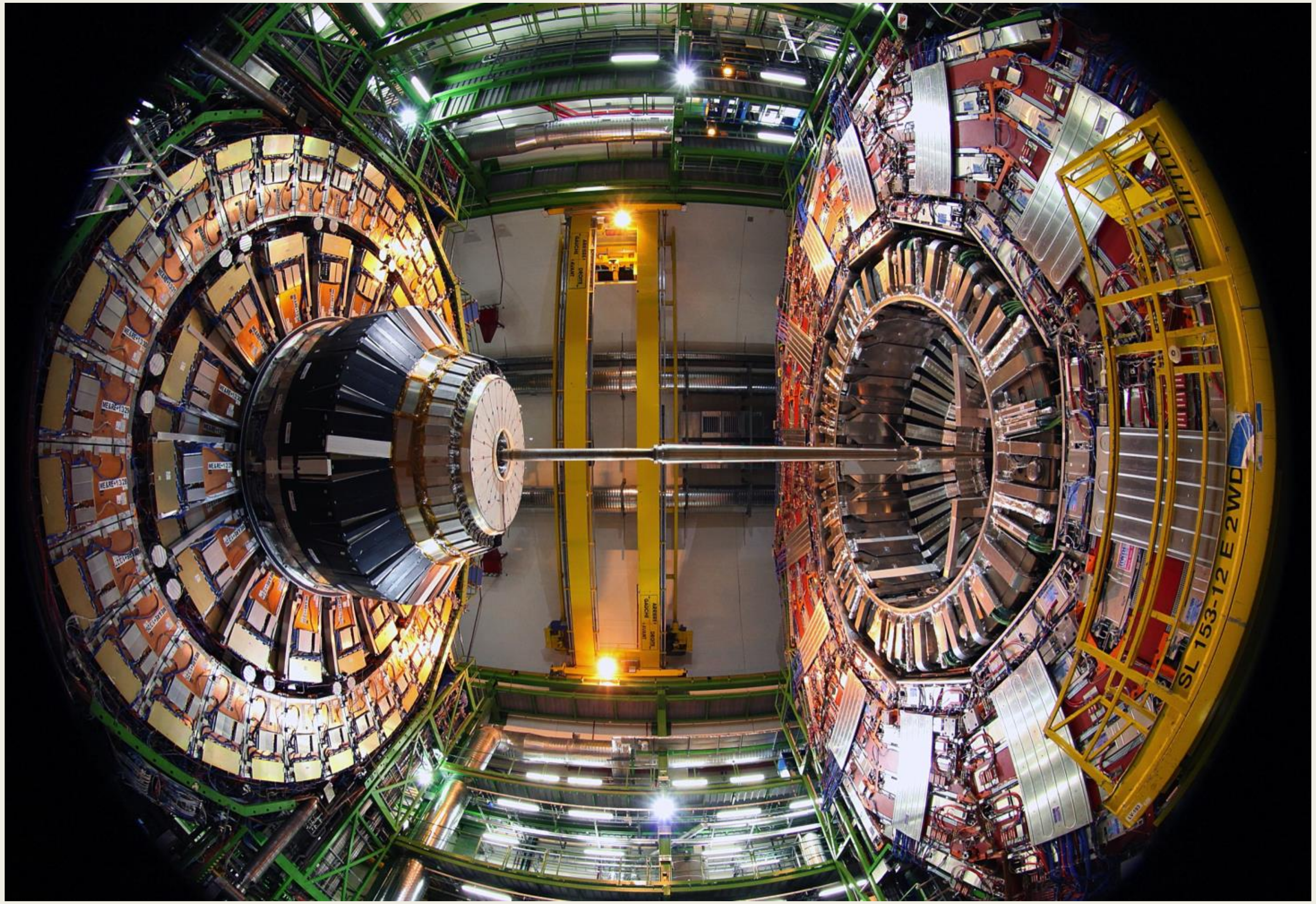
CMS Endcap calorimetry: Past, Present and the Future

International Scientific Seminar "Experimental Methods in Particle Physics”

