Heat Dissipation in High-Energy Physics: Investigating Thermal Management in the CMS GEM Detector

Author: **Omar Abdelhamid**

Mechanical Power Engineering Department, Cairo University

Supervisor: **Ivan Iliyanov Mihaylov**

CMS Experiment, CERN

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Abstract

The Compact Muon Solenoid (CMS) experiment at the European Organization for Nuclear Research (CERN) has been at the forefront of unraveling the mysteries of particle physics. The Gas Electron Multiplier (GEM) detector within CMS is a vital instrument, playing a crucial role in the detection of charged particles and their precise characterization. To maintain optimal detector performance and reliability, effective cooling and thermal management strategies are imperative.

This proposed research project focuses exclusively on the investigation of cooling and thermal management within the GEM detector of CMS. The study aims to comprehensively understand the thermal dynamics, heat dissipation characteristics, and the associated challenges inherent to this unique particle detection system.

Our methodology encompasses experimental thermal profiling, computational simulations, and data-driven analysis to gain deep insights into the thermal behavior of the GEM detector. We will scrutinize heat distribution patterns, identify potential hotspots, and evaluate the performance of existing cooling mechanisms. Moreover, the research will explore innovative cooling strategies and thermal optimization techniques tailored to the specific requirements of the GEM detector.

The significance of this study lies in its potential to enhance the reliability and precision of the CMS experiment. Efficient thermal management not only ensures the longevity of detector components but also maintains stable working conditions for accurate particle detection. Insights gained from this research will provide valuable guidance for future upgrades and improvements to the GEM detector's cooling systems.

GEMs are new detectors. So far, we have installed just 4 demonstrator pieces. The mass production and the full installation of these cutting-edge detectors we start this December.
There's very little practical knowledge of how these detectors will perform. That's why these measurements and simulations are so important. We expect big thing from this detectors. But there's is a lot of work to be done yet.

In conclusion, this research project aspires to shed light on the critical aspects of cooling and thermal management in the GEM detector of the CMS experiment. By addressing these challenges and optimizing thermal control, we aim to bolster the capabilities of CMS in its quest to further our understanding of the fundamental principles of the universe.

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Methodology

In the pursuit of advancing the precision and reliability of the Compact Muon Solenoid (CMS) experiment at the European Organization for Nuclear Research (CERN), this research focuses exclusively on the critical aspect of cooling and thermal management within the Gas Electron Multiplier (GEM) detector. Effective thermal control is essential for maintaining optimal detector performance, and this study employs a multi-method strategy to comprehensively investigate and enhance thermal management in the GEM detector.

Our research strategy involves the application of three distinct measurement methods under various operational scenarios: thermal imaging using infrared cameras, PT1000 temperature sensors, and infrared (IR) temperature guns. The different conditions were low voltage off, low voltage on, low voltage on and configured, low voltage on and configured and data taken. Each case of those translates to different power supplies by increasing the current while the voltage remains constant. These methods enable us to capture a comprehensive view of the thermal behavior within the GEM detector. The utilization of diverse measurement techniques ensures robust data collection and validation.

Furthermore, the acquired empirical data is rigorously compared with sophisticated simulations conducted on the ANSYS platform. This comparative analysis facilitates a comprehensive understanding of the thermal dynamics within the GEM detector and validates the accuracy of the simulation models. Discrepancies and deviations between empirical and simulated results are scrutinized to pinpoint areas requiring attention and potential improvement.

This research project holds the potential to yield invaluable insights into the cooling and thermal management challenges specific to the GEM detector, ultimately enhancing its reliability and performance. By leveraging a multi-method approach and combining empirical measurements with advanced simulation techniques, we aim to develop optimized thermal management strategies tailored to the unique requirements of the CMS experiment.

In conclusion, this research endeavors to advance our understanding of cooling and thermal management within the GEM detector of the CMS experiment at CERN. Through the judicious application of multiple measurement methods and rigorous comparison with ANSYS simulations, we aspire to contribute to the scientific community's efforts to explore the fundamental principles of the universe with increased precision and efficiency.

The Measurements

First Iteration

We managed to take the measurements two times. In the first one, we turned on the low voltage only and used the camera to give us an idea of where the hotspots were and the areas of interest to install the PT1000s on.

Figure 1: 1st Iteration

From the picture shown above, we came to the conclusion that we would put at least one probe per heating element type (Optohybrids, VFATs, and FEASTs) plus a probe for each of the cold and hotspots and one probe for the cooling source. Which makes them a total of seven interesting points to monitor specifically.

Second Iteration

After deciding the interesting points, the sensors were installed on those points and we took measurements at three different cases, each case with four different power supplies as discussed previously.

1st Case: Cooling plate installed but with no coolant circulating.

- **LV Off**

on picture		T PT1000	T camera	T IR gun
1	PT1	22.29	23.2	22.1
2	PT3	22.29	23.1	22.1
3	PT4	22.39	23.3	22.2
4	PT5	22.39	23.4	21.6
5	PT6	22.45	23.6	21.6
6	PT9	22.25	22.8	21.9
7	PT8	22.32	23.1	21.4

