Thermal analysis and testing of the electronical package for the new High Granularity Calorimeter (HGCAL) for the CMS detector

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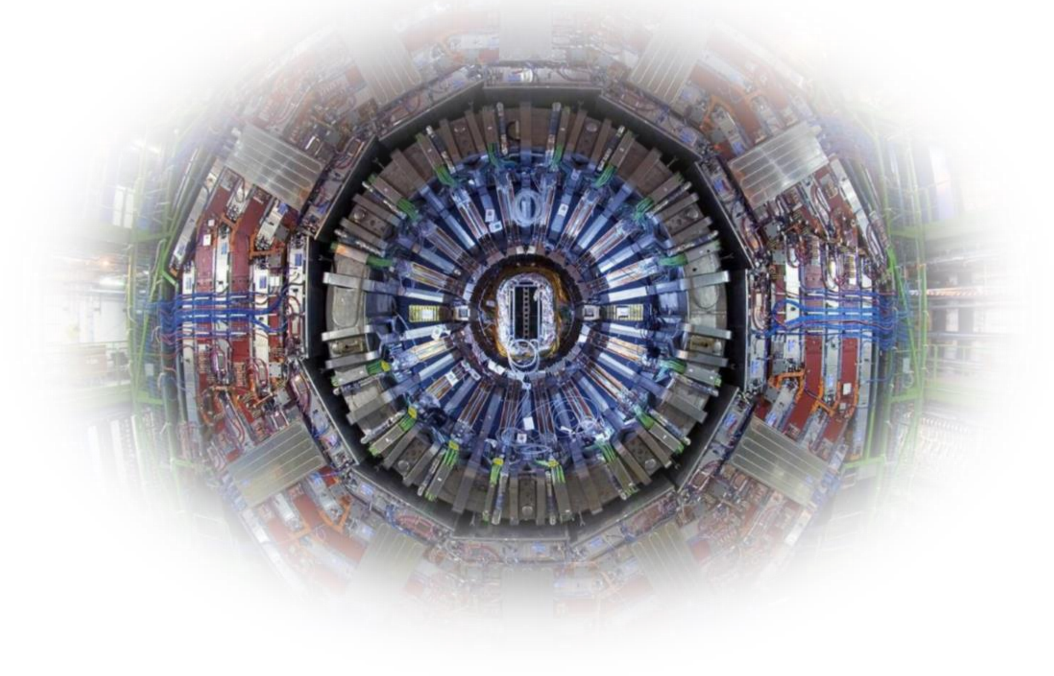
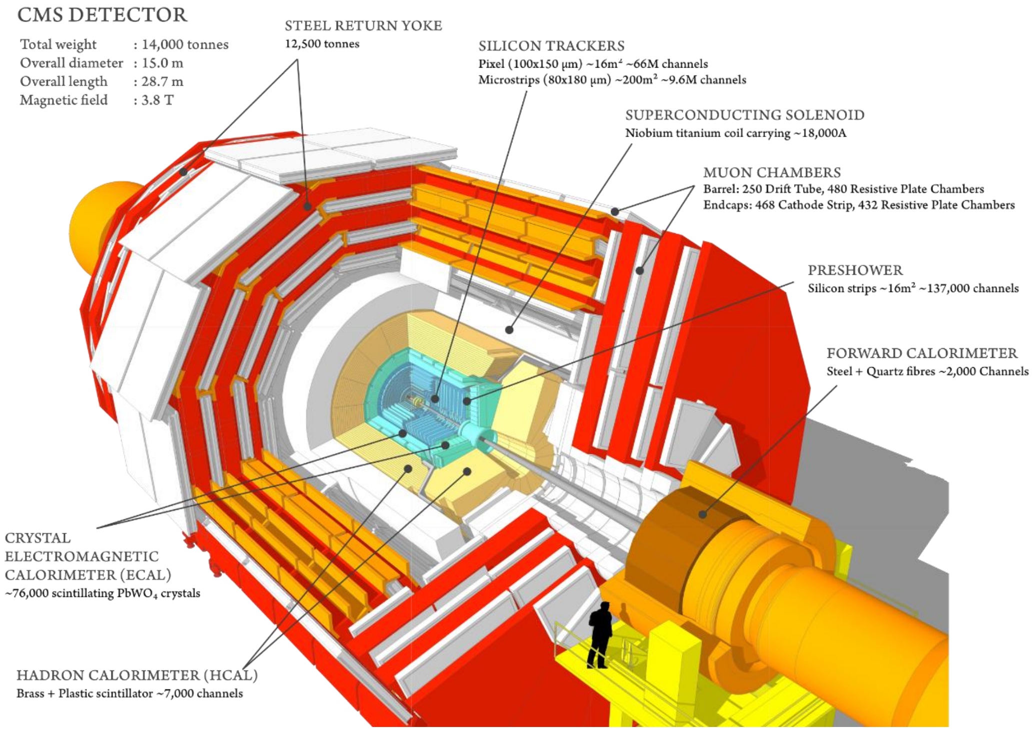
EP-CMX-EI