Dubna, Russia
August 8, 2019

Pawel de Barbaro,
University of Rochester, USA



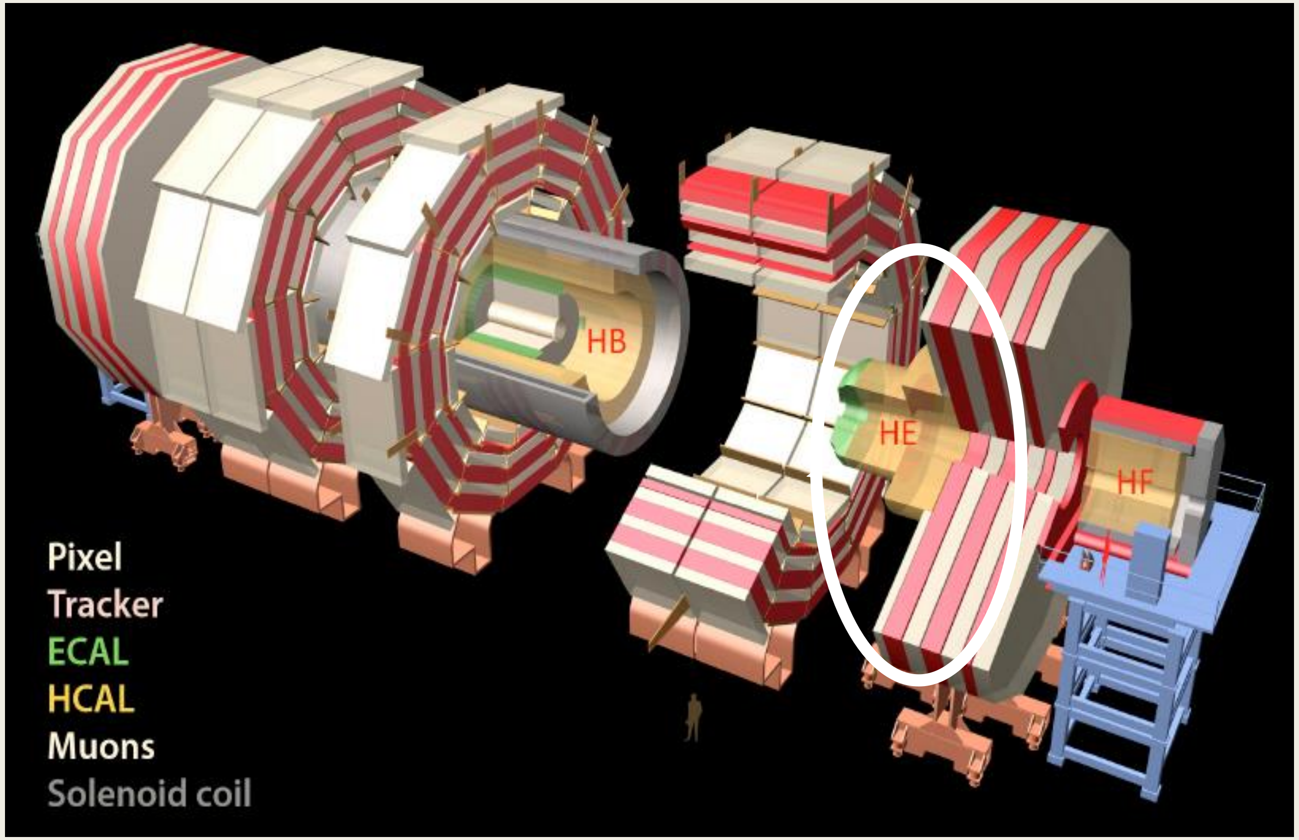
dedicated to

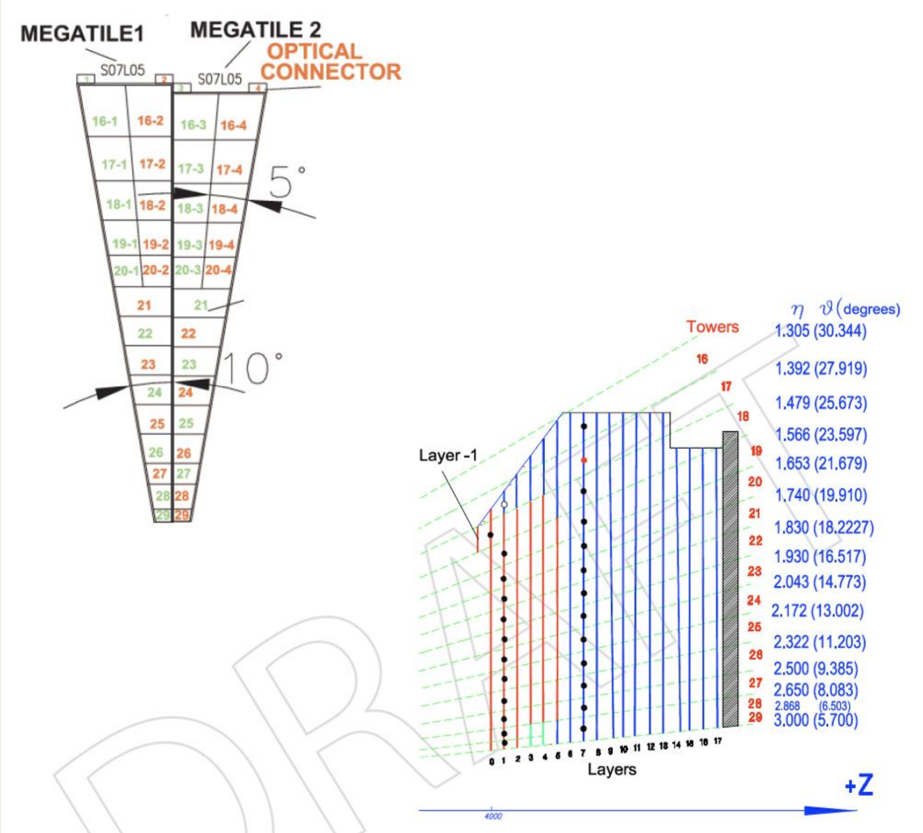
celebration of 85^{th} anniversary

of Prof. Igor Anatolievich Golutvin

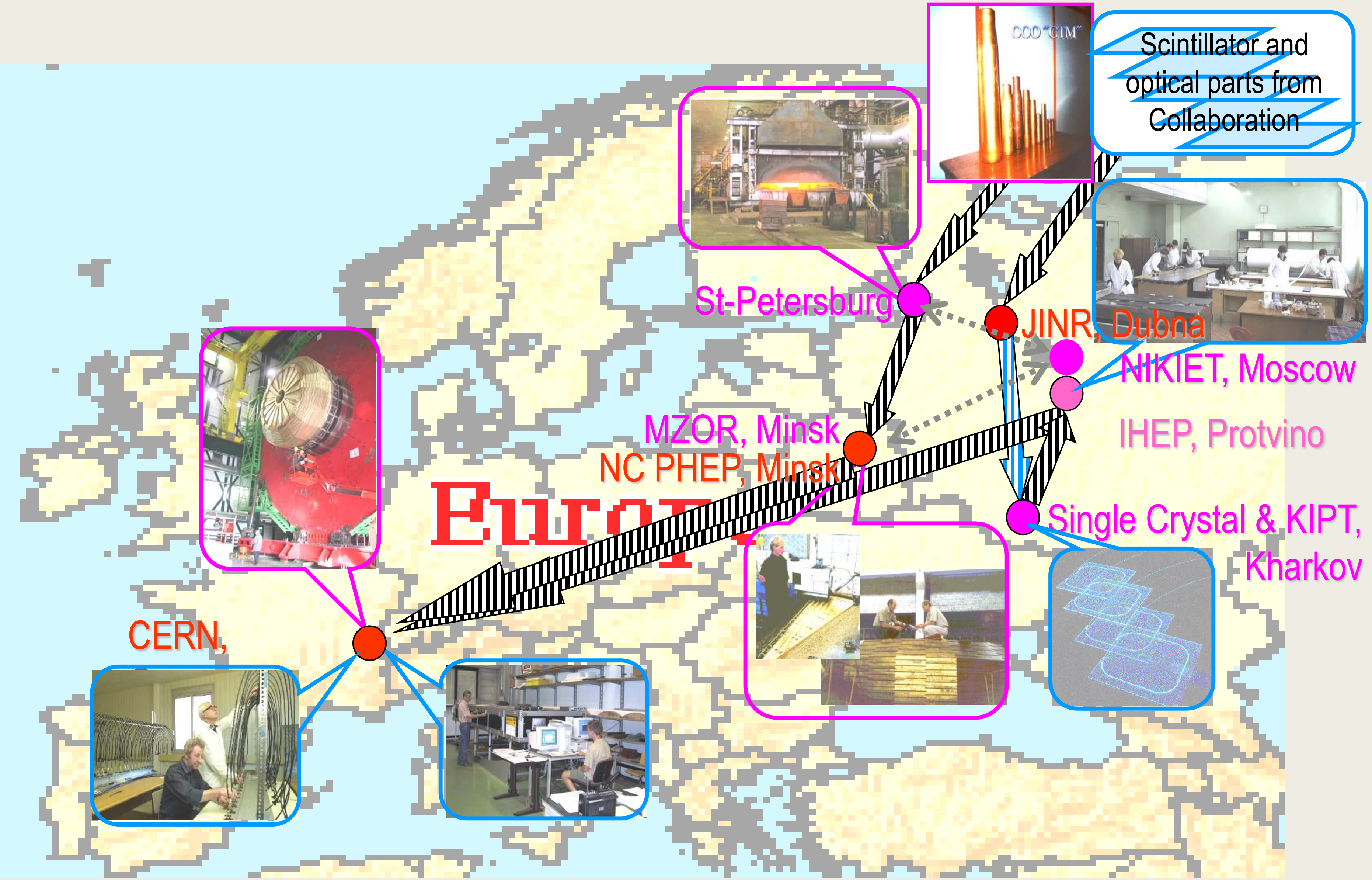
The CMS Detector and HCAL

Under leadership of Igor Golutvin, RDMS, and Dubna group in particular, played critical role in the design, construction and commissioning of CMS Hadron Endcap calorimeter. Endcap nose with brass absorber plates and scintillator megatiles were designed, built, tested and installed by RDMS groups.





Hadron Endcap calorimeter Manufacturing Sites

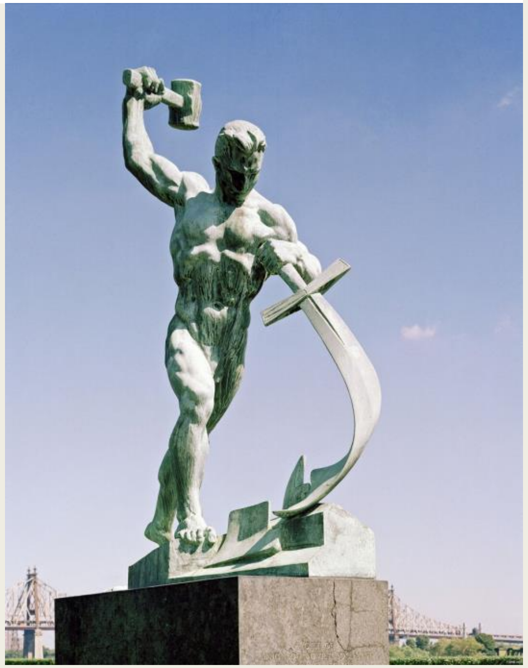


“Beat their swords into plowshares”

The RDMS groups, under leadership of Igor A. Golutvin made major contributions to the design and construction of HE (mechanics and optics) and mechanics of Hadron Forward (HF).

- **Mechanical design by NIKIET including connection to endcap yoke**
- **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**

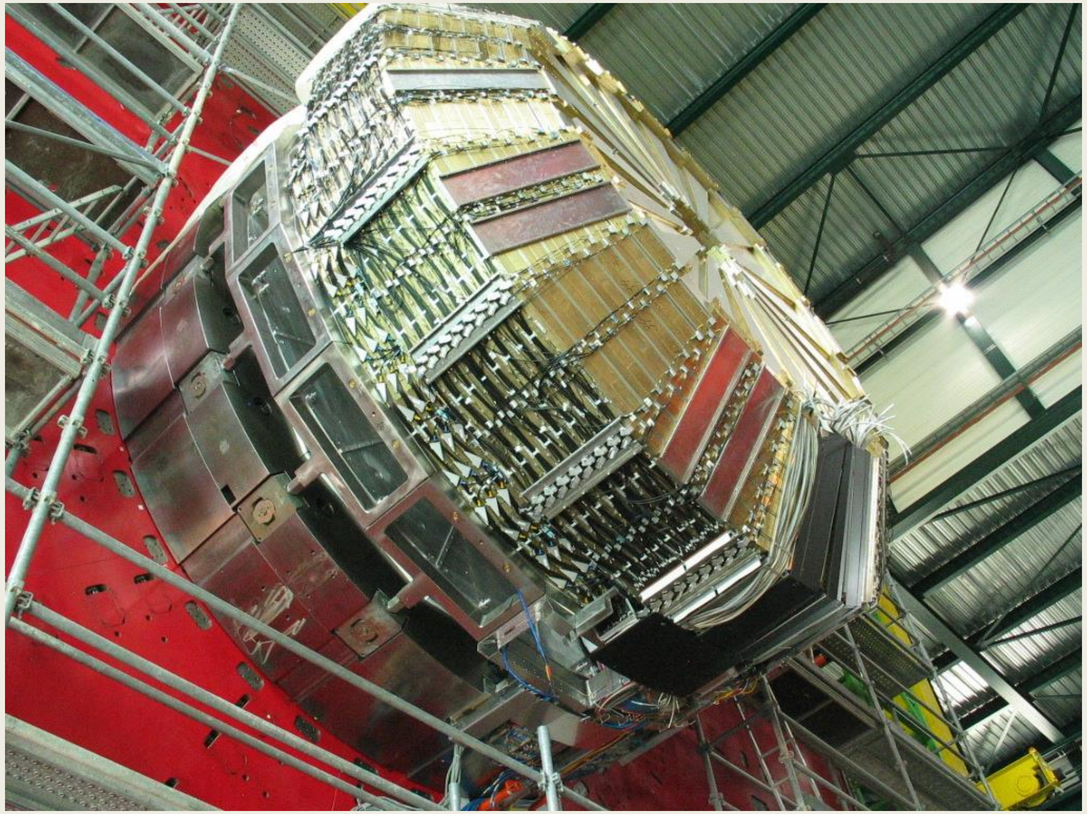
> “And he shall judge among the nations, and shall rebuke many people: and they shall beat their swords into plowshares, and their spears into pruninghooks: nation shall not lift up sword against nation, neither shall they learn war any more. (Isaiah 2:4).”



