Cooling Analysis of HVMAPS detector for Compton Polarimeter in Hall A

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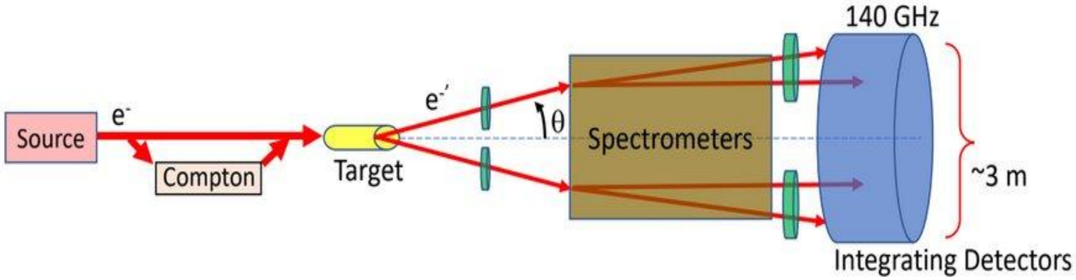
MOLLER (Measurement of Lepton-Lepton Electroweak Reaction) Experiment:

- MOLLER experiment will run at the Thomas Jefferson National Accelerator Facility, Virgina, USA.
- It will use high intensity high energy polarized electron beam.
- The experiment will be located in hall A.
- It is scheduled to commence in 2025-2026.
- MOLLER plans to take a longitudinal polarized beam of electrons, provided by JLab's Continous Electron Beam Accelerator Facility (CEBAF), scattering them off the unpolarised electrons in a liquid hydrogen target.

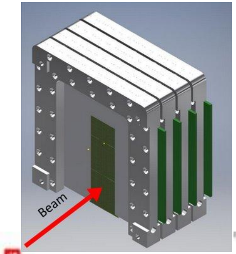


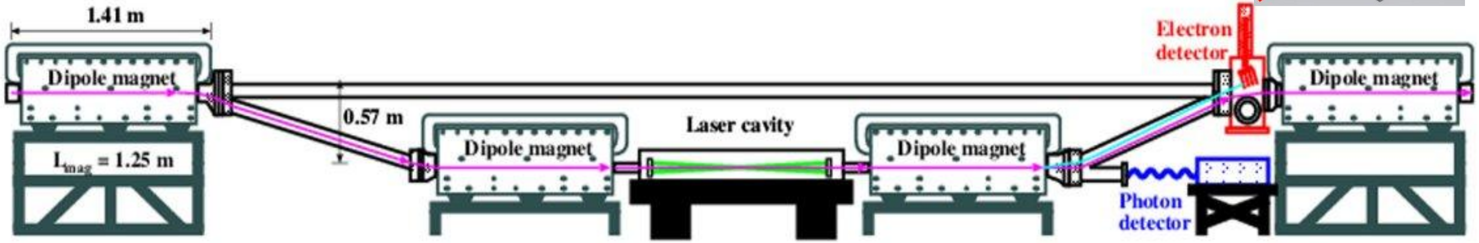
Experimental Setup

Thomas Jefferson National Accelerator Facility (JLab), Newport News, Virginia (USA).

Compton Polarimeter:

- The Compton Polarimeter is located in a chicane.
- It is about 15 m long.
- Chicane series consists of four dipole magnets.
- Momentum analyzation technique is used to separate the compton scattered electrons.
- There are plans to upgrade current setup of the electron detector with High Voltaic Monolithic Active Pixel Sensors (HVMAPS) technology.





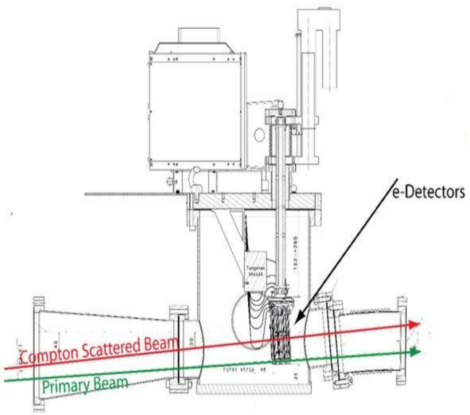
Motivation:

- The motivation of this experiment is to perform the cooling analysis of the designs of the Electron Detector to be placed behind the Dipole field D3 of the Compton Polarimeter in Hall A of the JLab.