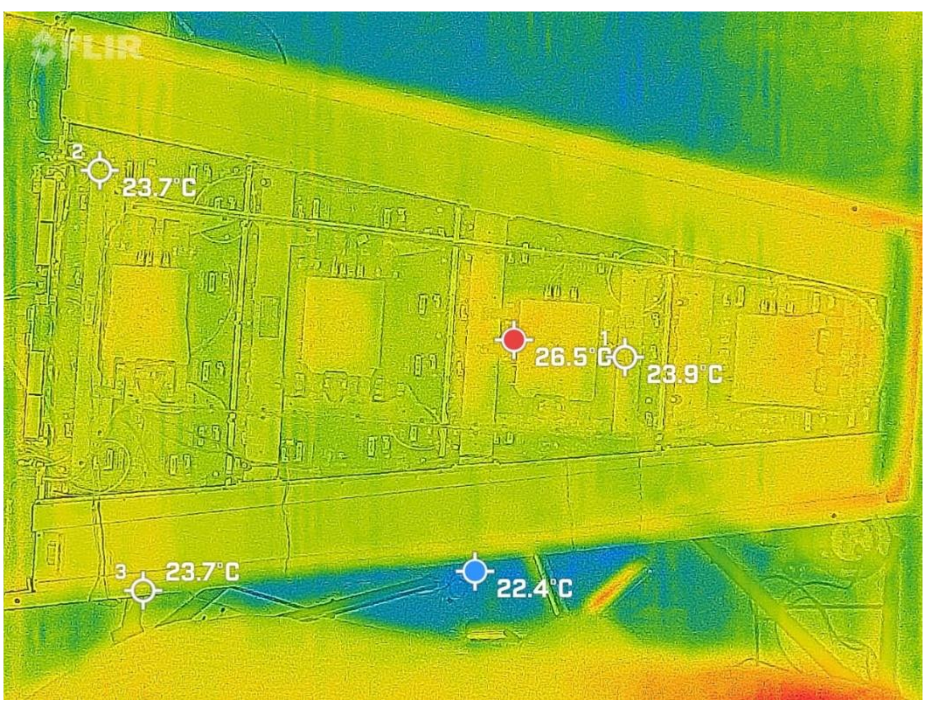

Figure 2: 1st Case(LV Off)

- **LV On (8 Volts, 4.38 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	25.5	24.4	22.6
2	PT3	26.04	23.8	22.9
3	PT4	24.21	24.5	22.1
4	PT5	22.45	23.2	21.3
5	PT6	23.06	23.6	21.4
6	PT9	22.35	23.2	21.4
7	PT8	25.19	24.6	22.7

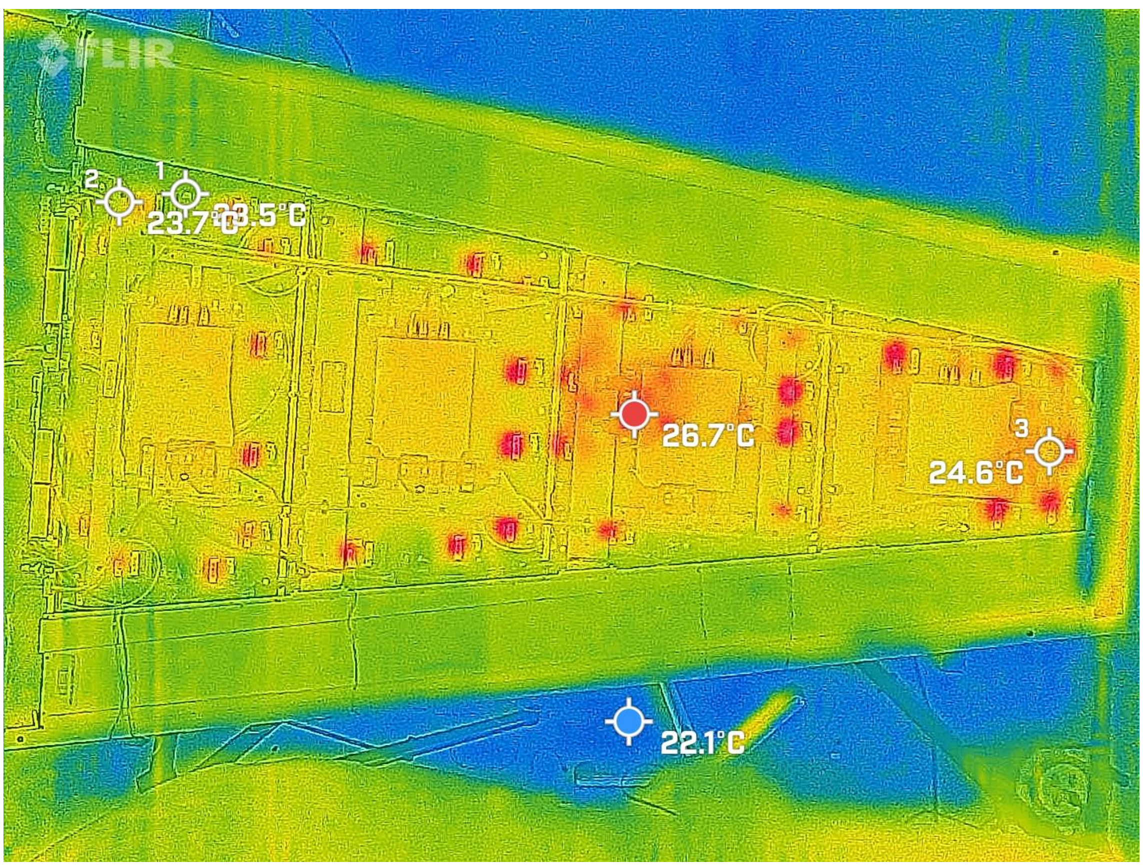

Figure 4: 1st Case (LV On)

- **LV On and Configured (8 Volts, 7.74 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	31.36	25.3	23.4
2	PT3	28.81	25	24.9
3	PT4	26.58	27.3	23.1
4	PT5	22.89	23.5	21.8
5	PT6	24.18	23.8	21.9
6	PT9	22.35	23.4	21.5
7	PT8	28.85	26.1	24.4