HE Installation at CERN

The HE installation team was lead by Vitali Kaftanov of Moscow – ITEP. His team included V. Smirnov (engineer from Dubna, Alexander Vishnevsky (also an engineer) and A.Volkov (physicist from Protvino)

The Megatiles were installed into the slots of the brass Matrix. The WLS fiber was Connected to Readout Boxes (RBXs) via clear fiber.



HCAL Endcap: Design and Manufacture

Long list of names of physicists and engineers from Dubna, Protvino, Minsk, Moscow, Kharkov, Sophia, …, who participated at the design and construction stage of CMS Hadron Endcap calorimeter.

PROTVINO-IHEP
1. Abramov Victor
2. Korablev Andrey
3. Korneev Yury
4. Krinitsyn Alexander
5. Krychkin Victor
6. Turchanovich Leonid
7. Volkov Alexey
8. Levine Andrey
9. Sourkov Alexandre
10. Evdokimov V.
11. Markov A.
12. Potapov V.
13. Sasov A.
14. Simonova Z.
15. Skvortsova E.
16. Uzunian Andrey
17. Azhguirei Igor

MINSK-NCPHEP
1. Emeliantchik Igor
2. Litomin Aliaksandr
3. Shumeiko Nikolai
4. Stefanovitch Roman

et al

1. Design of HE first prototypes and 20degree PPT2
2. Design of HE absorbers
3. Design of HE/YE1interfaces and Integration
4. Design of tiles, megatiles, and optical system - cables
5. Design of laser control system
6. Design of stands for pig tail and megatile quality test
7. Design of megatron stand for Al-coat of the fiber ends
8. Radiation calculations

DUBNA
1. Ershov Yuri
2. Golutvin Igor
3. Gramenitski Igor
4. Kalagin Vladimir
5. Lysiakov Vadim
6. Kosarev Ivan
7. Melnitchenko Igor
8. Moisenz Petr
9. Sergeev Sergey
10. Volodko Anton
11. Zarubin Anatoli

et al

MOSCOW-RDIPE
1. Druzhkin Dmitry
2. Ivanov Alexander
3. Kudinov Vladimir
4. Orlov Alexandre
5. Smetannikov Vladimir

et al

KHARKOV-ISC
1. Grinev Boris
2. Lyubynskiy Vadym
3. Senchyshyn Vitaliy

et al

KHARKOV-KIPT
1. Levchuk Leonid
2. Nemashkalo Anatoly
3. Sorokin Pavel

et al

1. **Manufacturing of brass for absorbers in "Krasny Vyborzhets"**
2. **Manufacturing and pre-assembly of HE absorbers in Minsk MZOR**
3. **Manufacturing of HE/YE1 Interface in Minsk MZOR**
4. **Supervision and quality acceptance control for mechanics manufacturing**
5. **Production of tiles and megatiles**
   - **Production of stands for fiber ends coat, pig tail, and megatile and pig tails quality test and control**
   - **Production and quality test of megatiles during production and after transportation at CERN**
6. **Production of laser control system and optical cables**
7. **Production of HE prototypes**
8. **Production of HV system**

DUBNA
1. Golutvin Igor
2. Kalagin Vladimir
3. Melnitchenko Igor
4. Volodko Anton
5. Zarubin Anatoli

et al

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3. Senchyshyn Vitaliy

et al

KHARKOV-KIPT
1. Levchuk Leonid
2. Nemashkalo Anatoly
3. Sorokin Pavel

et al

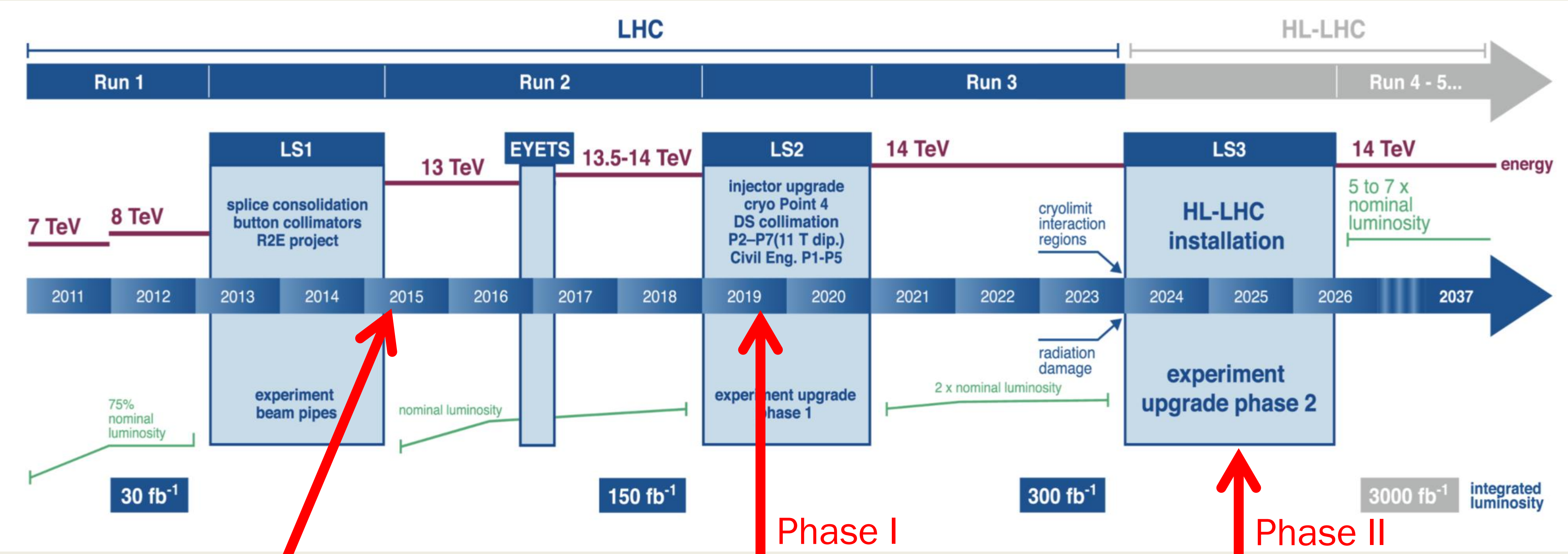
PROTVINO-IHEP
1. Goncharo Petr
2. Korablev Andrey
3. Korneev Yury
4. Krinitsyn Alexander
5. Krychkin Victor
6. Markov A.
7. Pavlov S.
8. Talov Vladimir
9. Tyurin Nikolai
10. Turchanovich Leonid
11. Volkov Alexey
12. Zaichenko Alexander