- The development of silicon pixel detectors based on High Voltaic Monolithic Active Pixel Sensors (HVMAPS) technology is underway for the Electron detector.

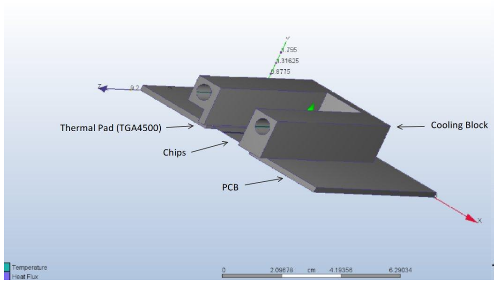
- The design includes integration of four pixel detector planes with each plane accommodating 3 (2 X 2 cm^2) chips. Each chip operates at 1W and will contain 64,000 (80 X 80 μm2) silicon pixel diodes (for the current experiment dummy chips have been used and heater is attached to them to deposit 3W of power over the chips).

- We designed the electron detector models keeping in mind all the cooling possibilities..

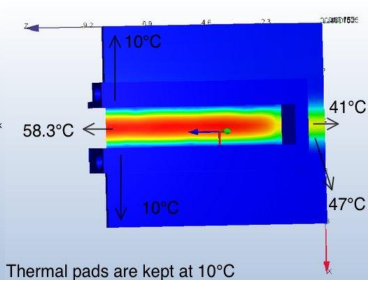


Cooling Analyses for the models:

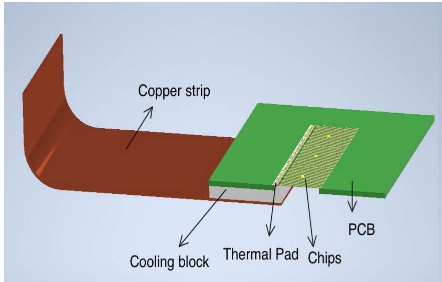
Chips: silicon, Thermal Pad: TG A4500, Cooling block: Aluminum (The CAD models have been modified by **Nafis Rafat Niloy**, PhD student, Department of Physics and Astronomy, the metal core PCB design was suggested and produced by **Dr. Jie Pan,** Postdoc in the MOLLER group.)



