JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

"System of temperature regulation and stabilization for the MPD-TOF detector"

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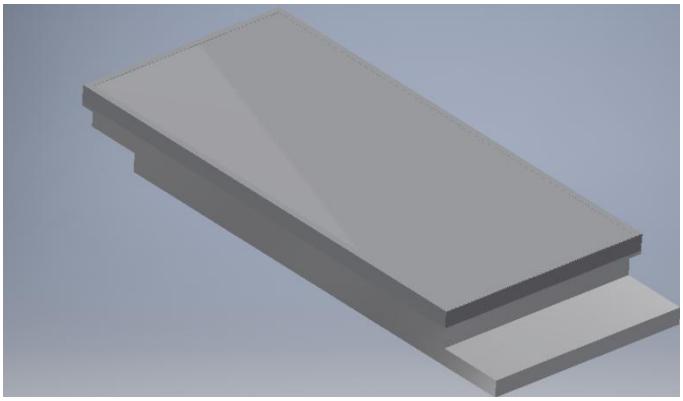

Picture 1. MPD-TOF detector created by myself in Autodesk Inventor 2018.

Dubna, 2017

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1. Theoretical admission.

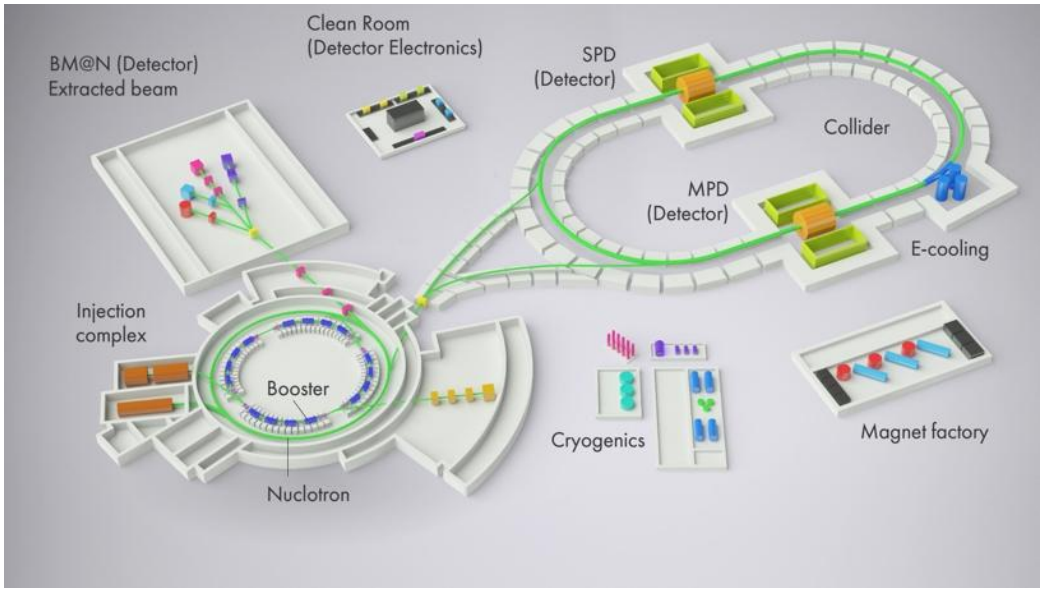
NICA (Nuclotron-based Ion Collider fAcility) is an accelerator complex designed in Dubna for the Joint Institute for Nuclear Research. The main task of that project is the examination of properties of dense baryonic matter.

The most important problems considered during NICA's experiments are:

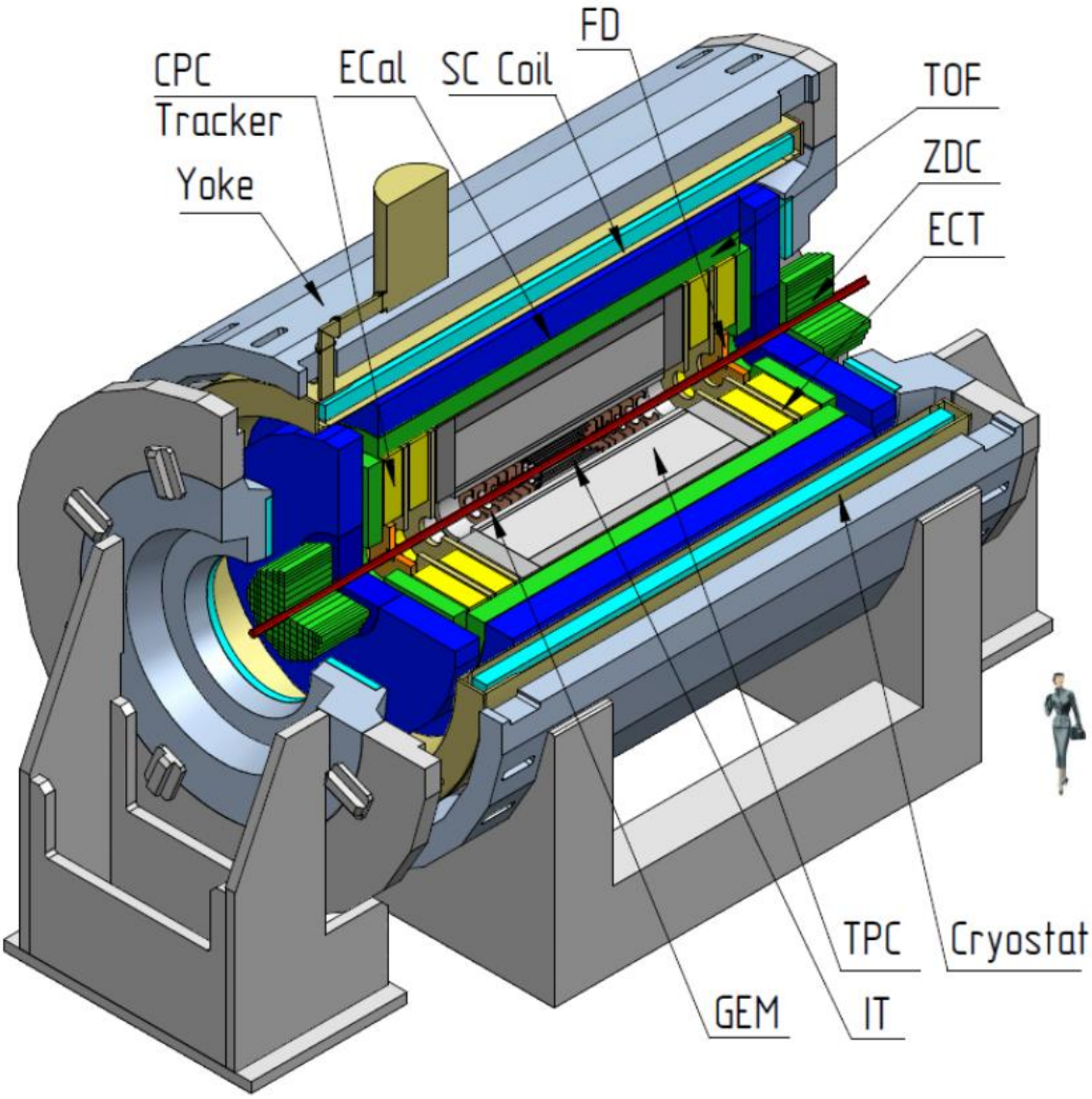
- the nature and properties of strong interactions between elementary constituents of the Standard Model (the Standard Model of particle physics is the theory describing three of the four known fundamental forces in the universe as well as classifying all known elementary particles)
- the search for signs of phase transition between hadronic matter and quark-gluon plasma (QGP)
- study of basic properties of the strong interaction vacuum and QCD symmetries