MINSK-MZOR
1. Chernyavsky Boris
2. Krivomaz Mikhail

SOFIA-INRNE
1. Genchev Vlado
2. Vankov Ivan

et al

The future at CERN: High Luminosity LHC Timeline



Spring 2015:
HGCal selected for upgrade of CMS Endcap

August 2019:
completion of Phase1 upgrade

Autumn 2025:
CMS Master Schedule
HGCal to be lowered into UX5

6 years

Signal loss of HE calorimeter vs Int. Luminosity

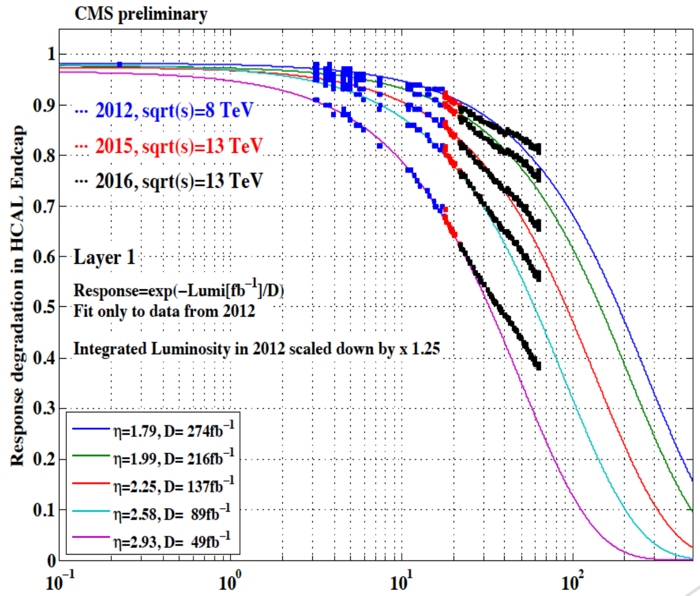
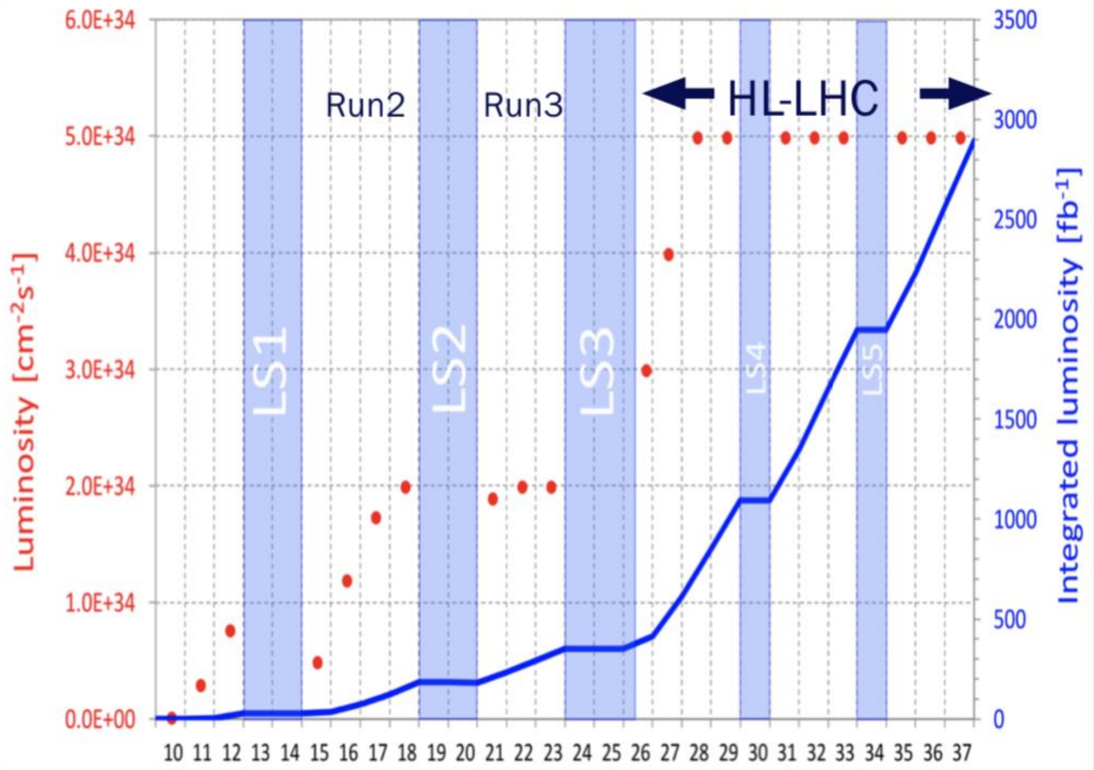


Figure 2.18: Response loss in HE Layer1 for various η towers, averaged over all ϕ towers, as a function of integrated luminosity. The response was normalized to the signal at the beginning of 2012. The normalization for Laser intensity variation was obtained using the lowest η ring.



Both Hadron Endcap (HE) with scintillator/WLS fiber readout and Electromagnetic Endcap (EE) with Lead tungstate crystals were designed for integrated luminosity of 500 fb $^{-1}$.
Radiation damage to active elements of present CMS Endcap detectors much beyond this integrated luminosity would lead to performance degradation, and in effect, unacceptable loss of physics performance.

Expected doses and fluence in CMS endcap region after 3000 fb^{-1}

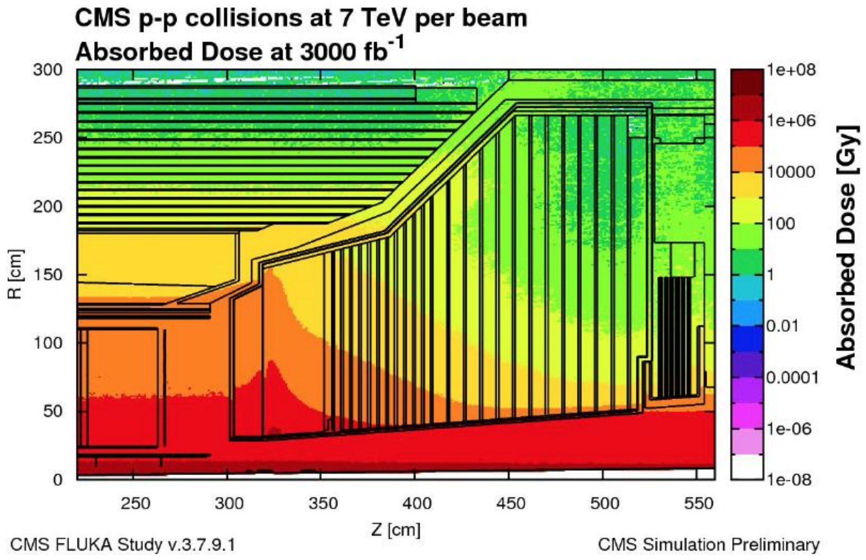


Figure 1.1: Dose of ionizing radiation accumulated in HGCAL after an integrated luminosity of3000 fb^{-1}, simulated using the FLUKA program, and shown as a two-dimensional map in the radial and longitudinal coordinates, *r* and *z*.

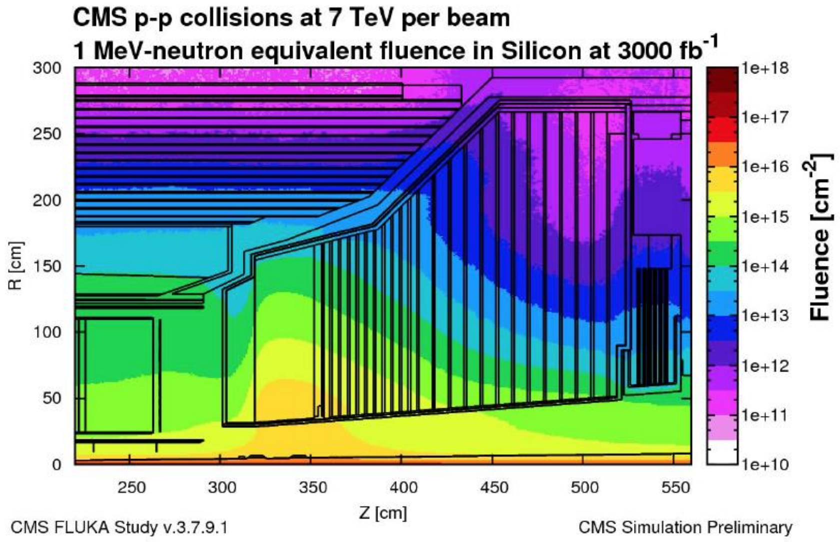
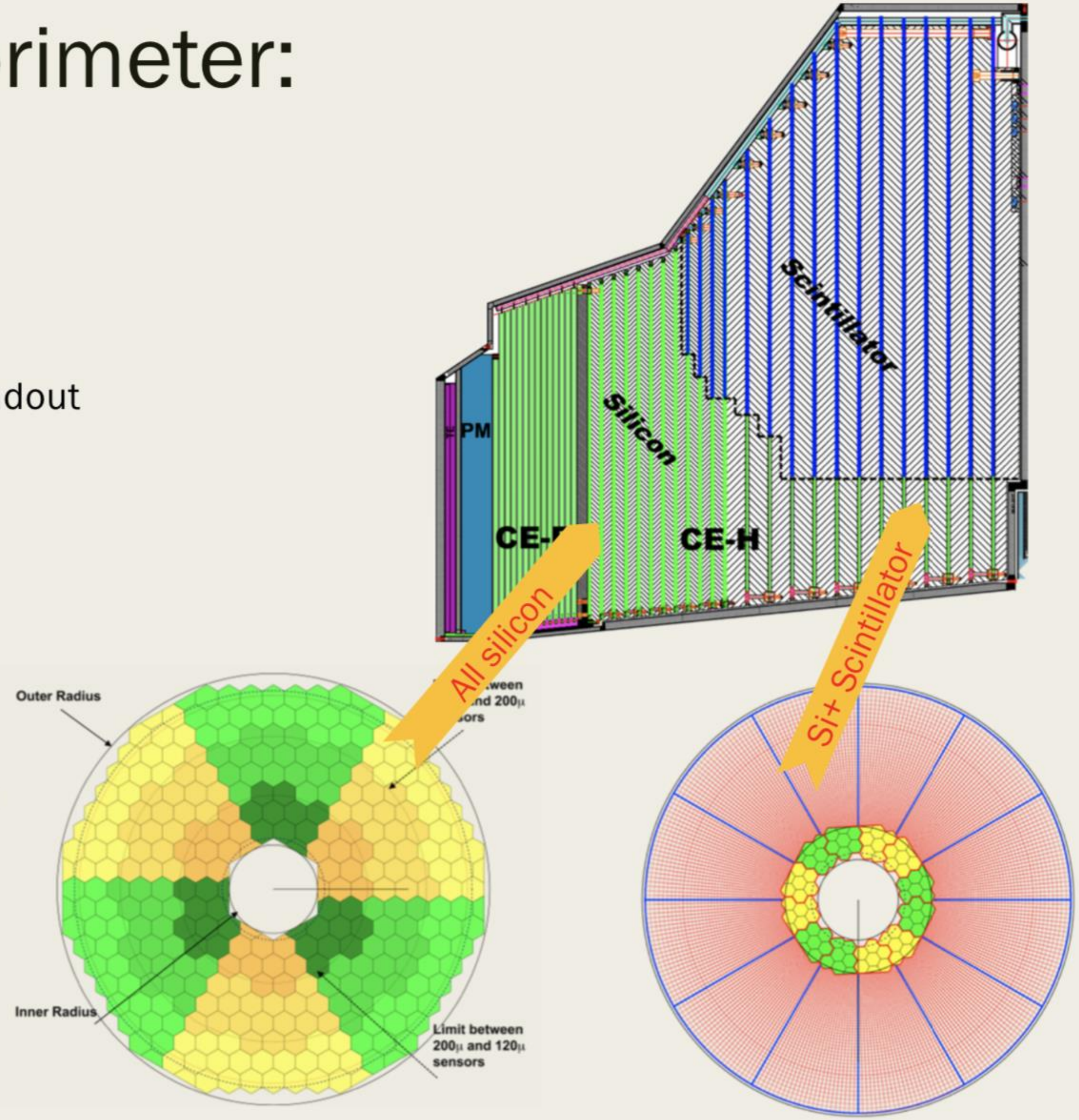