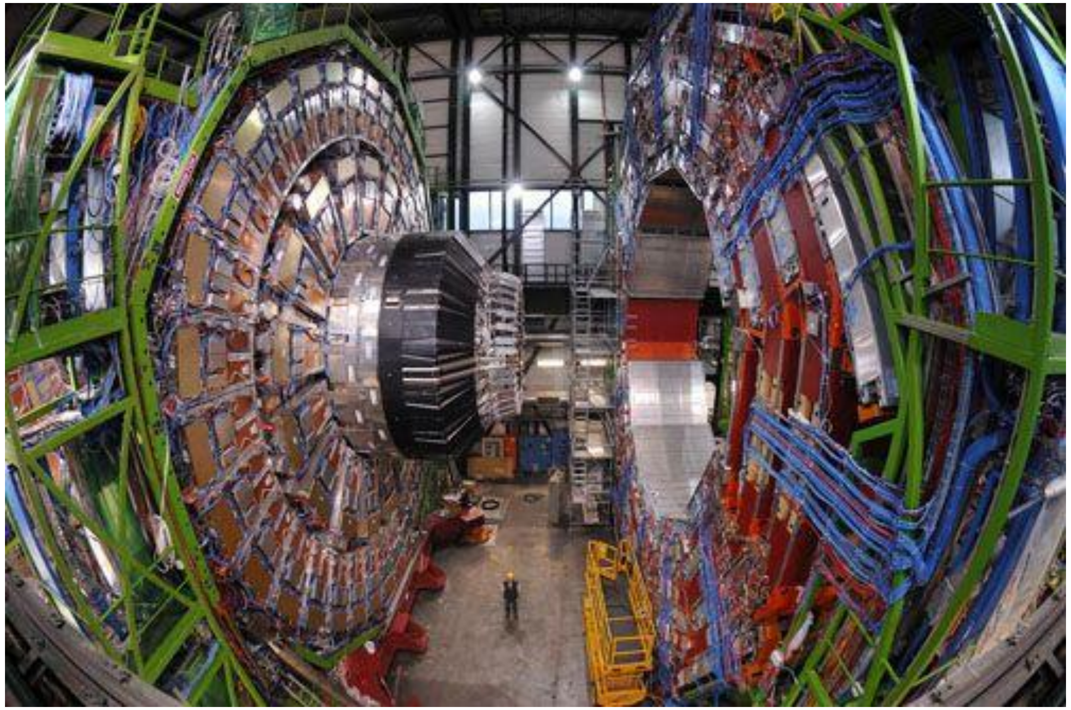


Context

What is the CMS?