The part of NICA complex is MPD (Multi-Purpose Detector). The MPD is designed to register particles emitted during heavy ions collisions. Among the various components of the MPD is also the TOF (Time Of Flight detector). The main subject of my research during Summer Student Program 2017 was to analyse how temperature of environment affect temperature inside the MPD-TOF.

The NICA complex is depicted in the delineation attached bellow. The MPD is located on the right side of picture.



Picture 2. NICA (http://nica.jinr.ru/)



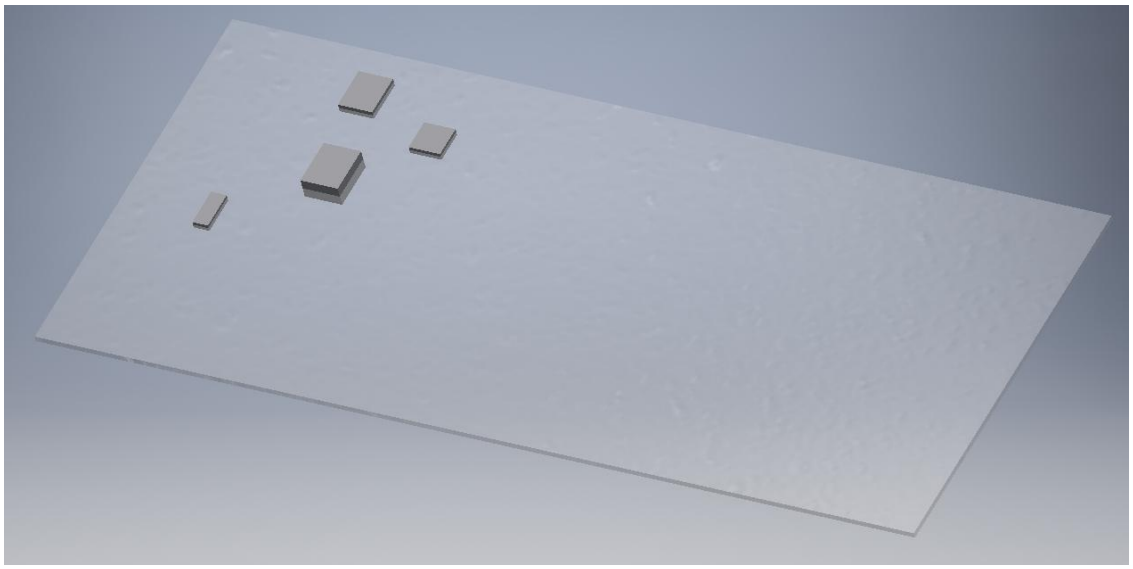
Picture 3. NICA Multi-Purpose Detector (MPD)

The MPD has been designed as a 4π spectrometer able to detect electrons, photons and charged hadrons in heavy-ion collisions in the energy range of the NICA collider. The detector is composed of the following subsystems showed in the *Picture 3*:

- SC Coil- SuperConductor solenoid
- IT- Inner Detector
- ECT- straw-tube tracker
- TPC- Time-Projection Chamber
- TOF- Time Of Flight system
- EMC- ElectroMagnetic Calorimeter
- FFD- Fast Forward Detectors
- ZDC- Zero Degree Calorimeter

2. Analysis of my results

At the beginning of my work I have created a prototypes model of MPD-TOF in the program *Autodesk Inventor 2018* (*Picture 1*).
As a material I used aluminum. The upper part of detector is filled with air. In the lower part is vacuum.



Picture 4. Acrylic plate with silicon elements.

In the *Picture 4* we can see four silicon elements on the acrylic plate. That model was created in program *Autodesk Inventor 2018.*
In program *Autodesk CFD 2018* I set suitable values of total heat generated by silicon elements: 0.015W, 0.07W, 0.182W, 0.195W.

My analysis was based on simulation of few situations where the MPD-TOF detector were located in different environment (I have changed the surrounding air temperature).
A part of my date is in table below.

T_e- temperature o environment (°C)
Number of iteration- measurements were made in time period. Iteration is understood as a number of measurement.

Table 1. Average temperature in the MPD-TOF detector.