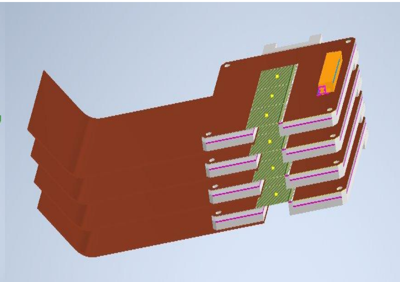
Model 1



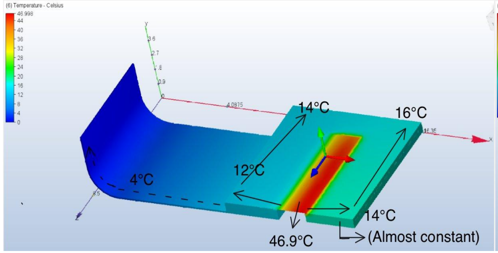
Simulation results from model 1



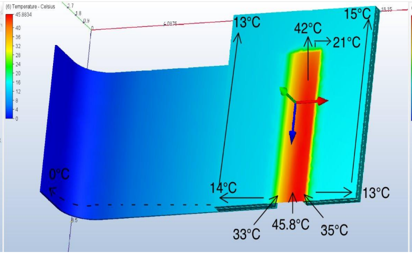
Model 2 with Cooling strip



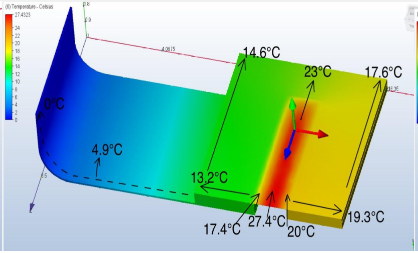
Model 3 with metal core PCB



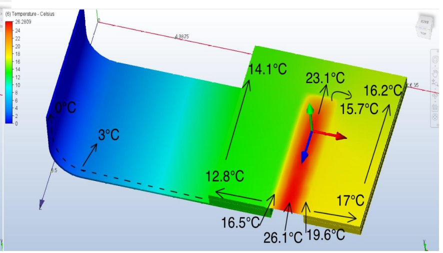
PCB: FR4
Cooling Block: Aluminum



PCB: FR4
Cooling Block: Copper



PCB: Aluminum
Cooling Block: Aluminum



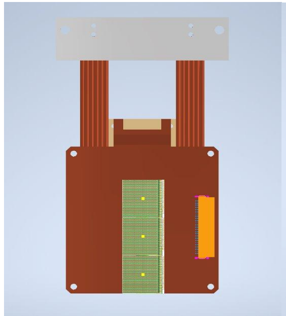
PCB: Aluminum
Cooling Block: Copper

Simulation results from model 3

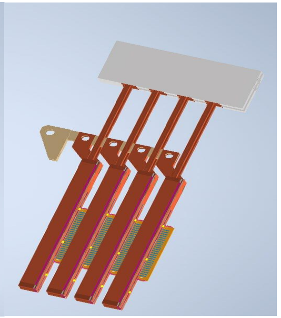
Cooling Analyses for the models:

- Cooling block: Copper
- Chips: Silicon
- Thermal Pad: TG A4500
- PCB: Metal Core
- Cooling strip: Copper.
- Thermal block : Aluminum

Model 6 with Heat Exchanger

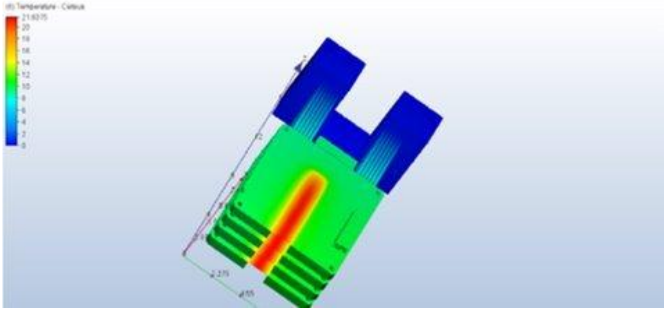


Front View



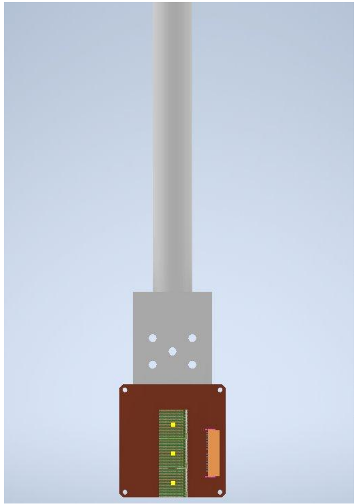
Side View

Simulation Results for Model 6



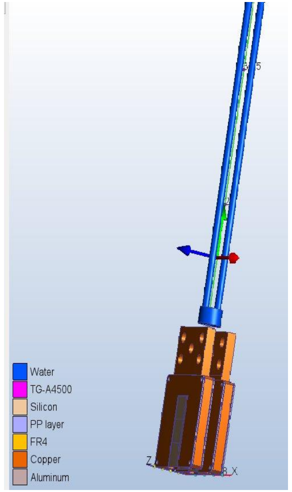
Cooling solution with new HVMAPS mounting and cooling structure:

Previous Model

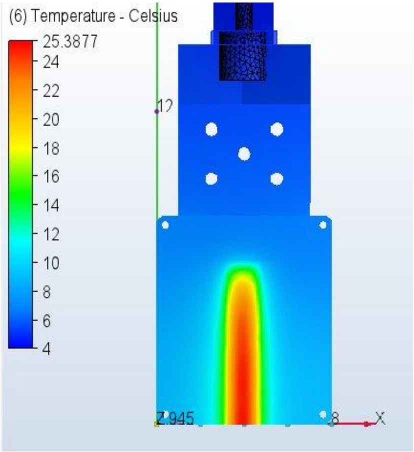


Front View

Side View with coolant passage



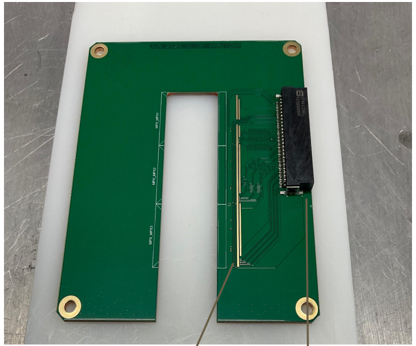
Water as Coolant



Simulation Results

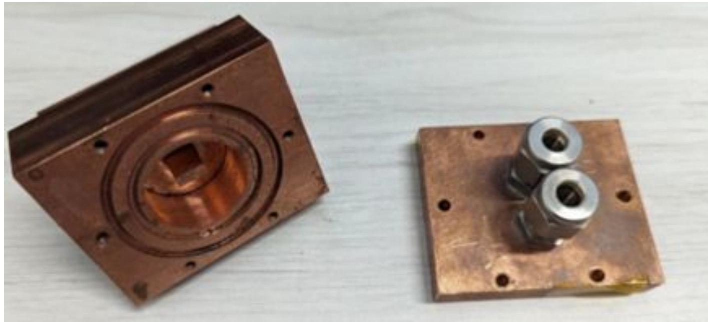
PCB, Dummy Chips and other machined parts:

(The parts are machined by the other members in the MOLLER Groups.)



PCB

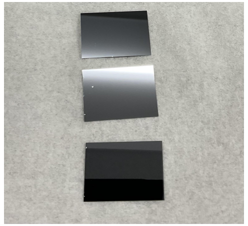
Cooling blocks



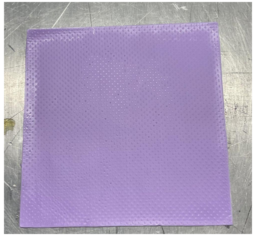
Heat Exchanger and coolant feed through system

Readout side of PCB

J1 Connector

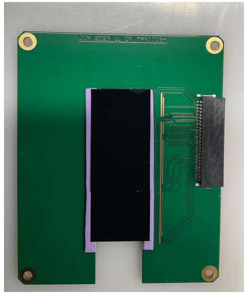


Silicon wafer chips



Thermal Pad

Integrating the parts together

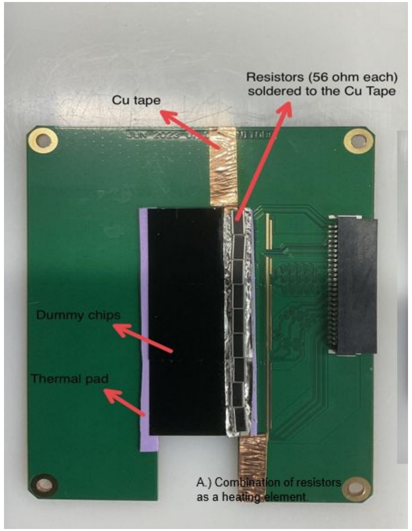


Assembling of chips over PCB

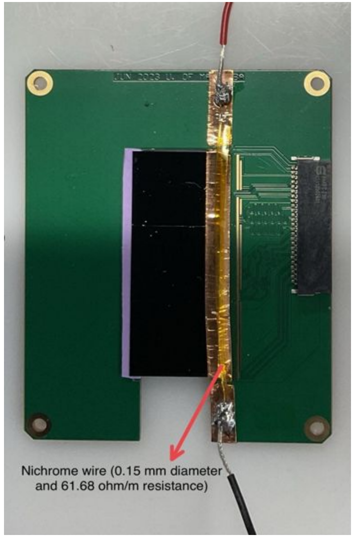
Dummy HVMAPS assembly with Nichrome wire vs Resistor:

We tried making heating element with two possibilities:

A.)Combination of resistors as heating element	B.)Nichrome wire as a heating element
Advantages of using Resistors: a) Properly soldered, so no worry of loose connection. b) Usually have a longer operational life as compared to Nichrome wire (In our short-term setup it would not matter much).	**Advantages of using Nichrome wire:** a) Simple to use(due to its flexibility) and easy to solder. b) Has high electrical resistance, so can dissipate a significant amount of power as heat. c) Fast response time.
Limitations of using Resistors: a) It is difficult to make a copper trace using tape and stick it onto the chips as one need to lay down copper tape on the delicate chips as traces for the resistors to be soldered on, while this was not required for the nichrome wire. b) The copper tape may have poor adhesion and thermal contact.	**Disadvantages of using Nichrome wire:** a) Secure connection of the wire to the chip is crucial,otherwise it would be difficult to fix once the assembly goes into the vacuum. Thermal epoxy was used to ensure proper heat conduction.