CMS detector – 3D model

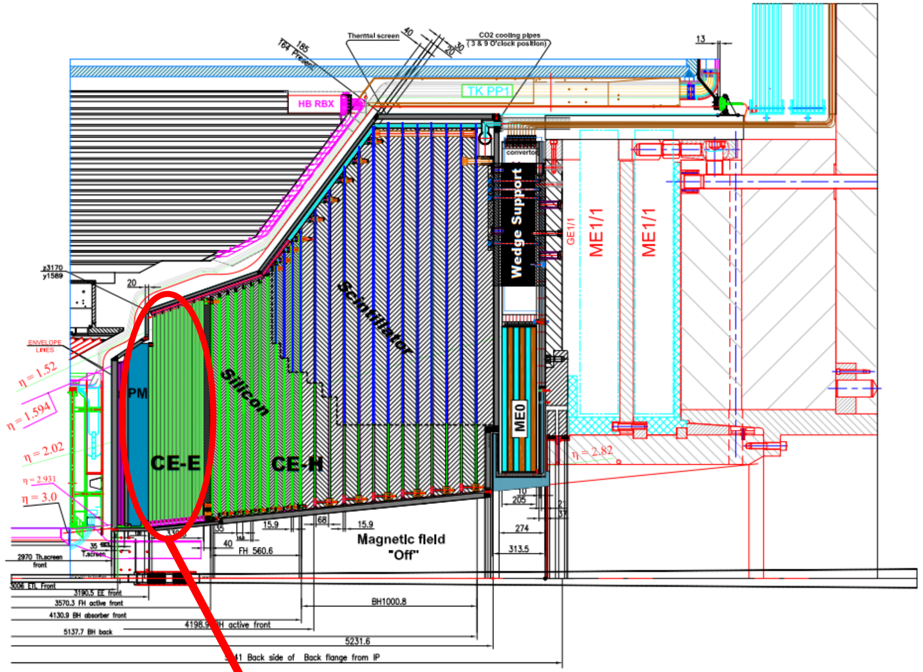


CMS detector – cavern photo

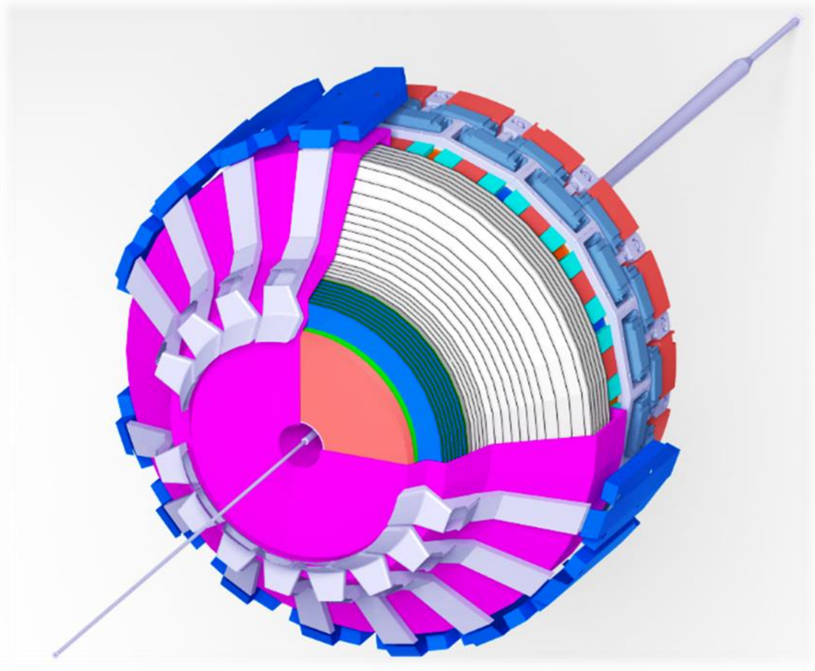
For the High Luminosity operation of the LHC, CMS will replace the endcap calorimeters with a new High Granularity Calorimeter.