Figure 1.2: Fluence, parameterized as a fluence of 1 MeV equivalent neutrons, accumulated in HGCAL after an integrated luminosity of3000 fb^{-1}, simulated using the FLUKA program, and shown as a two-dimensional map in the radial and longitudinal coordinates, *r* and *z*.

The replacement will need to tolerate up to 200 Mrad after 3000 fb^{-1}, and a fluence of 10^{16} n/cm^2.
It will also require good signal to noise ratio for minimum-ionizing particles for accurate calibration throughout HL-LHC.

High Granularity calorimeter: key features

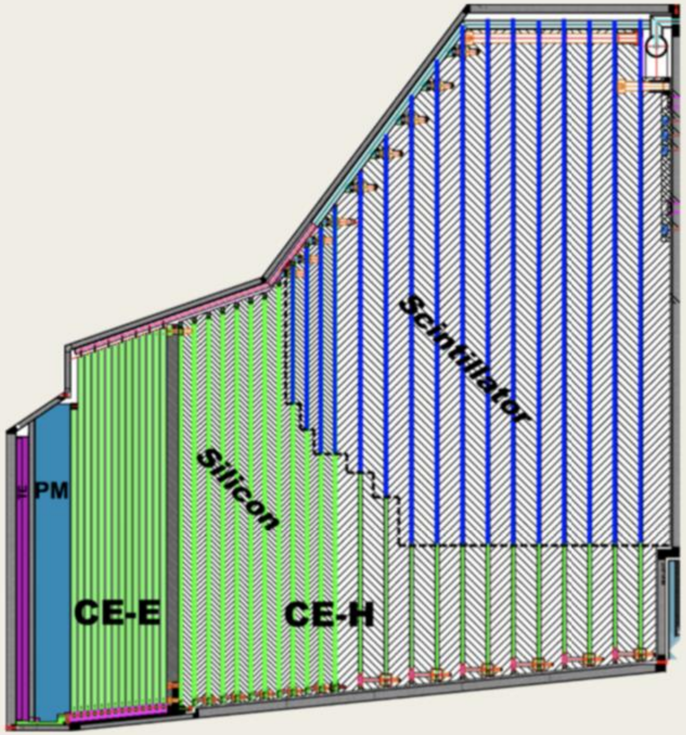
- Sampling calorimeter
- Unprecedented transverse and longitudinal readout segmentation
  - Silicon in high radiation areas
  - Scintillating tiles in the low-radiation region
- Covering 1.5 < η < 3.0, operated at -30 °C
- Nomenclature
  - HGCal = High Granularity Calorimeter
  - CE = Calorimeter Endcap (official CMS name) = HGCal
  - CE-E = Calorimeter Endcap - electromagnetic section
  - CE-H = Calorimeter Endcap - hadronic section

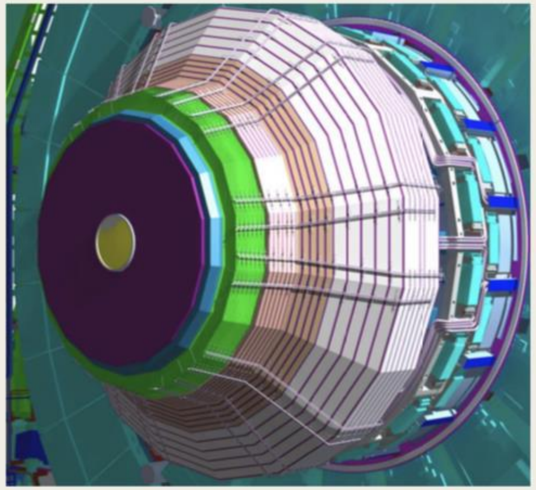


High Granularity calorimeter: absorber and active material

Per endcap	CE-E	CE-H (Si)	CE-H (Si + Scint)
Active	Silicon sensors		Scintillators
Absorber	Pb, CuW, Cu	Stainless steel, Cu	
Depth	26 X_0, 1.7 λ, 34 cm	9 λ	
Layers	28	8	16
Weight	23 t	205 t	

For both endcaps	Silicon sensors	Scintillators
Area	**600 m^2**	500 m^2
# Modules	27,000	2500
Channels Size	0.5-1 cm^2	4-30 cm^2
# Channels	6 Mio	400k
Op. temperature	-30 °C	-30 °C