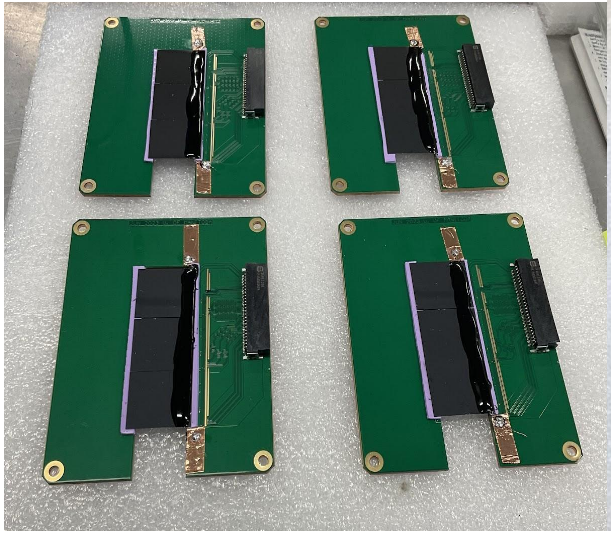


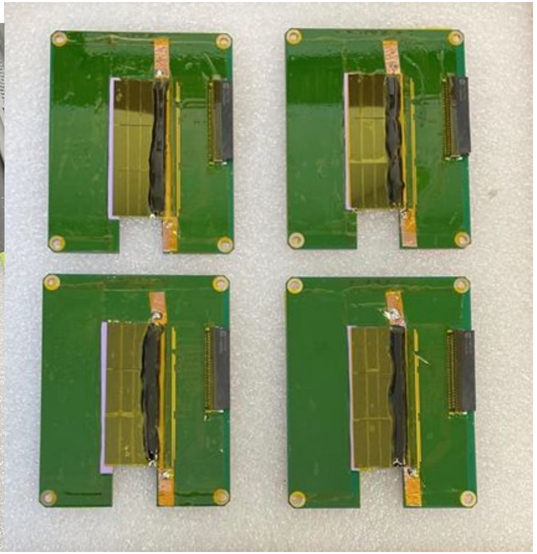
A.) Combination of resistors as a heating element



B.) Nichrome wire as a heating element

Nichrome wire final heater assemblies:





Electrical characteristics of the heaters for 3 W of power deposited onto the chip assembly:

Plane1

R_h= 4.57 Ω
Vsupply = 3.79 V
V_h = 3.6103 V
Isupply = 0.7973 A
P_1 = (3.79).(0.7913) = 3.022 Watt

Plane2

R_h = 4.52 Ω
Vsupply = 3.79 V
V_h = 3.6004 V
Isupply = 0.8038 A
P_2 = (3.79).(0.8038) = 3.015 Watt