Context

High Luminosity & High Granularity Calorimeter



HGCAL Slice drawing

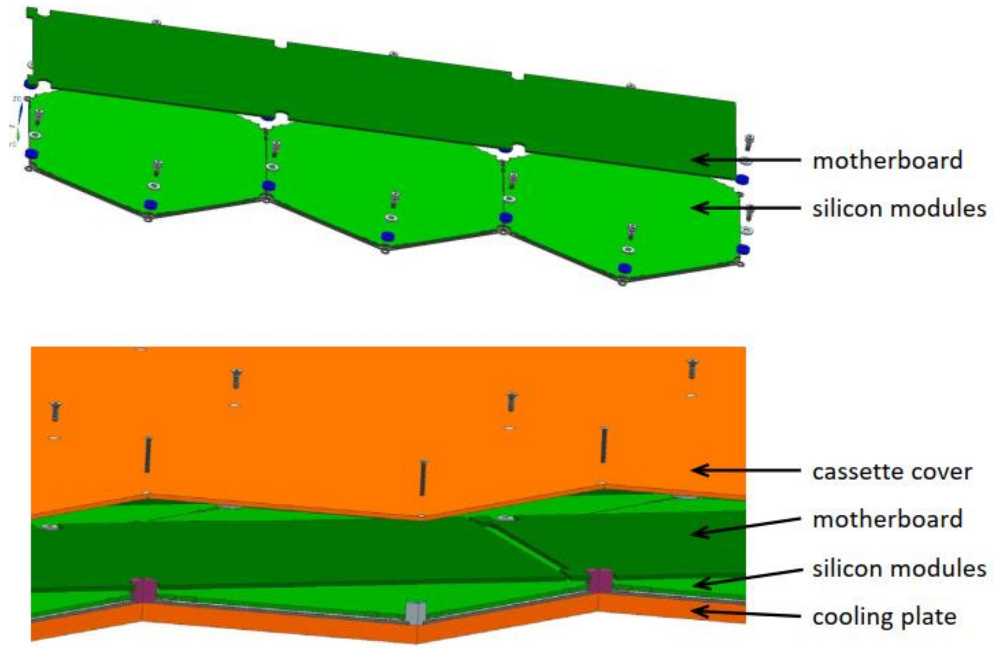


HGCAL 3D Model

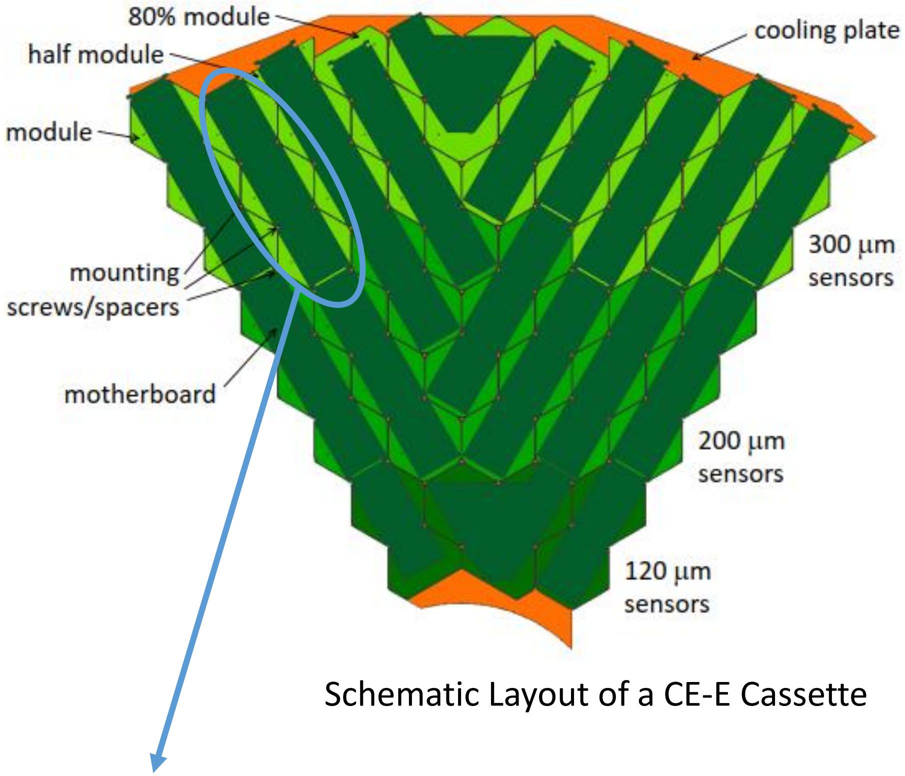
Initial focus will be on the Electromagnetic (CE-E)

Context

Cassette Layout?



Exploded diagram of a motherboard and three silicon modules on a cooling plate (at -30˚ C)



Schematic Layout of a CE-E Cassette

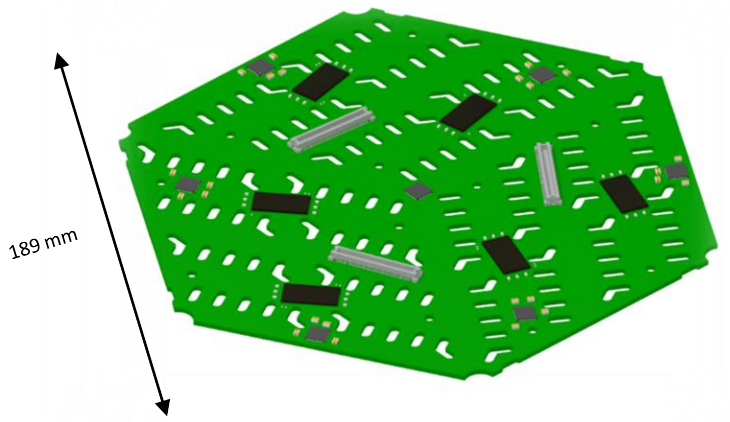
First analysis will be focused on a small section of the cassette composed by three modules (Silicon sensor, CU-W baseplate, Hexaboard), the cooling plate, motherboard and lead steel cover.

Internship objectives

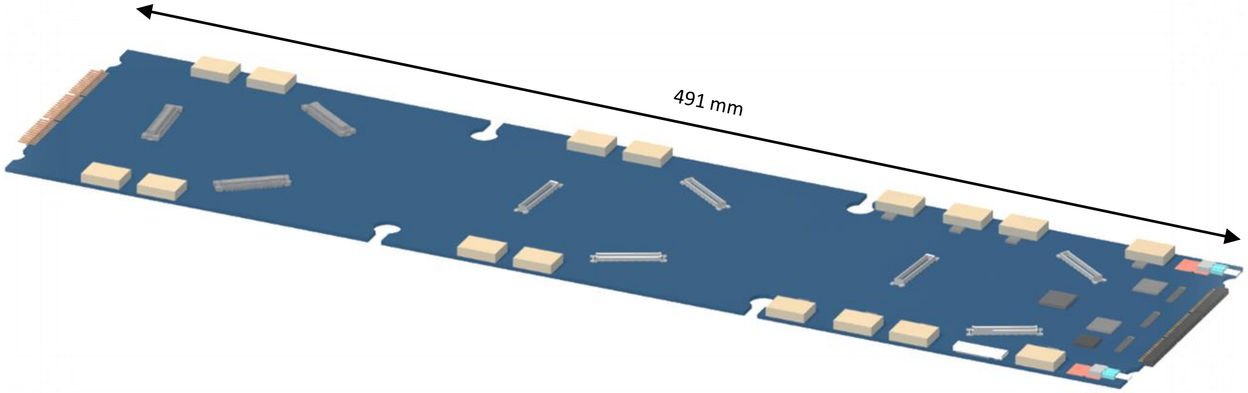
1. Thermal analysis of the Hexaboard-Motherboard (HB-MB) package
2. Proposal to improve the Thermal performance of the HB-MB configuration
3. Experimental setup and analysis to validate results
4. Thermal-mechanical model of the full cassette
5. Understand and propose new design solutions based on the obtained results