Number of iteration	T_e=40°C	T_e=30°C	T_e=20°C	T_e=10°C	T_e=0°C	T_e=-10°C	T_e=-20°C	T_e=-30°C
1	40,00	30,00	20,00	10,20	0,00	-10,00	-20,00	-30,00
2	40,00	30,00	20,00	10,20	0,00	-10,00	-20,00	-30,00
3	40,00	30,00	20,00	10,20	0,00	-10,00	-20,00	-30,00
4	40,00	30,00	20,00	10,00	0,00	-10,00	-20,00	-30,00
5	40,00	30,00	20,00	10,19	0,00	-10,00	-20,00	-30,00
6	40,01	30,01	20,01	10,20	0,01	-9,99	-19,99	-29,99
7	40,01	30,01	20,01	10,01	0,01	-9,99	-19,99	-29,99
8	40,01	30,01	20,01	10,01	0,01	-9,99	-19,99	-29,99
9	40,02	30,02	20,02	10,02	0,02	-9,98	-19,98	-29,98
10	40,02	30,02	20,02	10,02	0,02	-9,98	-19,98	-29,98
11	40,02	30,02	20,02	10,03	0,03	-9,97	-19,98	-29,98
12	40,05	30,05	20,05	10,05	0,05	-9,95	-19,95	-29,95
13	40,09	30,09	20,09	10,09	0,09	-9,91	-19,91	-29,91

14	40,17	30,17	20,17	10,17	0,17	-9,83	-19,83	-29,83
15	40,31	30,31	20,31	10,31	0,31	-9,69	-19,69	-29,69
16	40,53	30,53	20,53	10,53	0,53	-9,47	-19,47	-29,47
17	40,85	30,85	20,85	10,85	0,85	-9,15	-19,15	-29,15
18	41,19	31,19	21,19	11,19	1,19	-8,81	-18,81	-28,81
19	41,49	31,49	21,49	11,49	1,49	-8,51	-18,51	-28,51
20	41,69	31,69	21,69	11,69	1,69	-8,31	-18,31	-28,31
21	41,80	31,80	21,80	11,80	1,80	-8,20	-18,20	-28,20
22	41,85	31,85	21,85	11,85	1,85	-8,15	-18,15	-28,15
23	41,88	31,88	21,88	11,88	1,88	-8,12	-18,12	-28,12
24	41,88	31,88	21,88	11,88	1,88	-8,12	-18,12	-28,12
25	41,88	31,88	21,88	11,88	1,88	-8,12	-18,12	-28,12
26	41,88	31,88	21,88	11,88	1,88	-8,12	-18,12	-28,12
27	41,87	31,87	21,87	11,87	1,87	-8,13	-18,13	-28,13
28	41,85	31,85	21,85	11,85	1,85	-8,15	-18,15	-28,15
29	41,84	31,84	21,84	11,84	1,84	-8,16	-18,16	-28,16
30	41,83	31,83	21,83	11,83	1,83	-8,17	-18,17	-28,17
31	41,81	31,81	21,81	11,81	1,81	-8,19	-18,19	-28,19
32	41,79	31,79	21,79	11,79	1,79	-8,21	-18,21	-28,21
33	41,77	31,77	21,77	11,77	1,77	-8,23	-18,23	-28,23
34	41,75	31,75	21,75	11,75	1,75	-8,25	-18,25	-28,25
35	41,73	31,73	21,73	11,73	1,73	-8,27	-18,27	-28,27
36	41,70	31,70	21,70	11,70	1,70	-8,30	-18,30	-28,30
37	41,68	31,68	21,68	11,68	1,68	-8,32	-18,32	-28,32
38	41,65	31,65	21,65	11,65	1,65	-8,35	-18,35	-28,35
39	41,62	31,62	21,62	11,62	1,62	-8,38	-18,38	-28,38
40	41,59	31,59	21,59	11,59	1,59	-8,41	-18,41	-28,41
41	41,56	31,56	21,56	11,56	1,56	-8,44	-18,44	-28,44
42	41,53	31,53	21,53	11,53	1,53	-8,47	-18,47	-28,47
43	41,50	31,50	21,50	11,50	1,50	-8,50	-18,50	-28,50
44	41,47	31,47	21,47	11,47	1,47	-8,53	-18,53	-28,53
45	41,43	31,43	21,43	11,43	1,43	-8,57	-18,57	-28,57
46	41,40	31,40	21,40	11,40	1,40	-8,60	-18,60	-28,60
47	41,37	31,37	21,37	11,37	1,37	-8,63	-18,63	-28,63
48	41,34	31,34	21,34	11,34	1,34	-8,66	-18,66	-28,66
49	41,31	31,31	21,31	11,31	1,31	-8,69	-18,69	-28,69
50	41,28	31,28	21,28	11,28	1,28	-8,72	-18,72	-28,72
51	41,25	31,25	21,25	11,25	1,25	-8,75	-18,75	-28,75
52	41,23	31,23	21,23	11,23	1,23	-8,77	-18,77	-28,77
53	41,20	31,20	21,20	11,20	1,20	-8,80	-18,80	-28,80
54	41,18	31,18	21,18	11,18	1,18	-8,82	-18,82	-28,82
55	41,16	31,16	21,16	11,16	1,16	-8,84	-18,84	-28,84
56	41,14	31,14	21,14	11,14	1,14	-8,86	-18,86	-28,86
57	41,12	31,12	21,12	11,12	1,12	-8,88	-18,88	-28,88
58	41,11	31,11	21,11	11,11	1,11	-8,89	-18,89	-28,89
59	41,09	31,09	21,09	11,09	1,09	-8,91	-18,91	-28,91
60	41,08	31,08	21,08	11,08	1,08	-8,92	-18,92	-28,92
61	41,07	31,07	21,07	11,07	1,07	-8,93	-18,93	-28,93
62	41,06	31,06	21,06	11,06	1,06	-8,94	-18,94	-28,94
63	41,05	31,05	21,05	11,05	1,05	-8,95	-18,95	-28,95
64	41,04	31,04	21,04	11,04	1,04	-8,96	-18,96	-28,96
65	41,04	31,04	21,04	11,04	1,04	-8,96	-18,96	-28,96
66	41,03	31,03	21,03	11,03	1,03	-8,97	-18,97	-28,97
67	41,03	31,03	21,03	11,03	1,03	-8,97	-18,97	-28,97
68	41,02	31,02	21,02	11,02	1,02	-8,98	-18,98	-28,98
69	41,02	31,02	21,02	11,02	1,02	-8,98	-18,98	-28,98
70	41,02	31,02	21,02	11,02	1,02	-8,98	-18,98	-28,98
71	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
72	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
73	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
74	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
75	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
76	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
77	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
78	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
79	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
80	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
81	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
82	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
83	41,01	31,01	21,01	11,20	1,20	-8,99	-18,99	-28,99
84	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
85	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
86	41,01	31,01	21,01	11,20	1,20	-8,99	-18,99	-28,99
87	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
88	41,01	31,01	21,01	11,20	1,20	-8,99	-18,99	-28,99