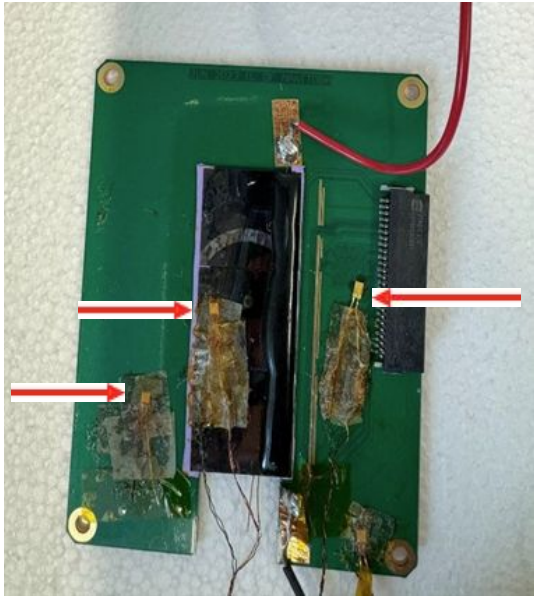
Plane3

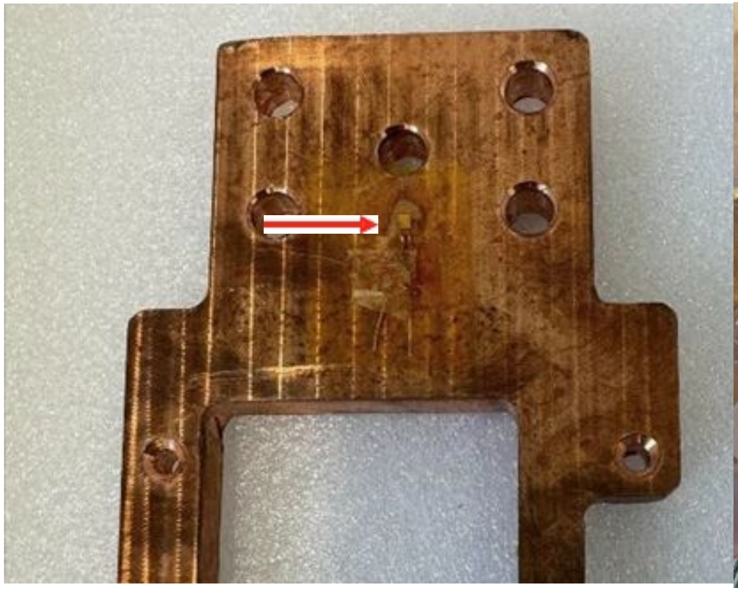
R_h = 4.52 Ω
Vsupply = 3.75 V
V_h = 3.5972V
Isupply = 0.8052 A
P_3 = (3.75).(0.8052) = 3.01725 Watt

Plane4

R_h = 4.86 Ω
Vsupply = 3.89 V
V_h = 3.7537 V
Isupply = 0.7785 A
P_4 = (3.89).(0.7785) = 3.027 Watt

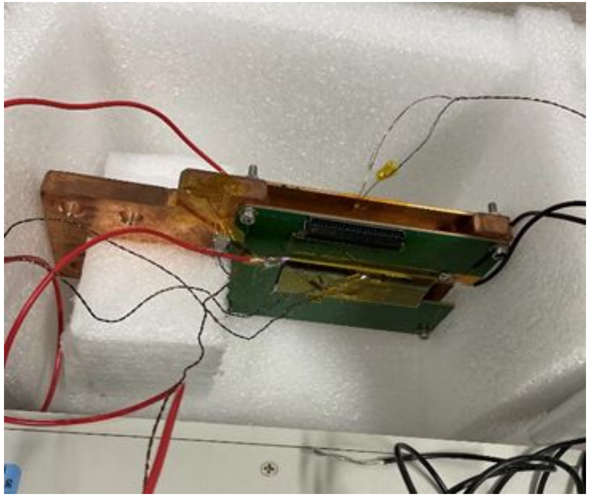
Placement of Temperature Diodes:

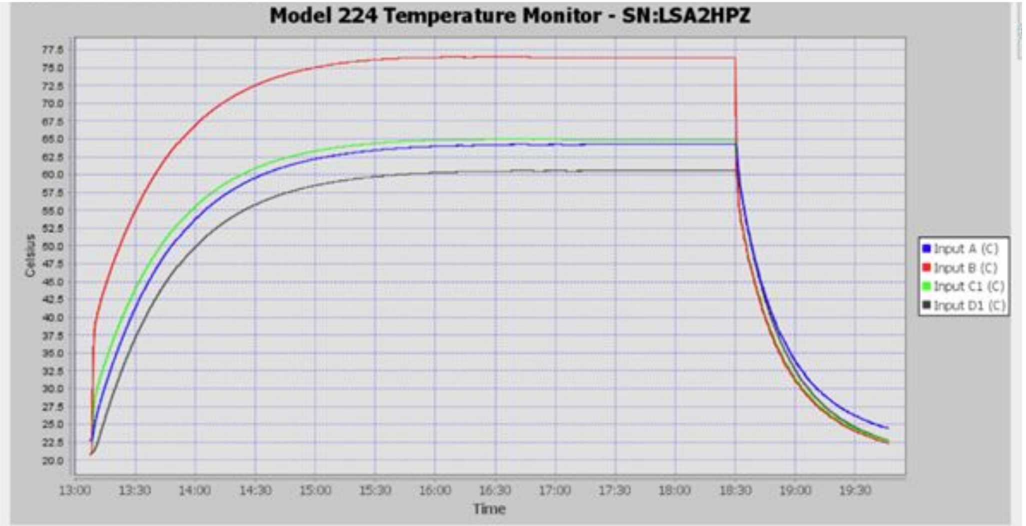




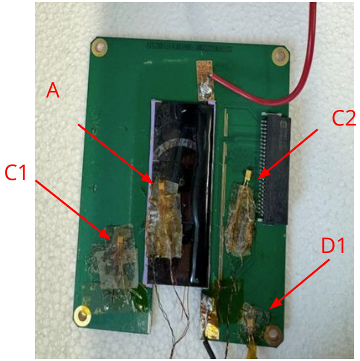
Temperature measurement with two planes (including cooling block in the arrangement):