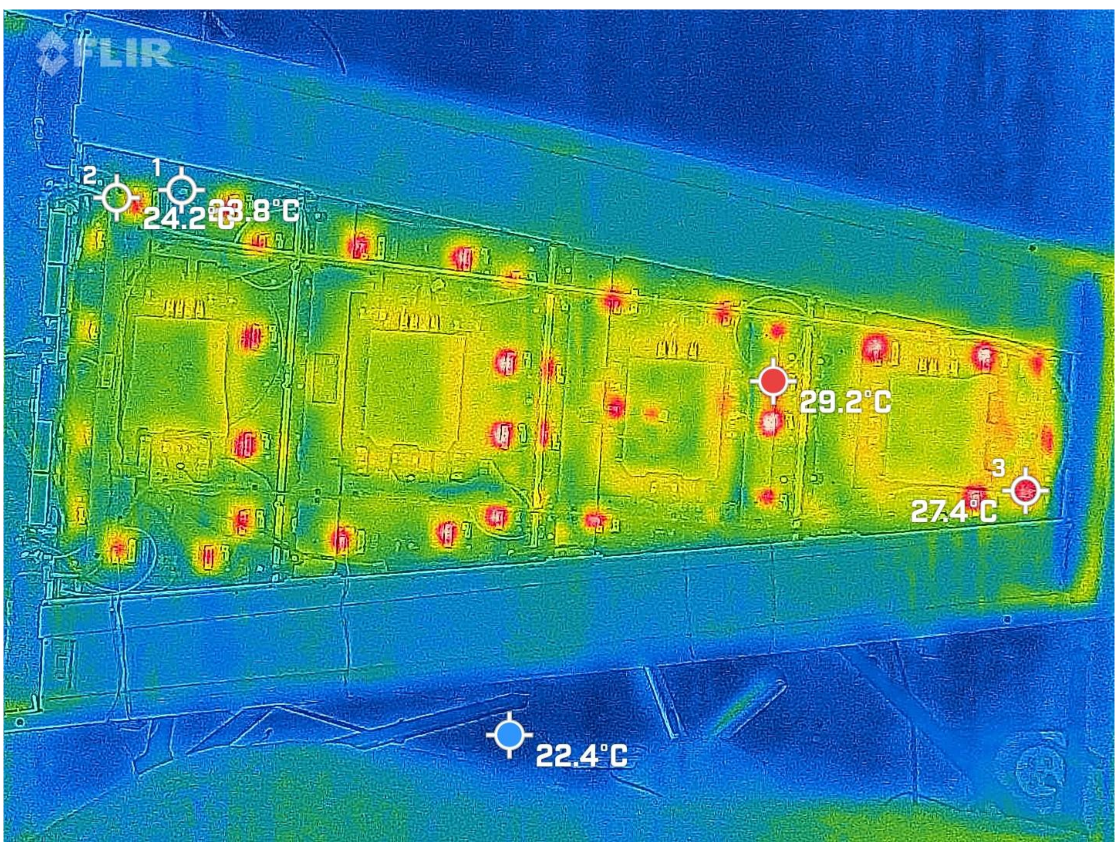

Figure 5: 1st Case (LV On and Configured)

- **LV On and DAQ Running (8 Volts, 7.89 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	32.41	24.6	23.2
2	PT3	29.56	24.9	25.3
3	PT4	26.88	28	23.4
4	PT5	23.1	24.5	21.8
5	PT6	24.58	24.2	22.1
6	PT9	22.42	22.9	21.6
7	PT8	29.7	27	25

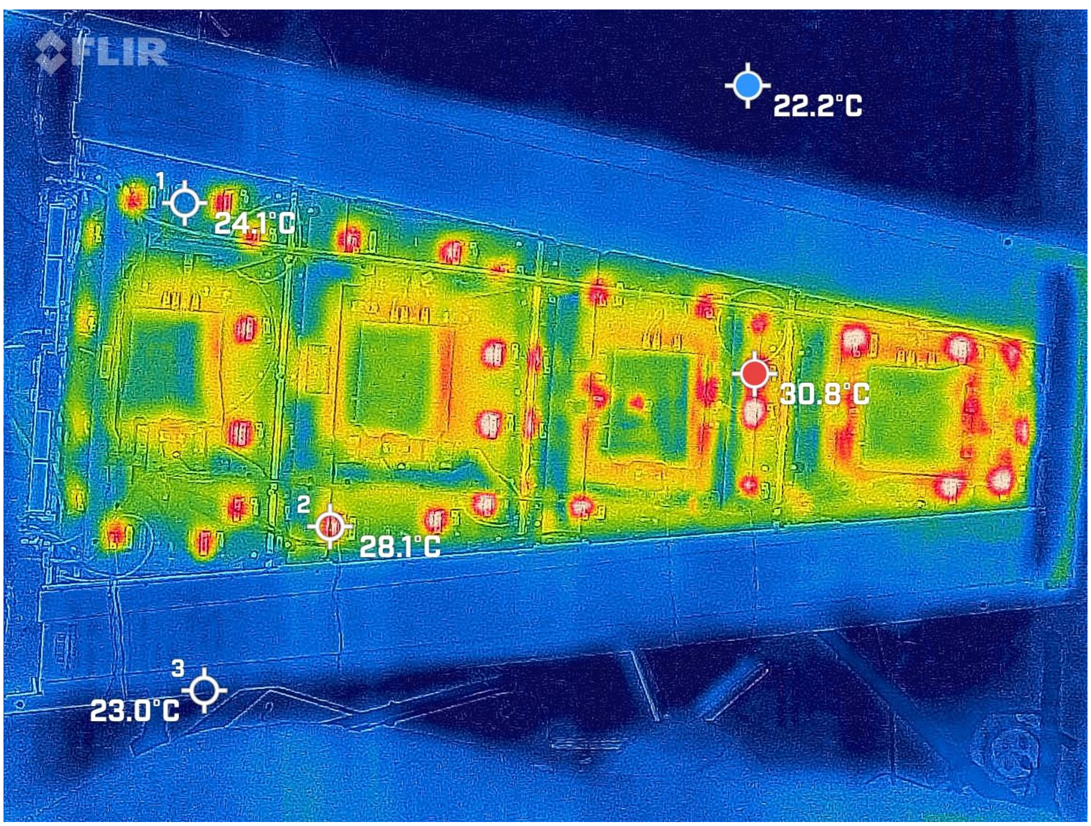

Figure 6: 1st Case (LV On and DAQ)

2nd Case: Cooling System On.

- **LV Off**

on picture		T PT1000	T camera	T IR gun
1	PT1	23.27	24.4	21.4
2	PT3	21.74	24.3	21.6
3	PT4	22.49	23.6	21
4	PT5	22.76	23.6	21
5	PT6	17.12	23.9	20.5
6	PT9	22.59	24.3	21.3
7	PT8	18.23	23.1	20.1

Figure 7: 2nd Case (LV Off)

- **LV On (8 Volts, 4.38 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	27.36	24.2	22.4
2	PT3	25.53	24.2	23.1
3	PT4	24.35	25.3	21.6
4	PT5	22.96	24	21.4
5	PT6	17.73	23.5	20.7
6	PT9	22.59	23.5	21.5
7	PT8	19.01	23.4	20.7