Silicon and SiPM-on-Scintillator Modules

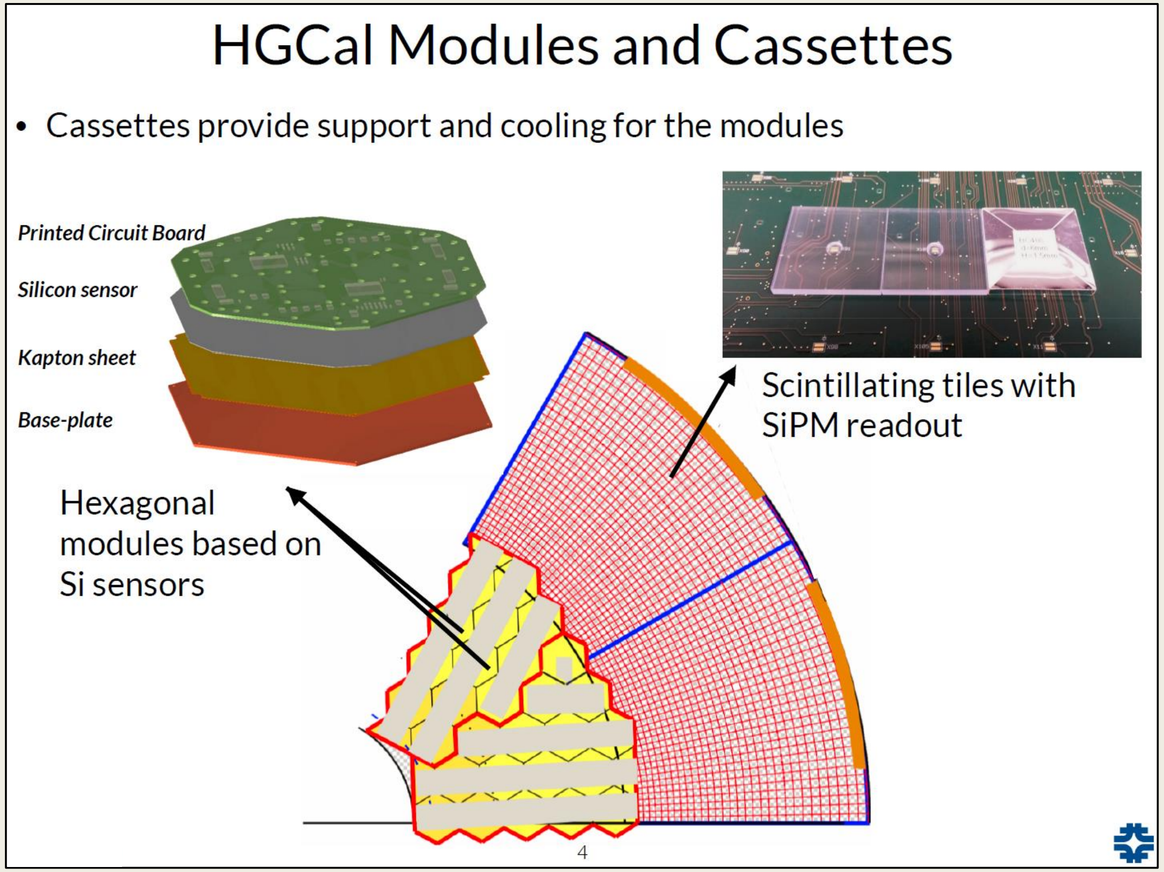


Figure from HGCal TDR

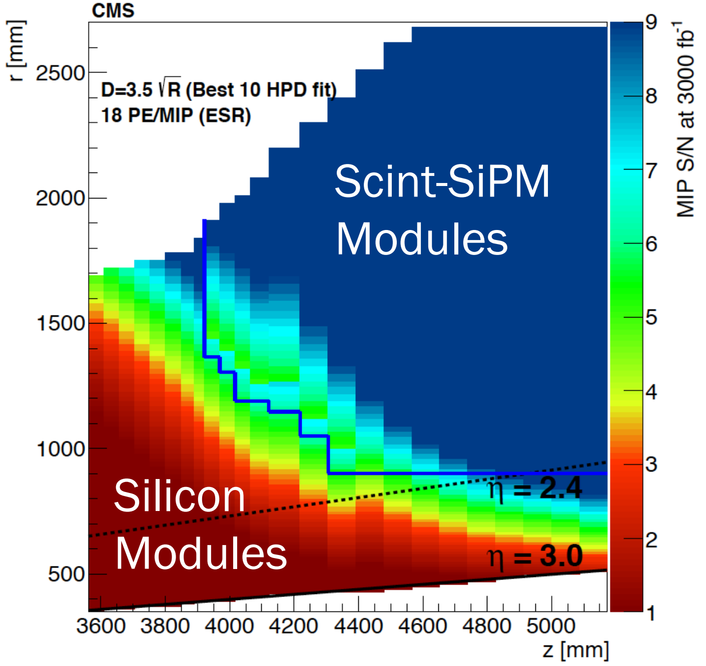


Figure 2.14: Signal-to-noise ratio for a MIP, after an integrated luminosity of 3000 fb^{-1}, shown as a two-dimensional map in r and z. The region, at larger z and r, in which SiPMs mounted on scintillator tiles can provide $S/N(\mathrm{MIP}) > 5$ after 3000 fb^{-1} is outlined.

Contributions of RDMS groups to the design of HGCAL

Under leadership of Igor Golutvin, Dubna group contributes to the design of future CMS endcap calorimeter, HGCAL

- Participation in the radiation damage of Scintillator tiles with direct SiPM readout
- Development of a technique of manufacturing and assembling of scintillator tiles and SiPM readout
- Prototype cooling plate for CE-H cassettes
- Other contributions

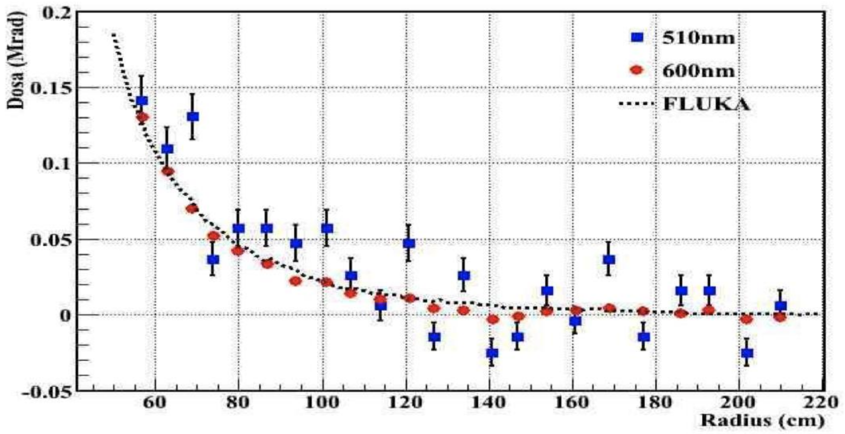
S.V.Afanasiev[1], A.Yu.Boyarintsev[2], Yu.V.Ershov[1], I.A.Golutvin[1], N.V.Gorbunov[1], A.I.Malakhov[1], V.A.Smirnov[1], N.I.Zamyatin[1],

[1] JINR, Dubna, Russia
[2] Institute for Scintillation Materials (ISMA), Kharkov, Ukraine

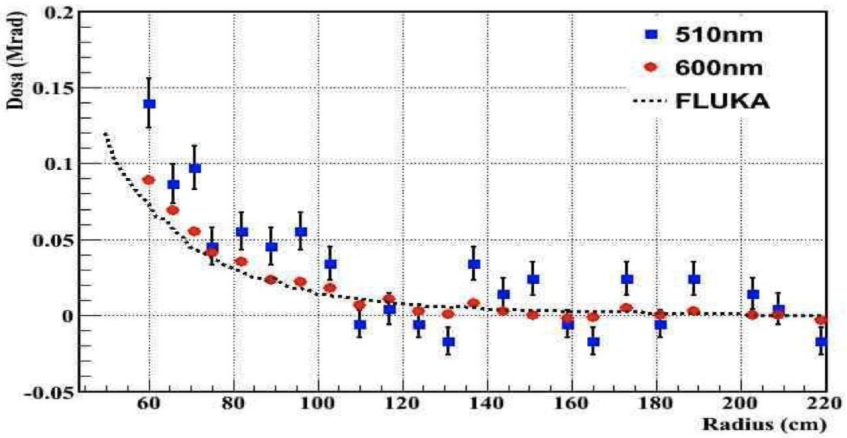
Absorbed dose measured by film dosimeters in the HE calorimeter

Installation of several raws of film radiachromic dosimeters (FWT-60):
two measurement sets along L1 megatiles and two sets along L2 megatiles.