89	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
90	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
91	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
92	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
93	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
94	41,01	31,01	21,01	11,20	1,01	-8,99	-18,99	-28,99
95	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
96	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
97	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
98	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
99	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99
100	41,01	31,01	21,01	11,01	1,01	-8,99	-18,99	-28,99

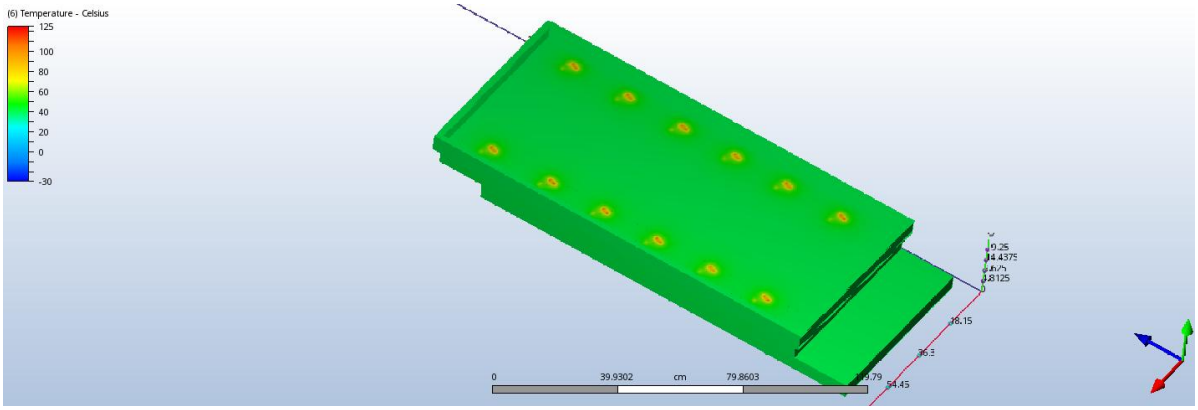
During simulations in *Autodesk CFD 2018*, differential equations have been solved. That is why value of first iteration might be wrong (different than temperature of environment).

Temperature inside detector is expressed by equation:

$$T = T_{complate} - T_e$$

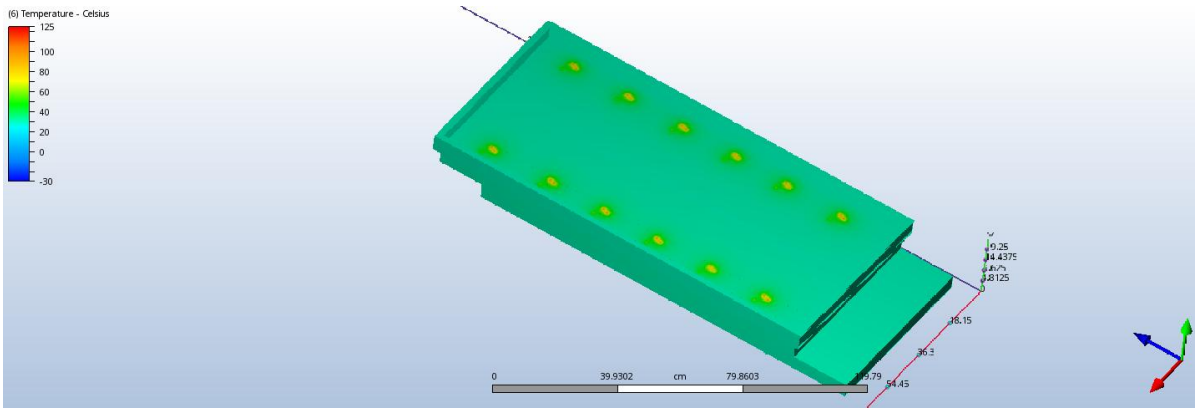
, where $T_{complate}$ is showed in *Table 1*.

Below I attached pictures showing how temperature changes affected the inside upper part of the MPD-TOF. The pictures were generated in program *Autodesk CFD 2018.*



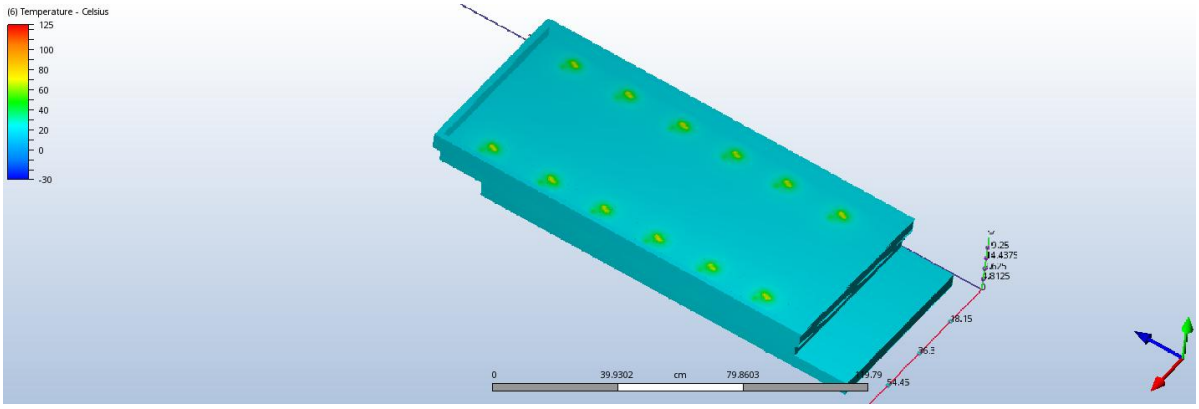
Picture 5. The MPD-TOF detector at a temperature of 40°C