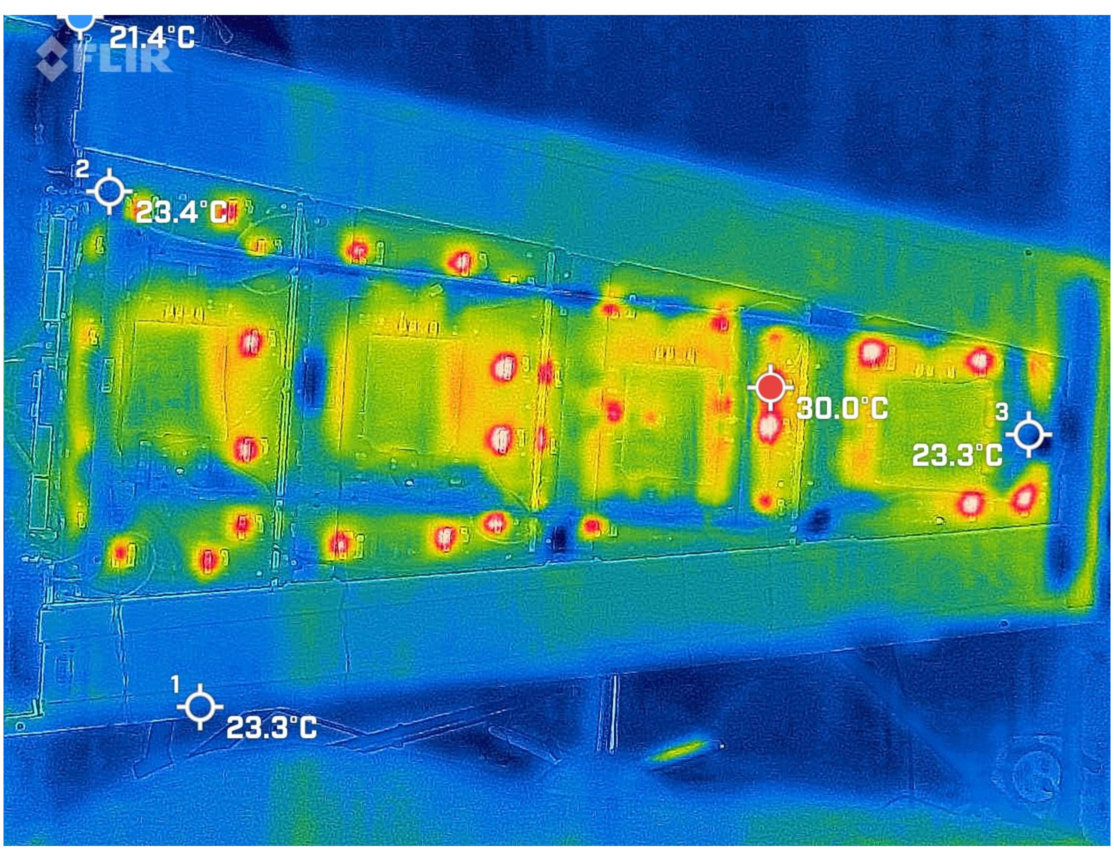

Figure 8: 2nd Case (LV On)

- **LV On and Configured (8 Volts, 7.73 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	29.46	25.1	22.6
2	PT3	26	24	24.1
3	PT4	25.9	27.8	22.5
4	PT5	23.06	24	21.6
5	PT6	17.39	23.1	21.1
6	PT9	32.56	23.8	21.7
7	PT8	19.14	23.3	20.9

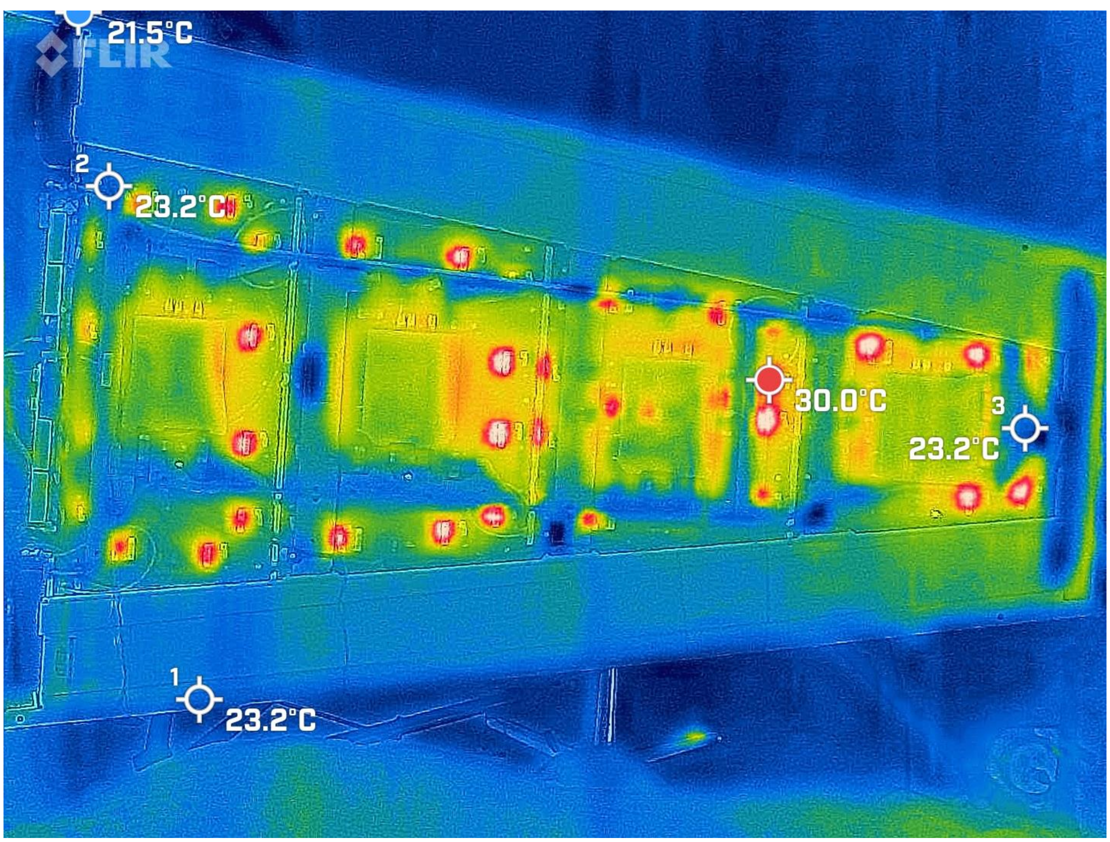

Figure 9: 2nd Case (LV On and Configured)