MB-HB Baseline

- Most recent models and heat loads provided by P. Rubinov (HGCAL Electronics Coordinator);
- Detailed electronic components with pin connections to the boards;
- Detailed plastic connectors between both boards;
- P. Rubinov also provided the heat loads of each one of the electronic components
- **Max. Allowable operating temperature for the chips is 60° C.**



Detailed 3D model of the Hexaboard

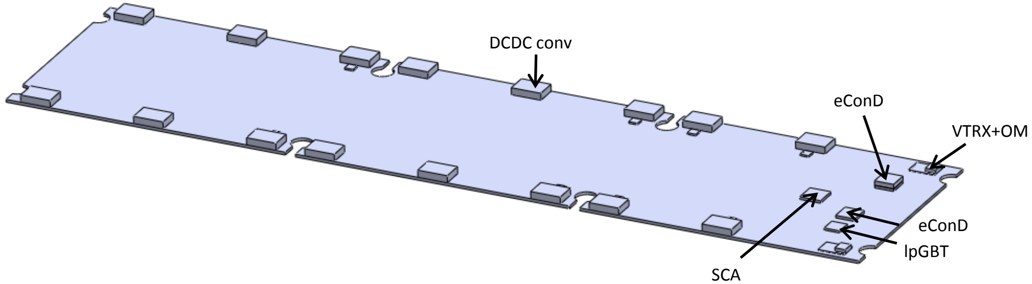


Detailed 3D model of the Motherboard

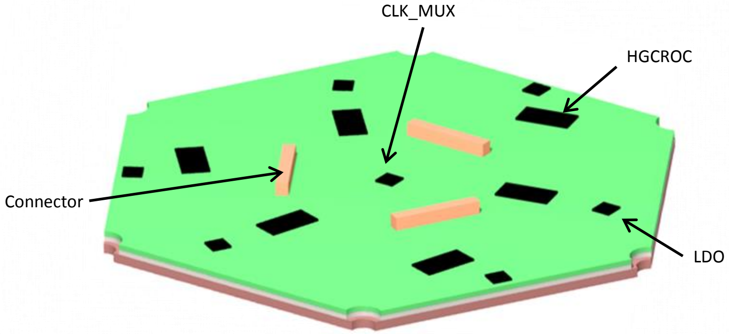
A **simplified** model **shall** be made (necessary for the thermal analysis)

MB-HB Model

- Electronic components cannot be moved due to motherboard design;
- Each electronic component is considered to be a silicon block with a specific internal heat generation;



Motherboard- 3D model



Hexaboard – 3D Model

Motherboard					
Component	Dimension [mm]			Power [W]	Internal Heat Generation [W/m^3]
SCA_GBT	12.00	12.00	1.50	0.10	4.63E+05
eConD	11.00	11.00	1.50	1.50	8.26E+06
lpBGT	9.00	9.00	1.25	0.75	7.41E+06
eConT	11.00	11.00	1.50	2.50	1.38E+07
VTRX+OM	15.00	10.00	0.50	0.75	4.72E+06
	7.00	6.00	2.00	0.75	
DCDC conv	17.00	12.00	4.00	1.50	1.78E+06
DCDC cont	5.00	5.00	1.00		

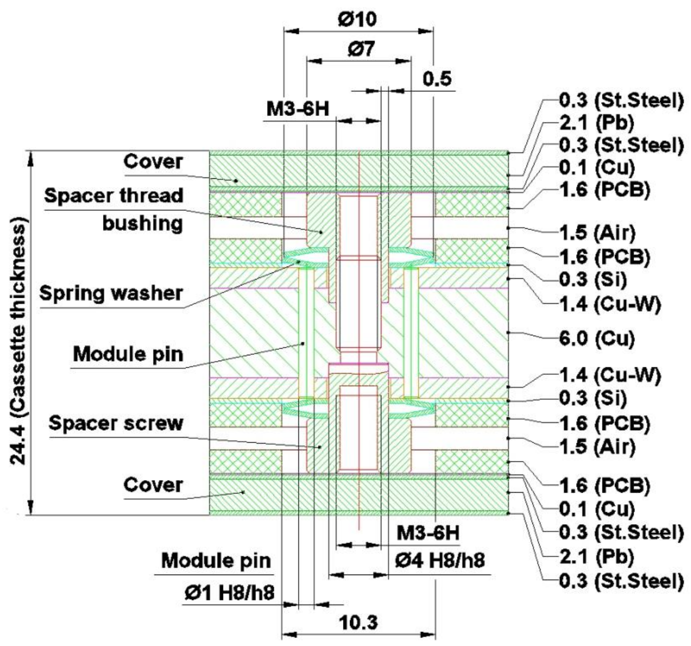
Motherboard components and specs

Hex Board					
Component	Dimension [mm]			Power [W]	Internal Heat Generation [W/m^3]
HGCROC	8.60	16.80	0.70	1.10	1.09E+07
LDO	6.10	6.10	0.70	0.13	4.99E+06
CLK_MUX	6.10	6.10	0.70	0.10	3.84E+06