As we can see, temperature in some places inside detector is much higher than 40°C. The highest temperature in the *Picture 5* is almost 120°C. It is also the highest temperature I have noted during my simulations.



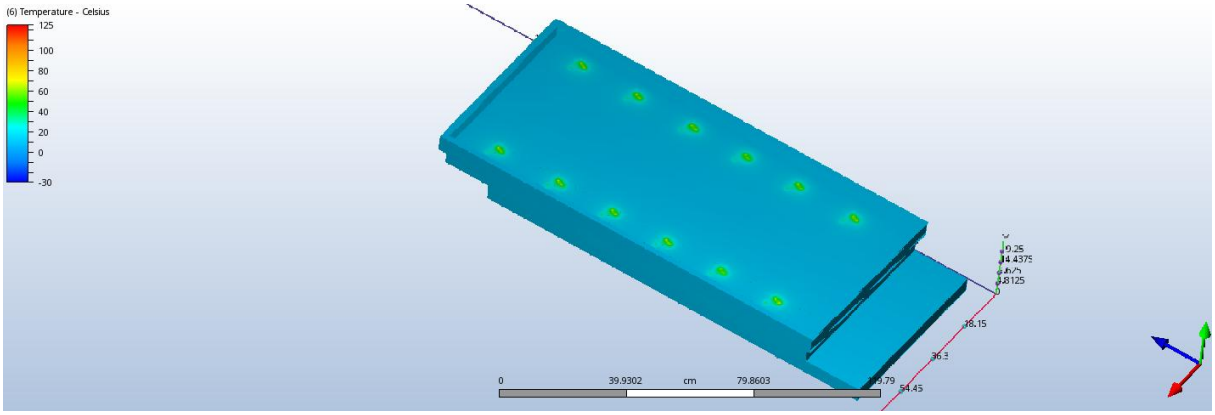
Picture 6. The MPD-TOF detector at a temperature of 30°C

In the *Picture 6* we can observe that temperature on silicon elements is still higher than 100°C.

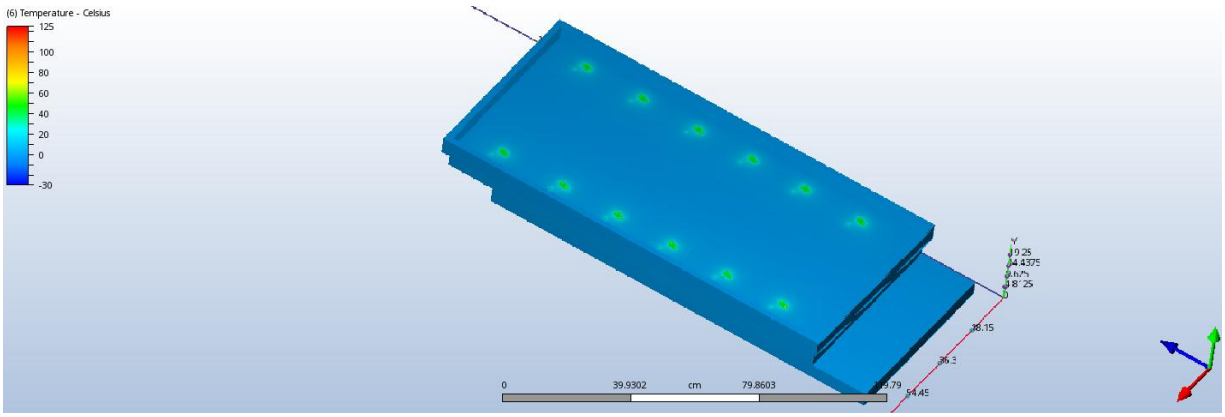


Picture 7. The MPD-TOF detector at a temperature of 20°C

If we put the detector in ambient temperature of 20°C the temperature of silicon element will be lower than 100°C.