L1b

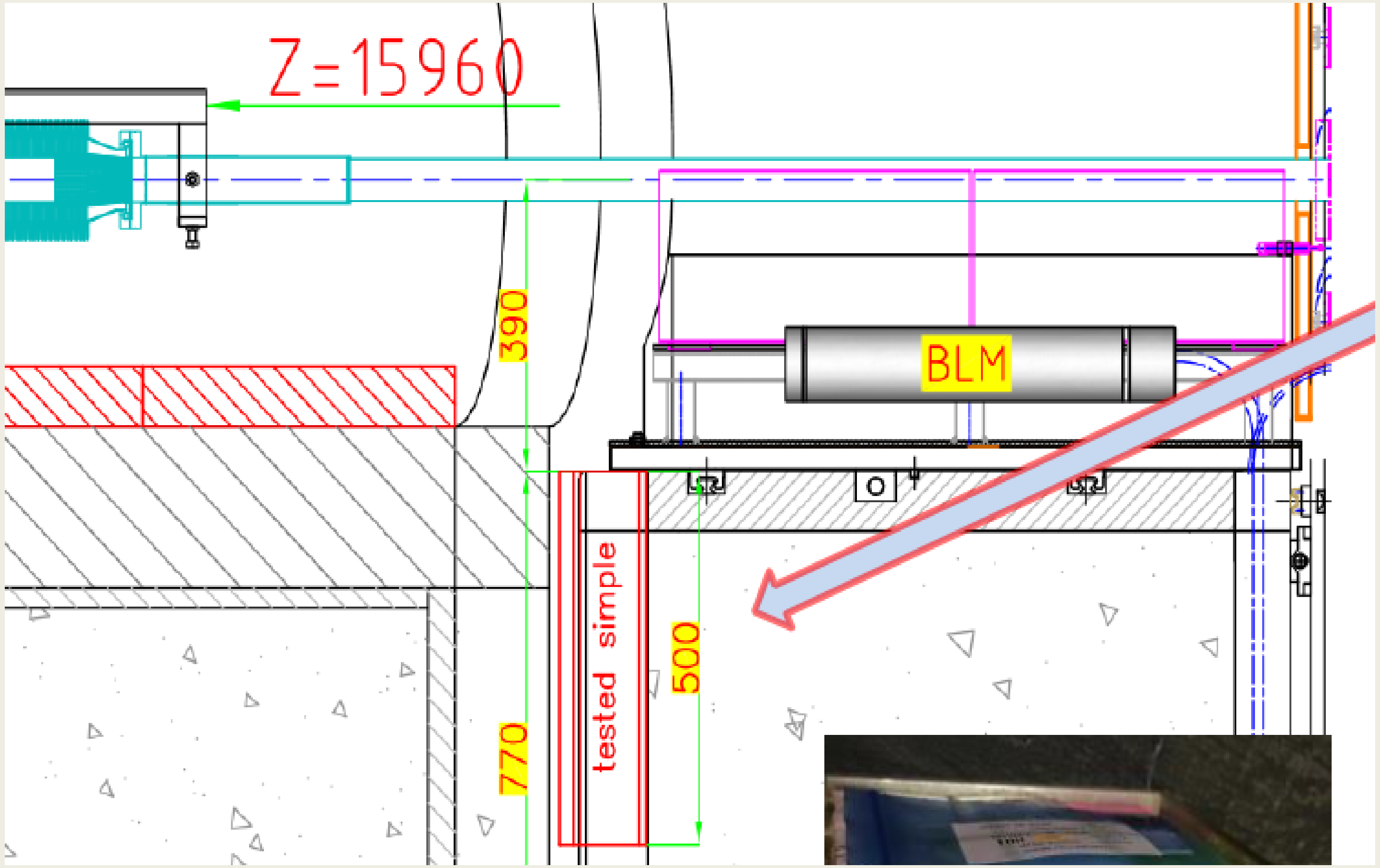


L2b



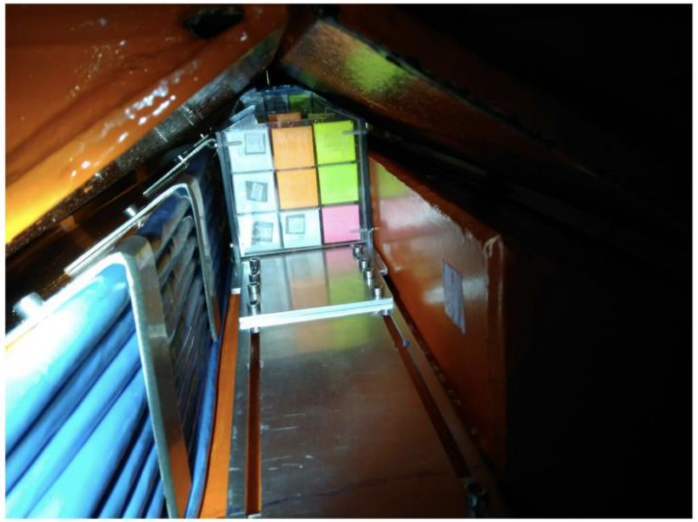
Castor Radiation Facility (CRF) at CMS

CRF was located in very forward region of CMS allowed to carry out radiation damage studies of Scintillator prototypes for Scint-SiPM section of HGCAL.



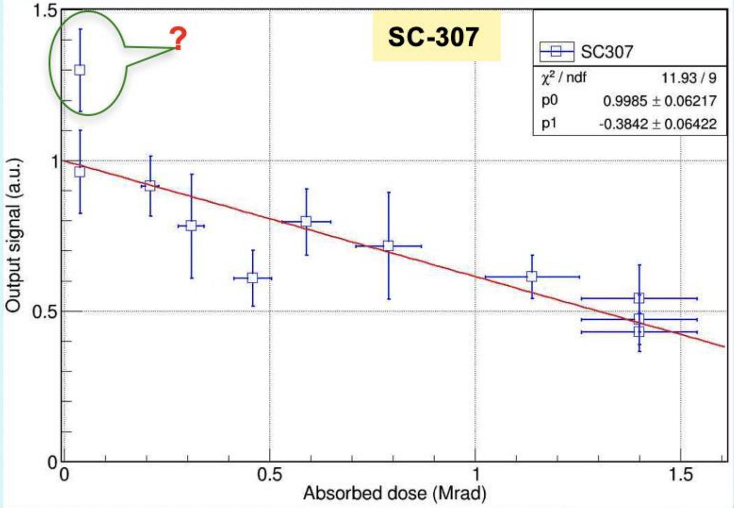
CRF Tower Assembled

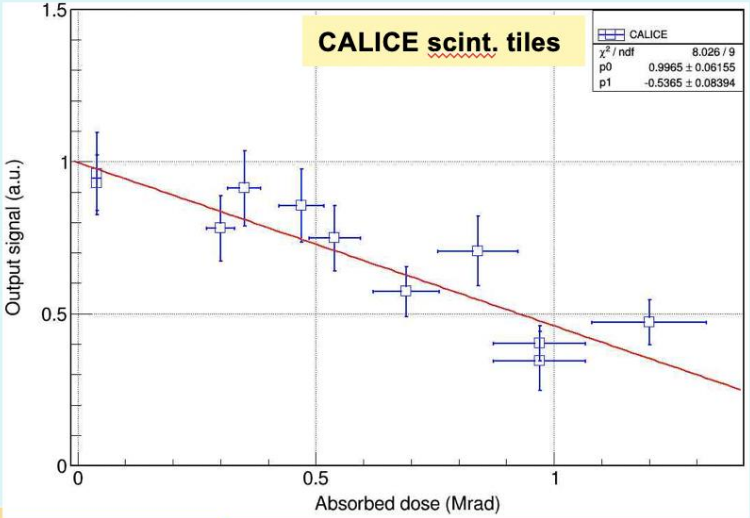
Inside CASTOR Vertical Slot



Scintillator tiles LO measurements at CERN cosmic rays setup (Sc307 & "Calice" type)

Data acquisition were provided by Dubna team (Sergey Afanasev et al.).
SiPM – MPPC S12572 -015P with active area 3x3 mm^2 (room temperature)
(Data processing from Protvino team)





Relative LO vs absorbed dose

LO degradation at the level of absorbed dose:
0.5 Mrad is about of 20%;
1 Mrad - ~40%

LO degradation at the level of absorbed dose:
0.5 Mrad is about of 30%;
1 Mrad - ~50%

Andrei Uzunyan HGCAL SiPM-on-Tile Meeting, 22 May 2019 8

Castor Radiation Facility at CMS: Collaborative effort of Dubna, INR, Protvino and Rochester groups

At CRF, dose of 0.5 Mrad was delivered with rate of 0.5 krad/hr.

At HGCAL, for the dose of 0.5 Mrad we expect rates ~ x20 lower !

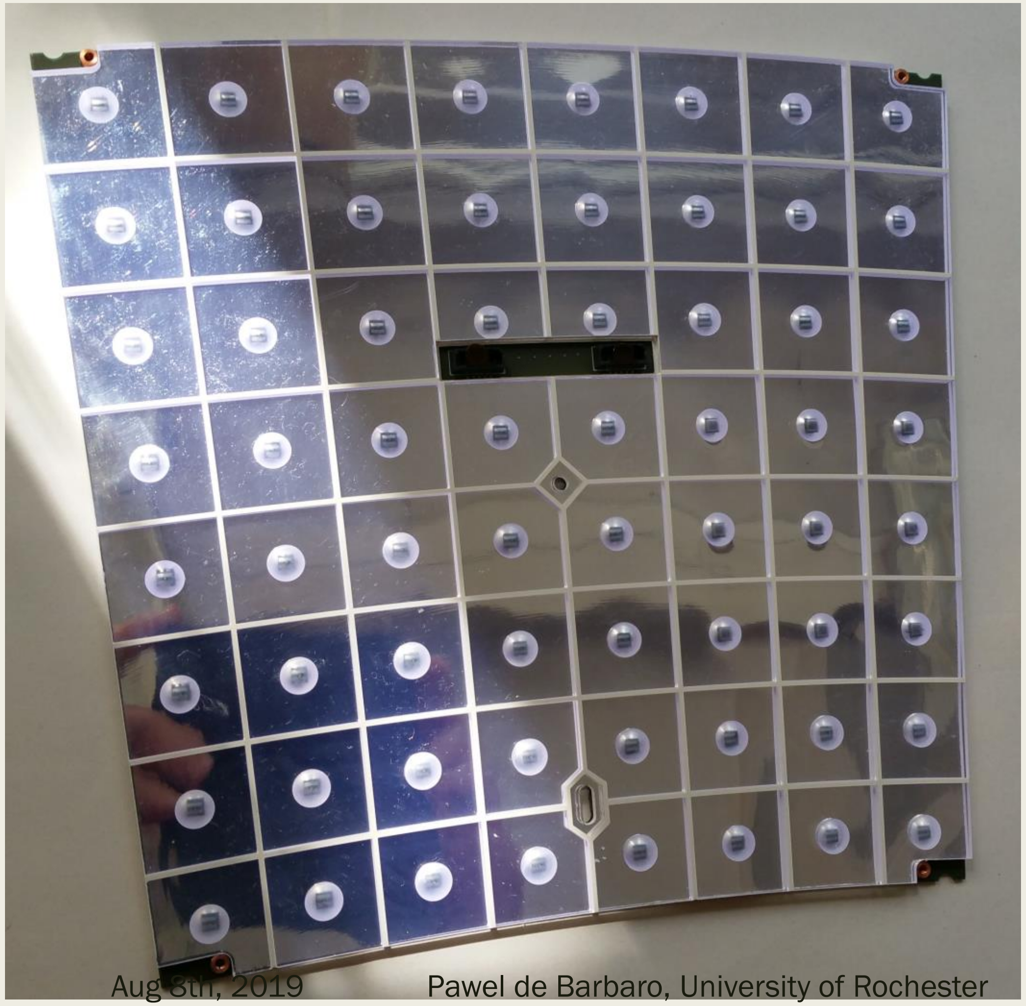
Based on CMS-HE data, we would expect dose constant to be ~ x4-5 smaller, implying damage will be lager.