Hexaboard components and specs

MB-HB Model

- Equivalent Thermal Contact Conductance (TCC) is going to be considered to simplify the model (no errors are introduced);
- Posts connect the copper layer to the lead-steel cover;
- No contact between the posts and the HB-MB;



Cross section through the thickness of a cassette

Hexagonon					
Layer	Name	Thickness [m]	Conductivity [W/K m]	Area [m^2]	Thermal Resistance [k/W]
1	Cu	3.00E-03	350	2.12E-02	4.04E-04
2	Cu+W	1.40E-03	15	2.12E-02	4.39E-03
3	Epoxy	7.50E-05	1.2	2.12E-02	2.94E-03
4	Kapton	1.05E-04	0.12	2.12E-02	4.12E-02
5	Epoxy	7.50E-05	1.2	2.12E-02	2.94E-03
6	Kapton	1.05E-04	0.12	2.12E-02	4.12E-02
7	Epoxy	7.50E-05	1.2	2.12E-02	2.94E-03
8	Silicon	3.00E-04	148	2.12E-02	9.54E-05
9	Epoxy	7.50E-05	1.2	2.12E-02	2.94E-03
10 plane	PCB	1.60E-03	20	2.12E-02	
10 perp	PCB	1.60E-03	0.38	2.12E-02	

Hexagonon Equivalent						
Layer	Name	Thickness [m]	Area [m^2]	Thermal Resistance [k/W]	Conductivity [W/K m]	C [W/k m^2]
1	Cu	3.00E-03	2.12E-02	4.04E-04	350.00	
2	Cu+W	1.40E-03	2.12E-02	4.39E-03	15.00	
3	Equivalent	4.35E-04	2.12E-02	9.12E-02	0.22	516.13
4	Silicon	3.00E-04	2.12E-02	9.54E-05	148.00	
5	Epoxy	7.50E-05	2.12E-02	2.94E-03	1.20	16000.0
6 plane	PCB	1.60E-03	2.12E-02		20	
6 perp	PCB	1.60E-03	2.12E-02		0.38	

Motherboard					
Layer	Name	Thickness [m]	Conductivity [W/K m]	Area [m^2]	Thermal Resistance [k/W]
1 - plane	PCB	1.60E-03	20		
1- perp	PCB	1.60E-03	0.38		
2	Cu	1.00E-04	350	5.01E-02	5.70E-06
3	air	1.00E-04	0.0234	5.01E-02	8.53E-02
4	steel	3.00E-04	60.5	5.01E-02	9.90E-05
5	Pb	2.10E-03	34.7	5.01E-02	1.21E-03
6	steel	3.00E-04	60.5	5.01E-02	9.90E-05

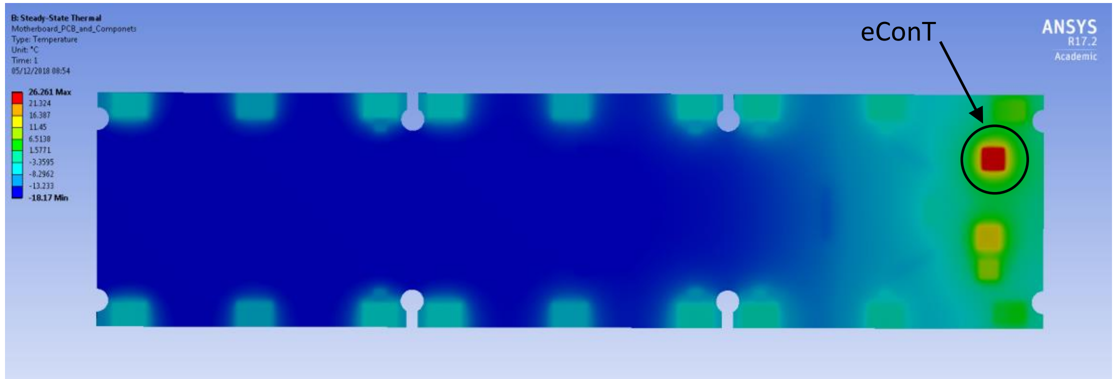
Motherboard						
Layer	Name	Thickness [m]	Area [m^2]	Thermal Resistance [k/W]	Conductivity [W/K m]	C [W/k m^2]
1 - plane	PCB	1.60E-03	5.01E-02			
1- perp	PCB	1.60E-03	5.01E-02			
2 3	Equivalent	2.00E-04	0.050101	8.53E-02	4.68E-02	2.34E+02
4	steel	3.00E-04	5.01E-02	9.90E-05	6.05E+01	
5	Pb	2.10E-03	5.01E-02	1.21E-03	3.47E+01	
6	steel	3.00E-04	5.01E-02	9.90E-05	6.05E+01	