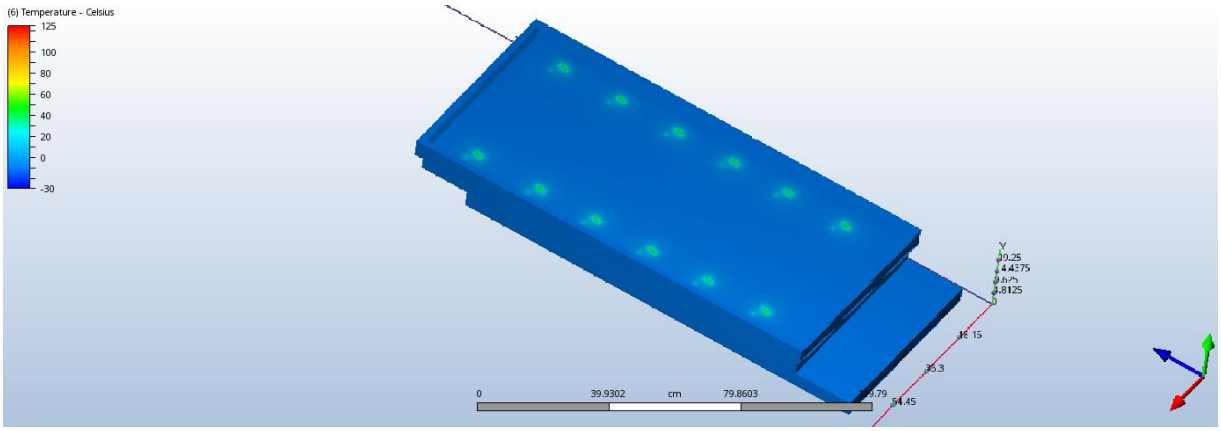


Picture 8. The MPD-TOF detector at a temperature of 10°C

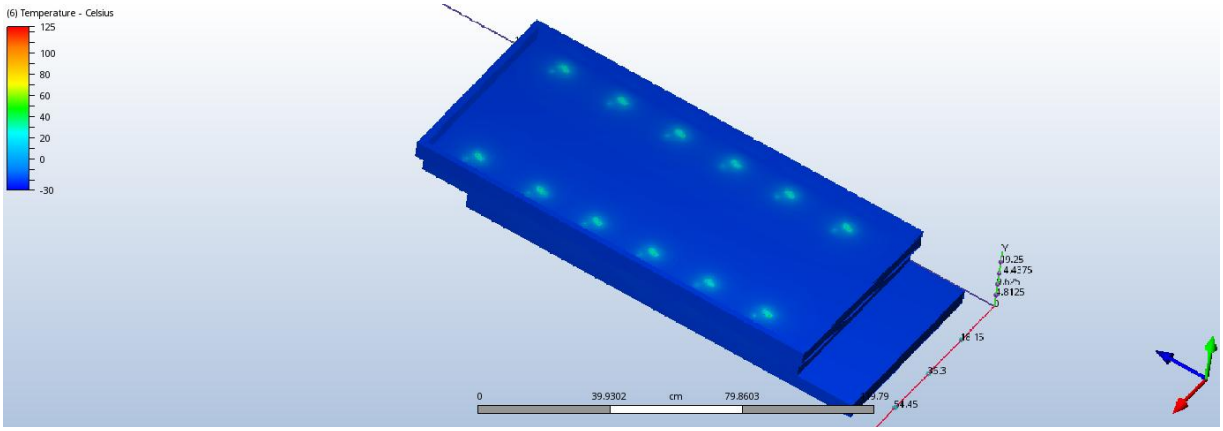


Picture 9. The MPD-TOF detector at a temperature at a 0°C

In ambient temperature of 0°C the temperature of the hottest elements oscillate between 40°C and 60°C.

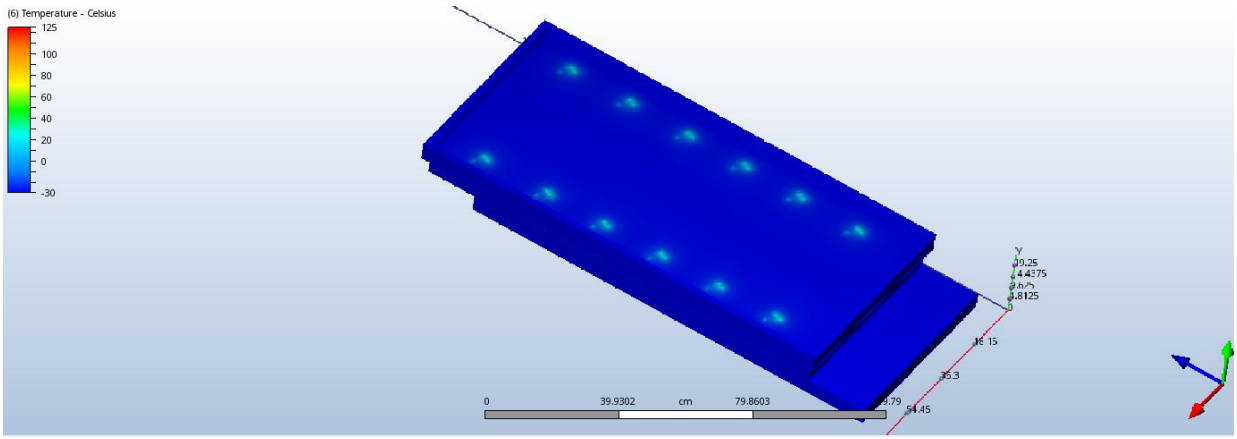


Picture 10. The MPD-TOF detector at a temperature of -10°C



Picture 11. The MPD-TOF detector at a temperature of -20°C

Under the above conditions the temperature inside is much lower than 40°C.



Picture 12. The MPD-TOF detector in temperature of -30°C

According to our prediction the temperature of heat generating elements is the lowest in the lowest ambient temperature. Under these conditions the highest noted temperature is lower than 25°C.

Below I enclose charts present how the temperature was changing as a function of time.
As I mentioned under *Table 1*, the differential equations were solved during simulations and they were converge to a constant value.