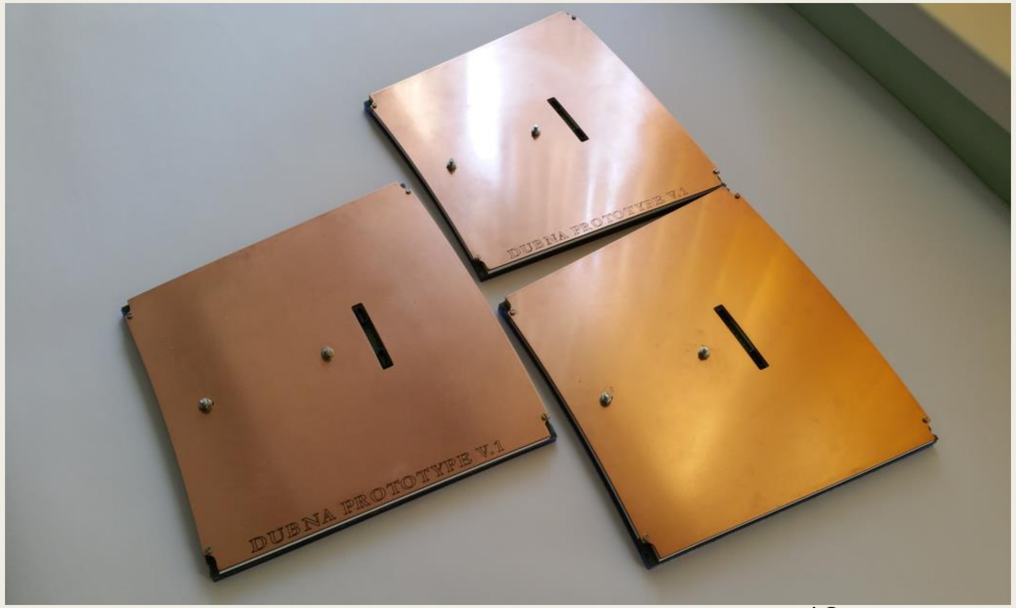
Prototype of macro-tile developed at Dubna

Prototype modules were designed and built in Dubna. Modules were also provided to CERN, FNAL and DESY for parallel tests and evaluation.

S.V.Afanasiev[1], A.Yu.Boyarintsev[2], M.V.Danilov[3,4], Yu.V.Ershov[1], I.A.Golutvin[1], N.V.Gorbunov[1], B.V.Grynyov[2], A.I.Malakhov[1], E.V.Popova[4], V.A.Smirnov[1], B.S.Yuldashev[5], N.I.Zamyatin[1], A.V.Zarubin[1]

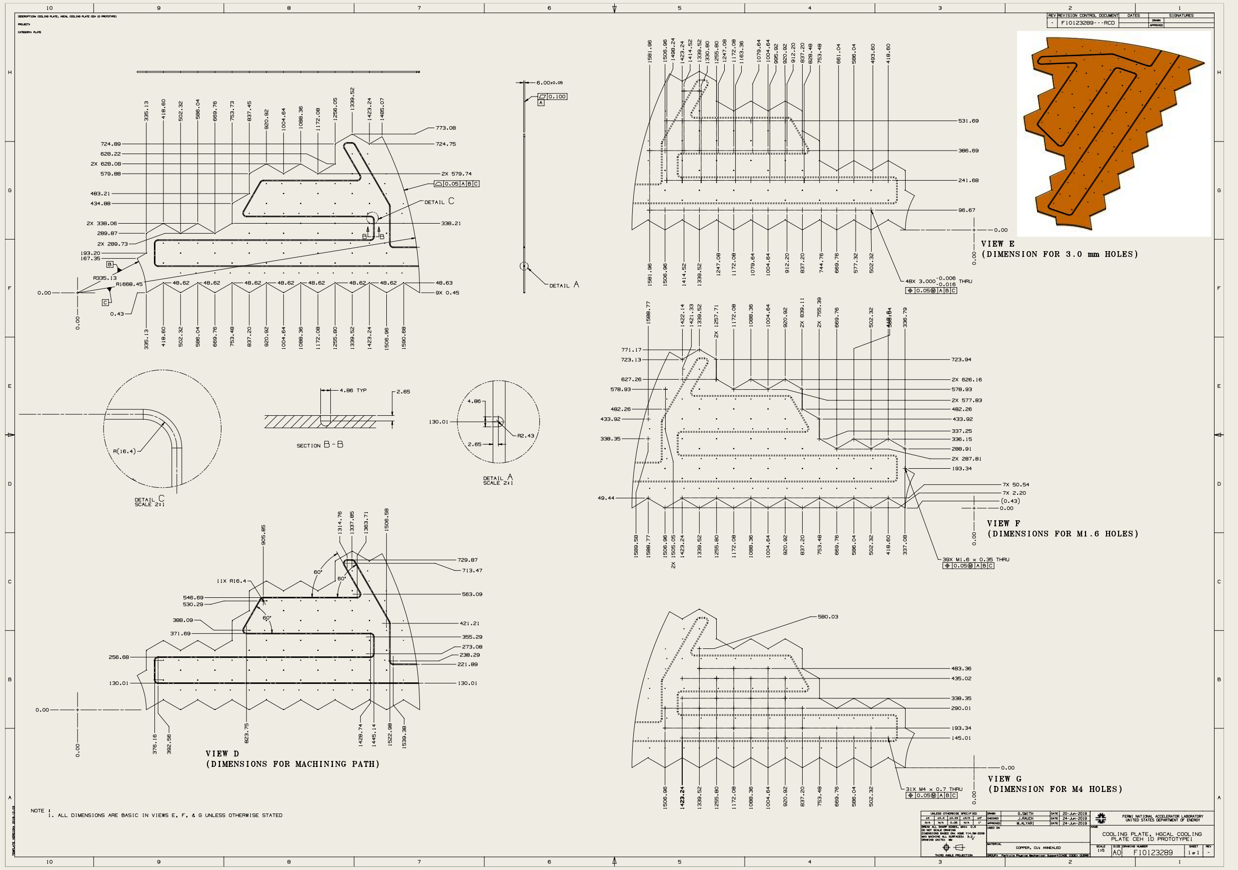
[1] *JINR, Dubna, Russia*
[2] *Institute for Scintillation Materials (ISMA), Kharkov, Ukraine*
[3] *Lebedev Physical Institute (LPI), Moscow, Russia*
[4] *National Research Nuclear University (MEPhI), Moscow, Russia*
[5] *Institute of Nuclear Physics (INP), Tashkent, Uzbekistan*





Example of other contributions to HGCAL by RDMS groups: copper cooling plates for CE-H

Last year, Minsk group has produced several small size prototypes of cooling panels for studying and mastering the technological process of production of this product.
This year, they are preparing full size prototype cooling plate for CE-H.



Last slide

Under Igor Golutvin's leadership RDMS has provided critical contributions to the development of CMS endcap calorimetry at the initial stage of its design in 1990-ties, during construction in early 2000s, as well as throughout the years of operation of the detector.

We are now preparing CMS or High-Luminosity upgrade of LHC.
High Granularity Calorimeter is designed to be a superb detector providing an unprecedented amount of information, but it is also obvious that realizing this detector involves serious technical challenges.

RDMS groups participate to the design effort of Scintillator/SiPM section of HGCAL.

Thank you Igor for years of your involvement, your wisdom and leadership role in this effort.