- **LV On and DAQ (8 Volts, 8.53 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	30.41	25.5	23.4
2	PT3	26.82	23.8	24.9
3	PT4	26.85	27.2	22.9
4	PT5	23.23	24	22.1
5	PT6	17.86	23.8	21.5
6	PT9	22.52	24.1	21.8
7	PT8	19.31	23.6	22.2

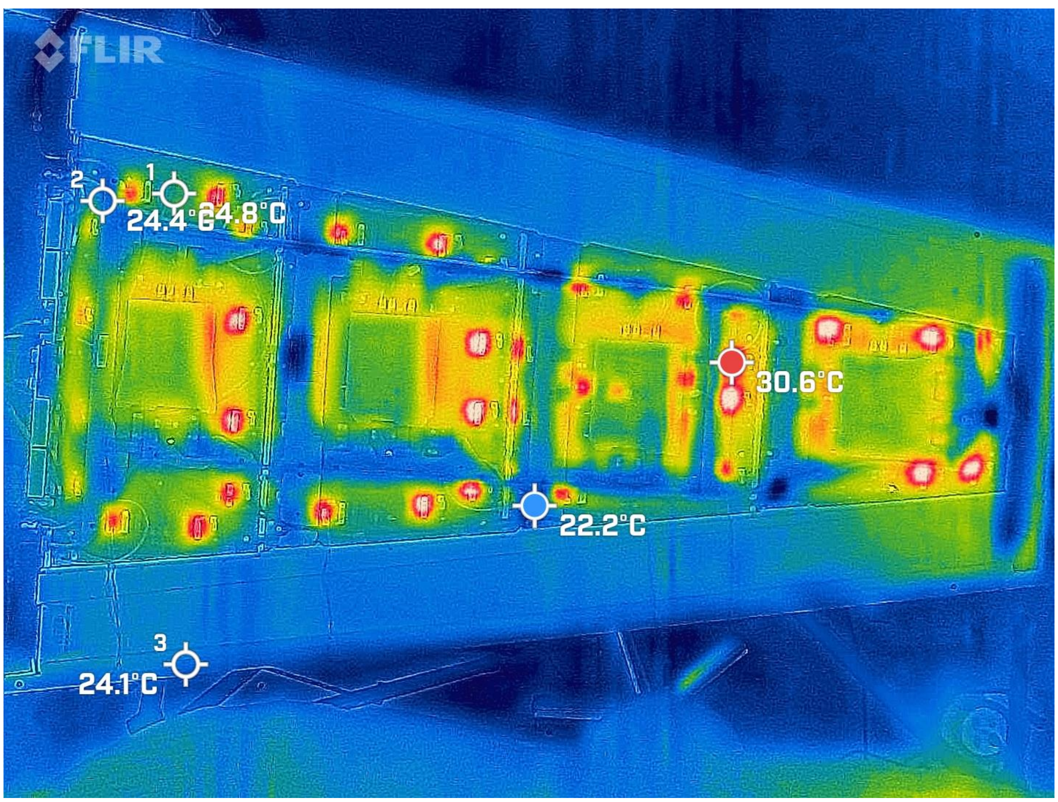

Figure 10: 2nd Case (LV On and DAQ)

3rd Case: Cooling Plate Off.

After removing the cooling system, we wanted to monitor the temperatures of the main heating elements inside the Optohybrids. Thus, two more probes were added to the OH.

- **LV Off**

on picture		T PT1000	T camera	T IR gun
1	PT1	23.13	24.1	22.2
2	PT3	23.2	24	22.3
3	PT4	22.89	23.7	22.2
4	PT5	22.96	23.3	22.2
5	PT6	23.16	23.7	22.3
6	PT9	22.72	23.1	22.3
7	PT8	23.16	23.7	22.4
	PT7	23.13	23.7	22.4
	PT2	23.43	23.8	22.4

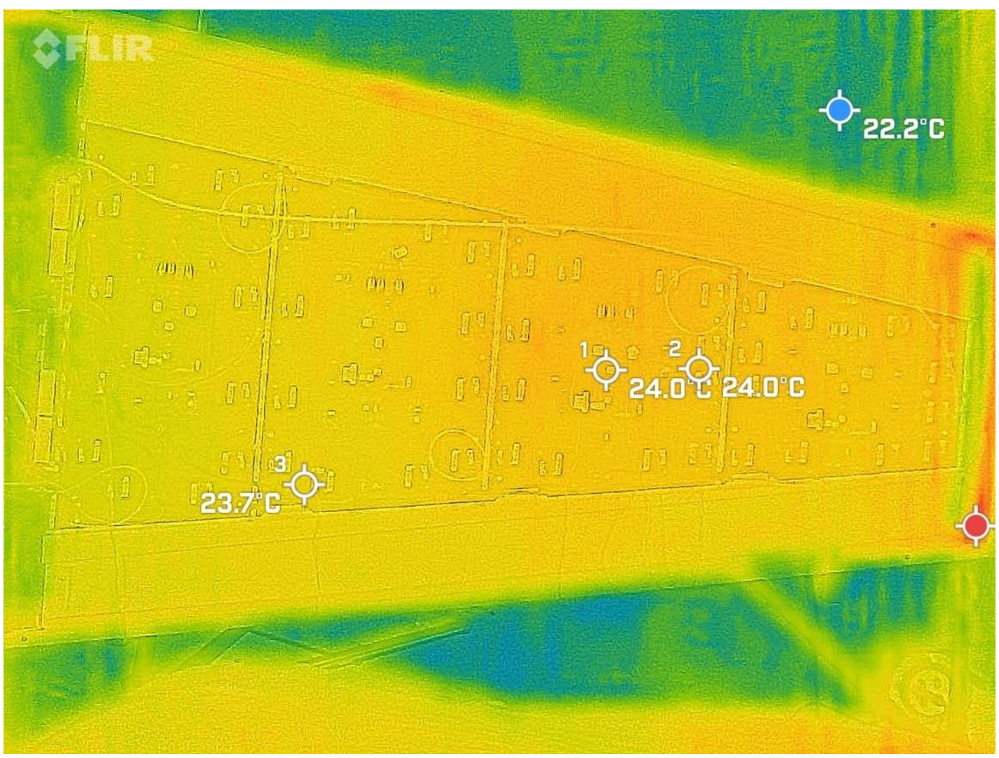

Figure 11: 3rd Case(LV Off)