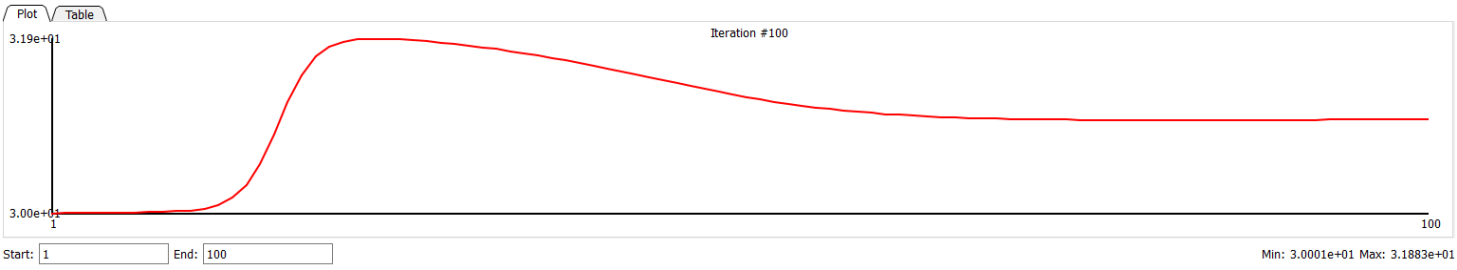


Chart 1. Temperature of complex in ambient temperature *of 40°C*

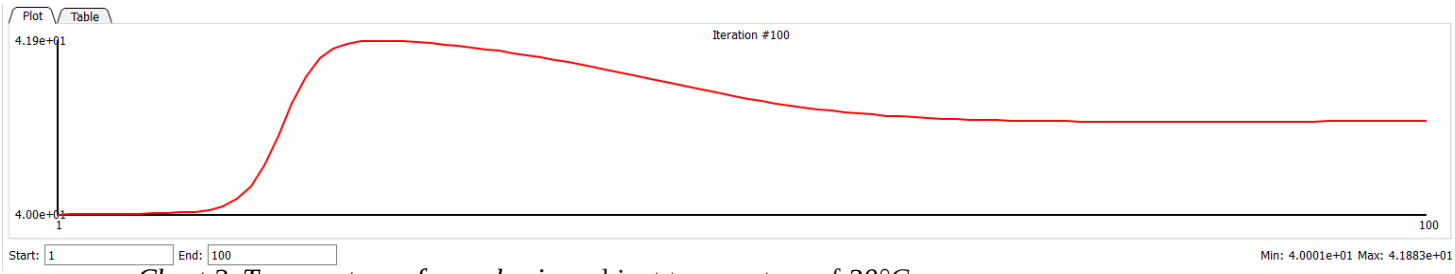


Chart 2. Temperature of complex in ambient temperature of *30°C*

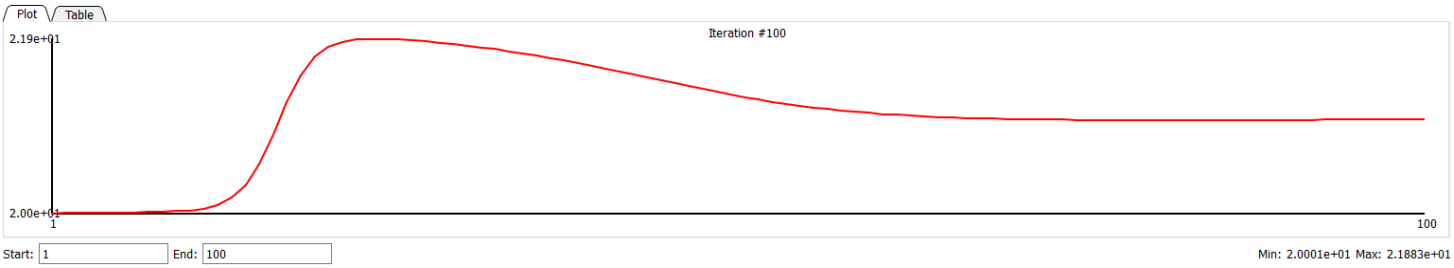


Chart 3. Temperature of complex in ambient temperature *of 20°C*

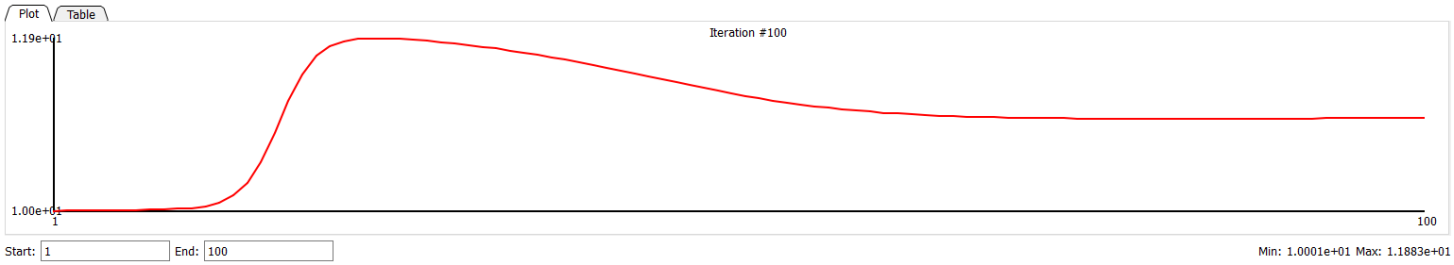


Chart 4. Temperature of complex in ambient temperature *10°C*

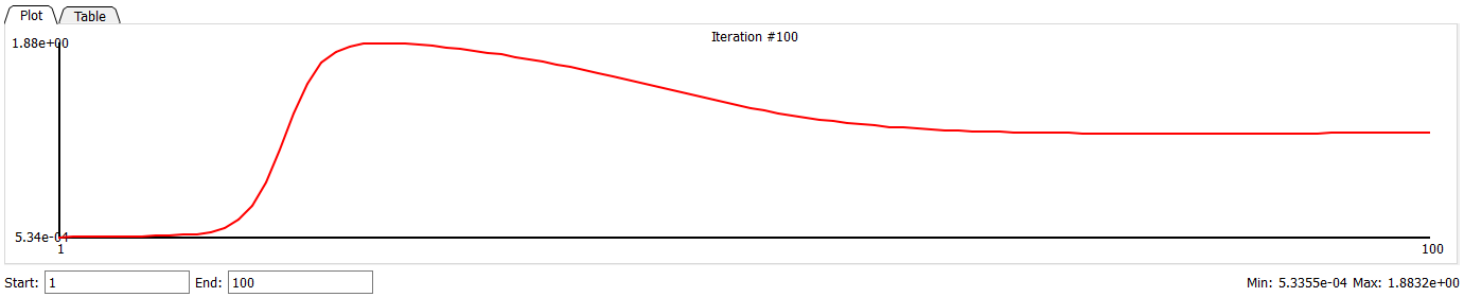


Chart 5. Temperature of complex in ambient temperature *of 0°*

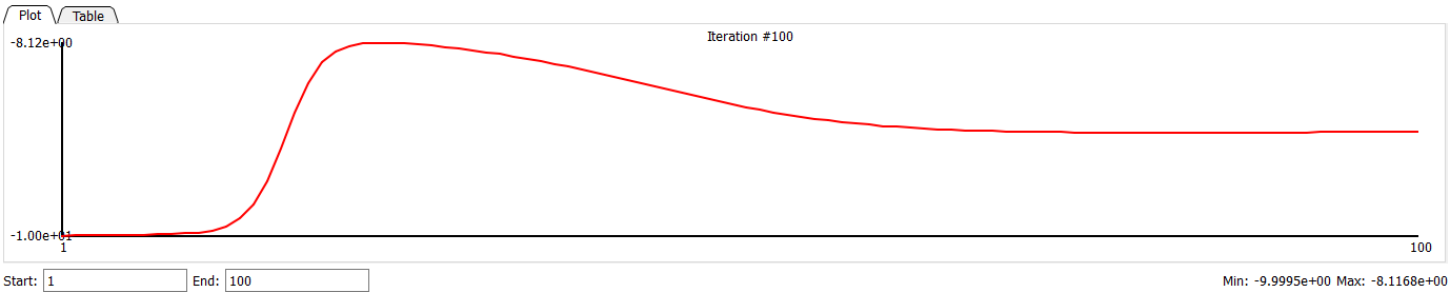


Chart 6. Temperature of complex in ambient temperature *of -10°C*

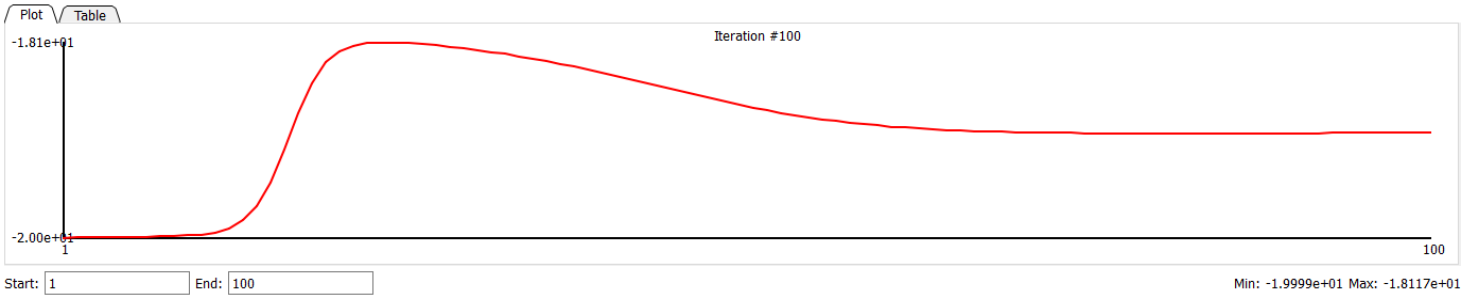


Chart 7. Temperature of complex in ambient temperature *of -20°C*

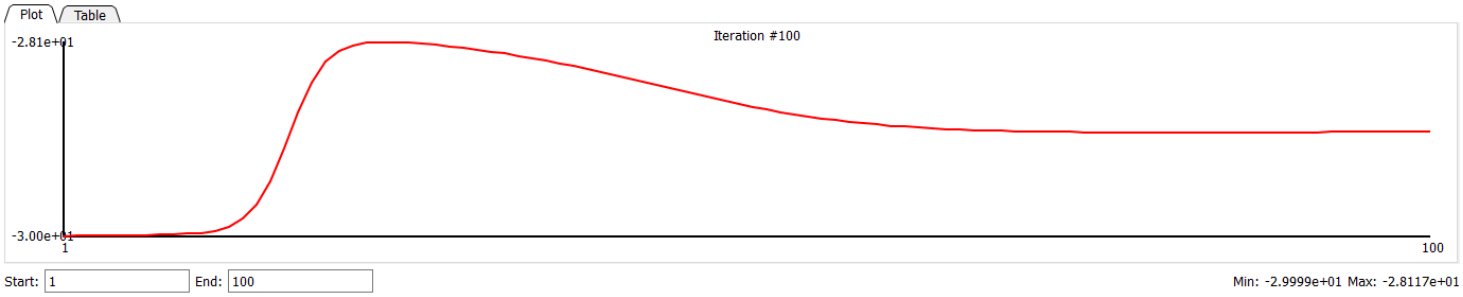


Chart 8. Temperature of complex in ambient temperature of *-30°C*

All of the above pictures are quite similar. The shape differences are very small, almost invisible. The biggest difference is between values where charts settle on.

3. Summary

My results are satisfying. The MPD-TOF detector might be a little overheated during the work in high ambient temperature (more than 30°C), because at that time the temperature of silicon will be higher than 70°C. Although there will be no permanent damaged, because the silicon melting temperature is 1400°C. 70°C is too much for silicon and integrated circuits may not work too efficiently. The highest temperature inside upper chamber where integrated circuits are located was not much higher than 120°C. Because of low thermal conductivity of acrylic plates, they are good separator between hot elements and the rest of detector.
During my research at Summer Student Program I had a few problems with the software.
At first I had problem with compatibility of *Autodesk Inventor 2018* and *Autodesk CFD 2018*, but the problem was solved after replacing detailed made model of synthetic plate with a simpler one. I also had problem with simulation, but it was only because I choose wrong options in *Autodesk CFD 2018* which was absolutely a new program for me. As far as I know that it is very useful program and I might have opportunity to use it again soon.
I will mention about the fact that during my internship I also participated in the creation of cooling system of RACK (RACK is defined as a standardized frame for mounting multiple electronic equipment modules) for Slow Control (SCS). I will not write more about it, because it is not part of my SSP topic.
I believe that my work during program was well done and someone will use it in the nearest future.

4. Bibliography

- http://nica.jinr.ru/ (theoretical admission)
- https://indico.cern.ch/event/629532/ (summary)