Materials and layers of the cassette

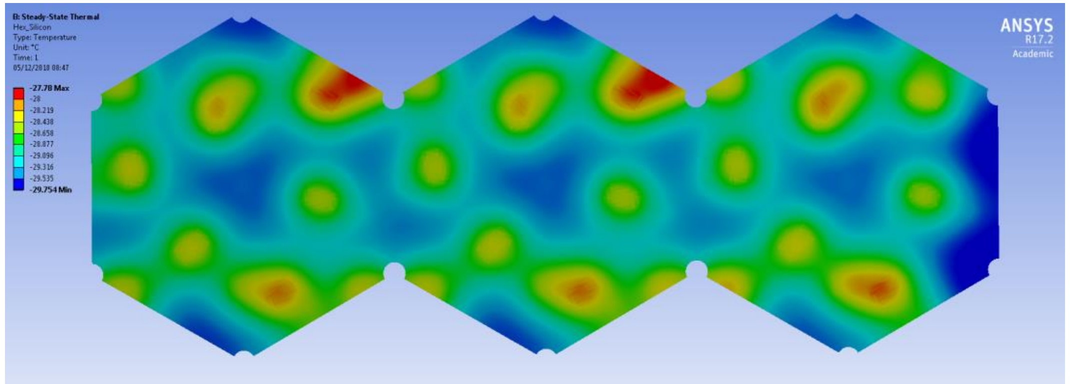
Major assumptions

- Simplified model using equivalent Thermal Contact Conduction (TCC);
- Cooling plate at -30 ˚C;
- Vacuum between Hexaboard and Motherboard (no difference by adding static air);
- Perfect connection between the posts, copper plate and the lead-steel cover;
- Perfect connection between each electronic components and the boards;
- Only conduction is considered (neither convection or radiation)
- Adiabatic system;
- Steady-state;

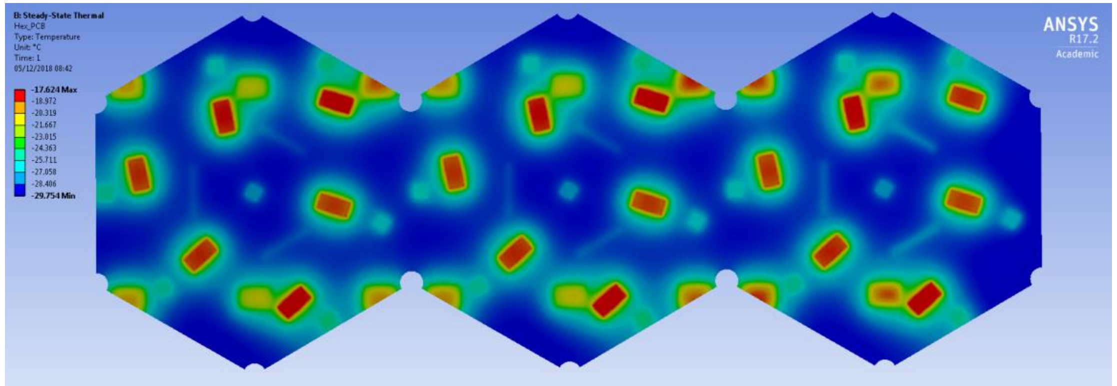
Baseline results



Baseline Model temperature - Motherboard



Baseline Model temperature – Silicon layer



Baseline Model temperature – PCB of Hexaboard

Results:

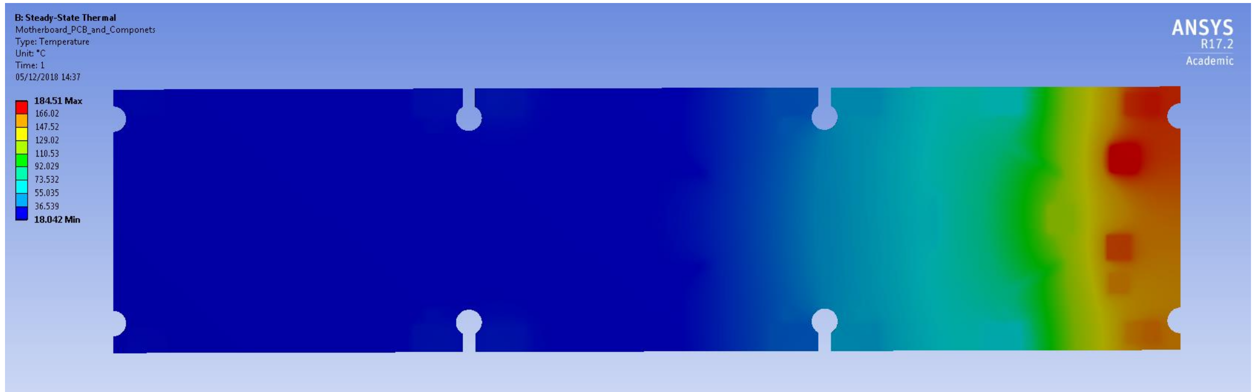
- eConT is the hottest electronic componet: **26.2 ˚C**;
- Maximum temperature reached by the sillicon layer is **-27.8 ˚C**;
- PCB does not contribute to the heat dissipation (as expected);