Figure 12: 3rd Case (LV Off)

- **LV On (8 Volts, 4.43 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	24.72	27.5	24.6
2	PT3	27.63	26	27.9
3	PT4	24.45	24.1	22.8
4	PT5	22.96	23.7	22.3
5	PT6	41.9	34.4	29.8
6	PT9	22.69	23	22.6
7	PT8	23.81	24.9	23.4
	PT7	41.47	35.7	32
	PT2	29.9	31.4	28.6

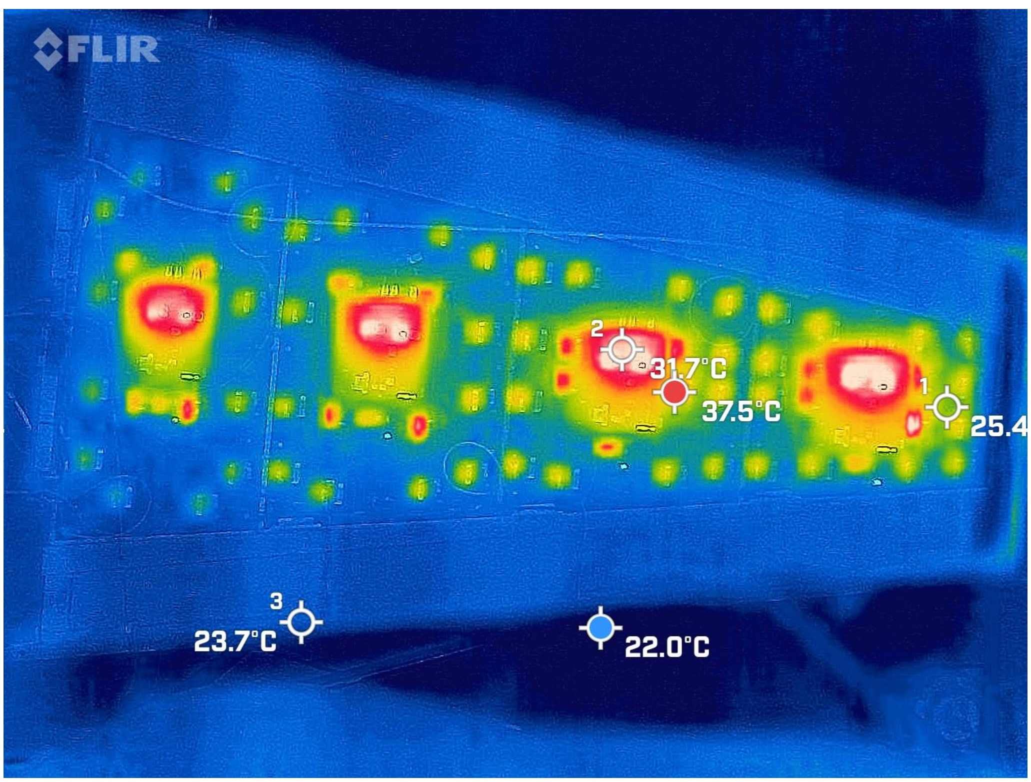

Figure 13: 3rd Case (LV On)

- **LV On and Configured (8 Volts, 7.91 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	30.64	32.4	28.6
2	PT3	28.85	29.1	29.6
3	PT4	26.28	27.4	23.3
4	PT5	23.2	24.2	22.3
5	PT6	46.91	38.7	33.6
6	PT9	22.69	23.3	21.6
7	PT8	25.09	27.3	24.8
	PT7	45.25	34.1	34.1
	PT2	47.76	37.9	35

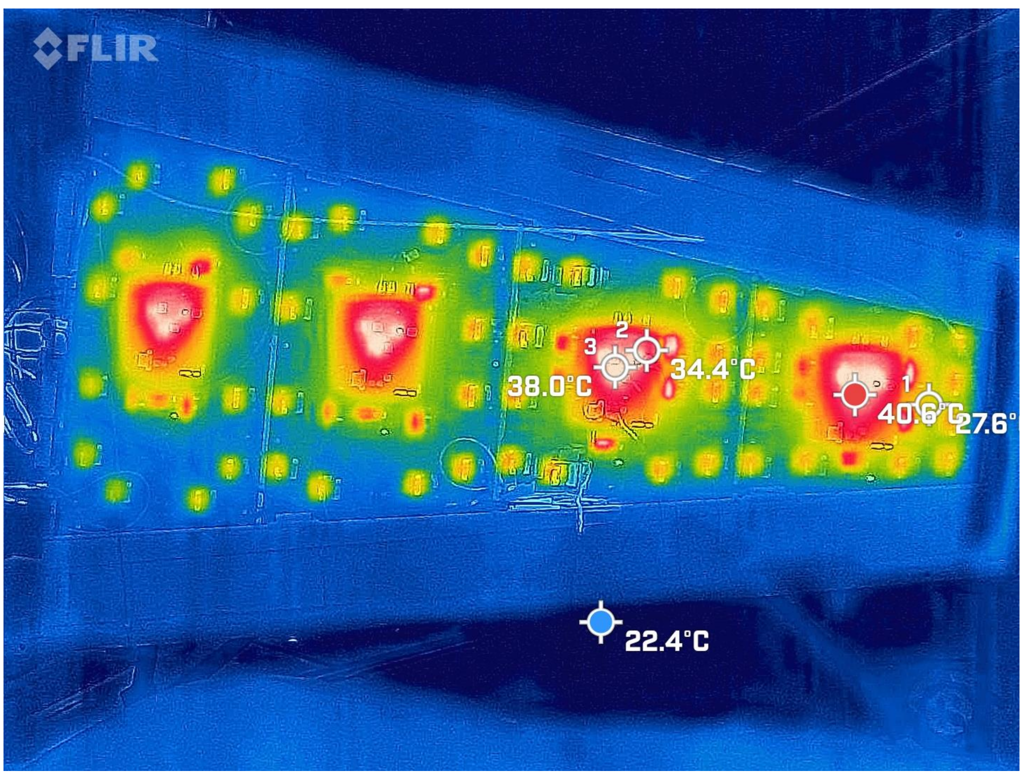

Figure 14: 3rd Case (LV On and Configured)