The eConT temperature ΔT with respect to the cooling plate is about **56 ˚C.**

This would represent a problem for the foreseen testing period with cooling plate at 15 ˚C

Importance of the cover

- **Without** lead-steel **cover** temperatures **will rise umpredictably**;
- Almost **no heat transfer through** the plastic **connectors;**

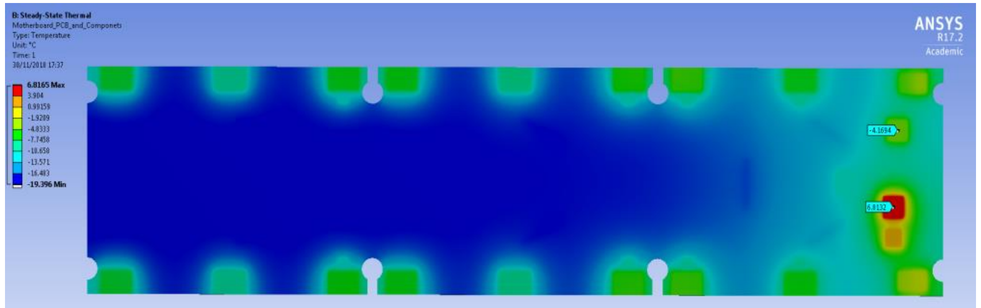


Motherboard temperature – Standard model with no lead-steel cover

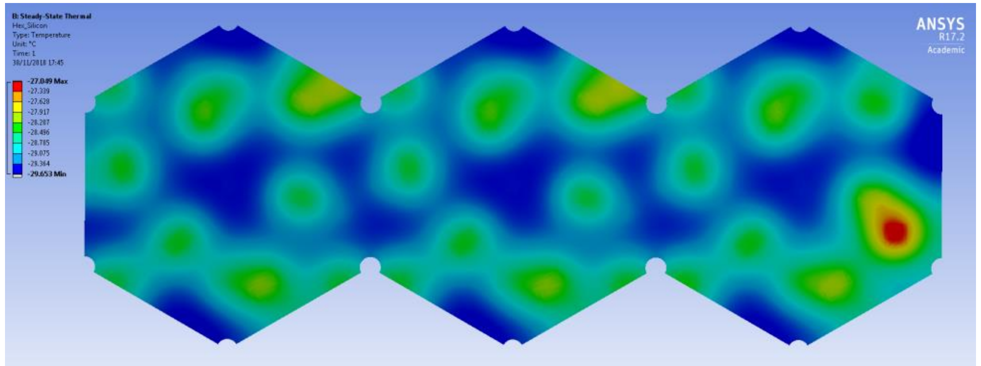
Good contact must be ensured between
the posts, lead-steel cover and the cooling plate

Most promising solution

- Possible solution could be the application of a **thermal pad (10 W/m K)** on eConT to the Hexaboard;
- Robustness of this solution to be evaluated;



Motherboard temperature considering a thermal pad



Silicon temperature considering a thermal pad

	Baseline	Thermal pad on eConT
eConT	26.2 ˚C	-4.2 ˚C
eConD	15.3 ˚C	6.8 ˚C

Results:
- Hottest electronic component is now eConD at 6.8 ˚C;
- Local increase of the temperature on the silicon layer to -27.0 ˚C;
- Lead-Steel cover has an extreme importance on the cooling of the motherboard;

Summary

- Lead-Steel cover has a significant impact on the motherboard cooling;
- High heat generation on several electronic components, specially on eConT – hottest component;
- The use of a thermal pad seems to be a promising solution (allowing thermal testing at room temperature);
- Convection has no influence on the results;
- Given the harsh environment (i.e. radiation, cooling cycles) degradation of the thermal pad material must be considered;

Challenges for 2019

- Improve the thermal contact modeling of the different considered parts (electronic components; cover; cooling plate and posts)
- Collaborative work with the cassete and electronic design engineers to optimize the thermal performance of the HB-MB package;
- Validate the obtained results (with experimental tests);
- Expand the thermal-mechanical analysis to the all cassette;

Questions?

References

[1] CMS Collaboration, "The Phase 2 Upgrade of the CMS endcap calorimeter", Technical design report, 9 April 2018, ISBN 978-92-9083-459-5