- **LV On and DAQ (8 Volts, 8.4 Amperes)**

on picture		T PT1000	T camera	T IR gun
1	PT1	32.98	33.8	30.2
2	PT3	29.86	30.6	31.2
3	PT4	26.65	28.3	24
4	PT5	23.57	25	22.4
5	PT6	48.62	35.6	33.4
6	PT9	22.69	23.5	21.6
7	PT8	36	27.3	26.4
	PT7	47.19	37	37.1
	PT2	49.57	34.7	35.3

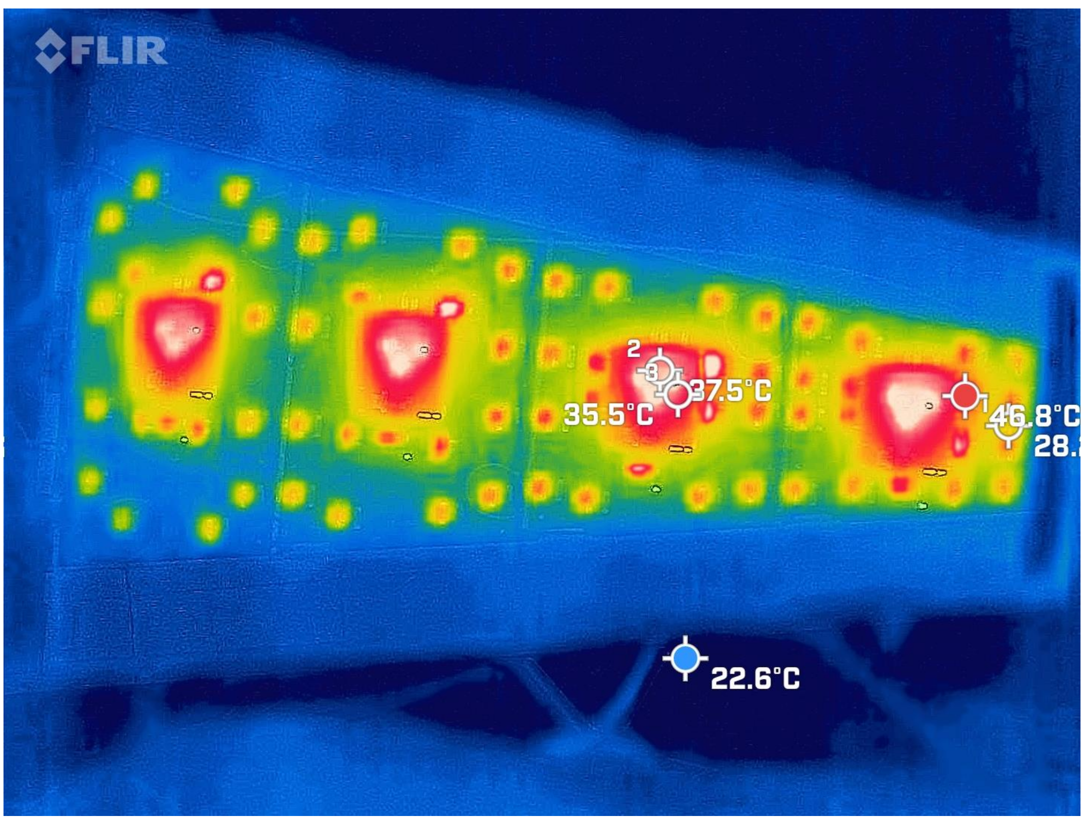

Figure 15: 3rd Case (LV On and DAQ)

The Simulation

A numerical approach was conducted using a steady-state thermal simulation using the ANSYS package. In the quest to optimize the cooling and thermal management of the Gas Electron Multiplier (GEM) detector within the Compact Muon Solenoid (CMS) experiment at CERN, a pivotal component of our research strategy involves the application of ANSYS steady-state thermal simulations. These simulations represent a cornerstone of our investigation, providing a powerful tool to comprehensively analyze and predict the thermal behavior of the GEM detector under various operating conditions.
The ANSYS software suite is renowned for its versatility and precision in simulating complex thermal systems, making it an ideal choice for our study. By adopting steady-state thermal simulations, we aim to model the thermal equilibrium of the GEM detector, allowing us to gain valuable insights into the distribution of temperature, heat flux, and thermal gradients within the detector components.

The first and the most time-consuming step is to prepare and clean the CAD geometry, below you can see the original geometry which was full of unwanted details. It took about two weeks to prepare the CAD to be ready for the simulation.

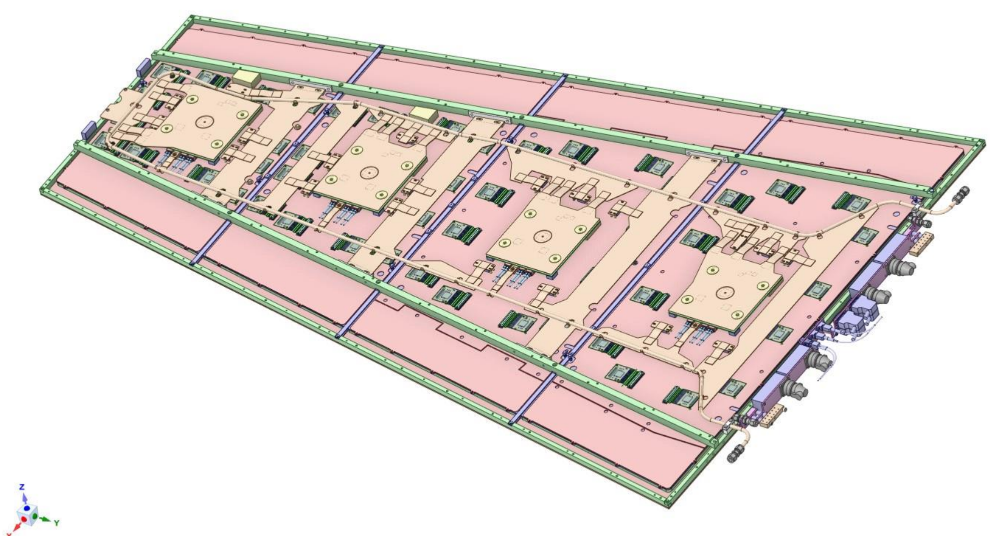

Figure 16: Original CAD

Due to the short time, only one iteration was performed.

Below you can see the mesh used to perform the simulation. Mainly, we used 50 mm global sizing on the whole domain and local sizing of 1 mm on the cooling pipe which yielded about 400k elements.

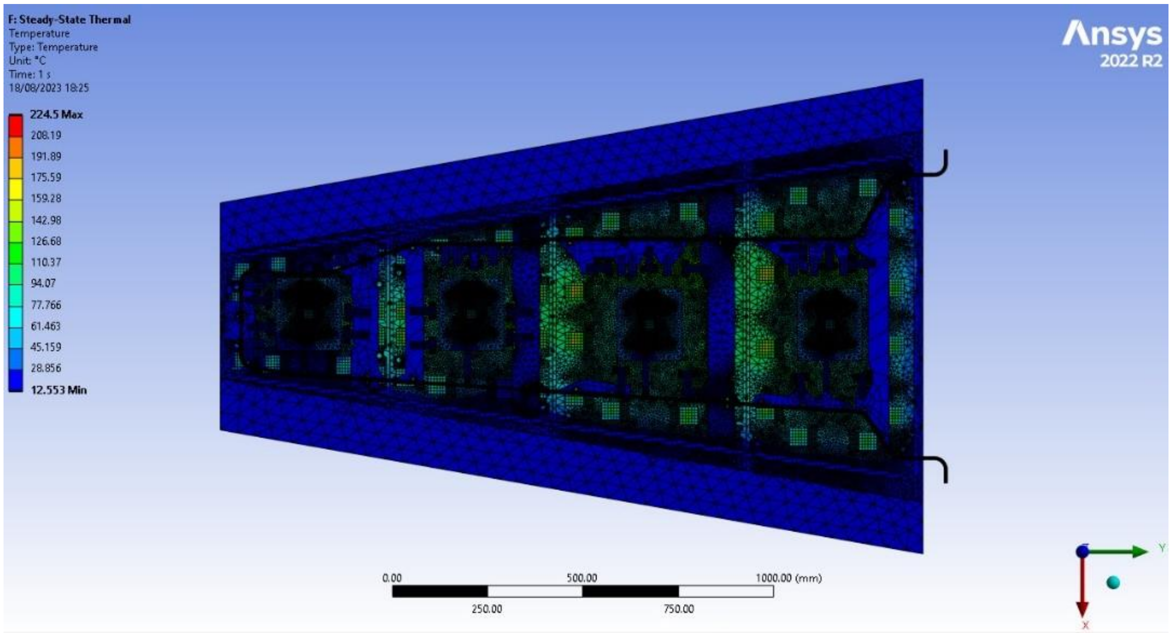

Figure 17: The Used Mesh

Below you can see the temperature results from the simulation. A maximum temperature of 225 and a minimum of 12 degrees Celsius is reached, which is completely different than the results we got from the measurements.

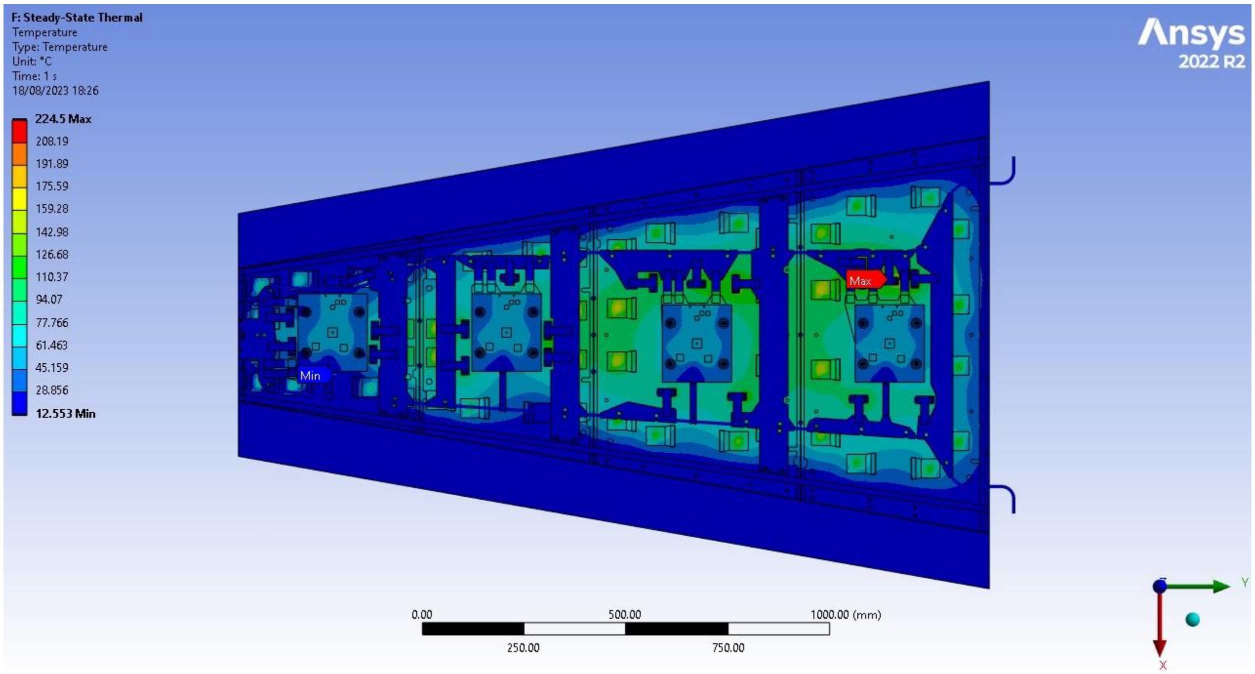

Figure 18: 1st Iteration

The reason for this huge difference is the assumptions we made and some known faults. The most important faults are:

- Replacing the thermal paste with the same element material without making sure that the heating elements are in direct contact with the cooling plate. Thus, the heat is not transferred by conduction and is only maintained inside the element yielding a huge rise in its temperature.
- Neglecting an important factor, which is defining convective surfaces on the heating elements.
- Assuming the inner surface of the pipe to have a constant temperature of 16 degrees Celsius, which means not simulating the fluid.
- Not checking the mesh quality metrics.
- Not performing mesh independence study.

Conclusion

To conclude, in order to get more accurate results, we should take the previous recommendations into consideration. More iterations are to be done in the following weeks with these guidelines to get results that can be compared to the measurements and start analyzing the cooling performance.