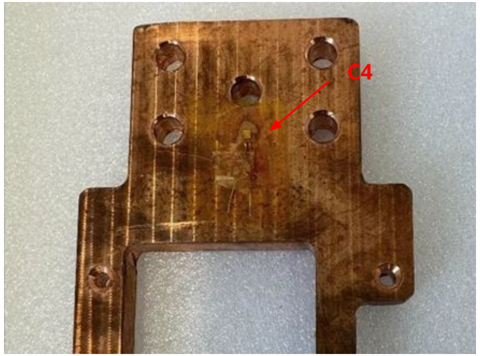
- Input A (C) : Sensor attached to the backside of the PCB
- Input B (C) : Sensor attached to the heater (over the epoxy)
- Input C1 (C) : Sensor attached to the opposite side of the heater/periphery of the chip.
- Input D1(D) : Sensor attached to the cooling block
- Run time : 6 hours 30 mins.
- Power = 6 watt

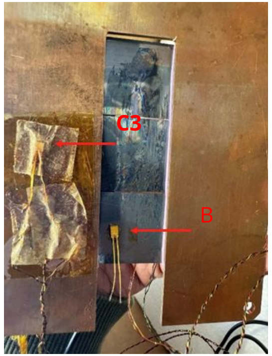


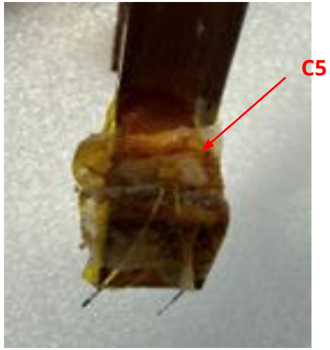


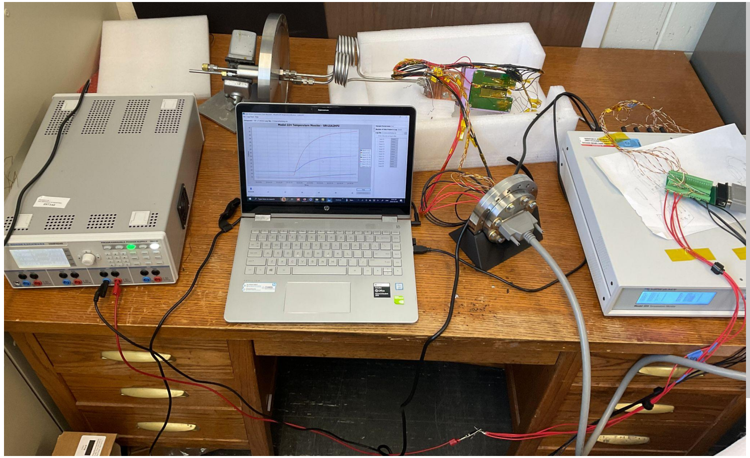
Temperature measurement with the complete assembly:

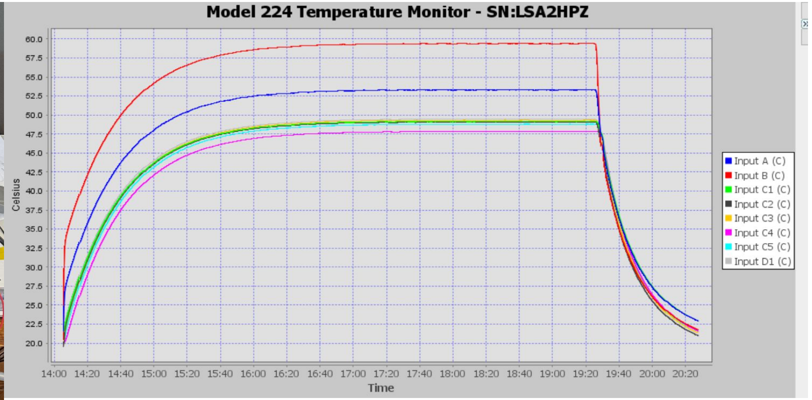










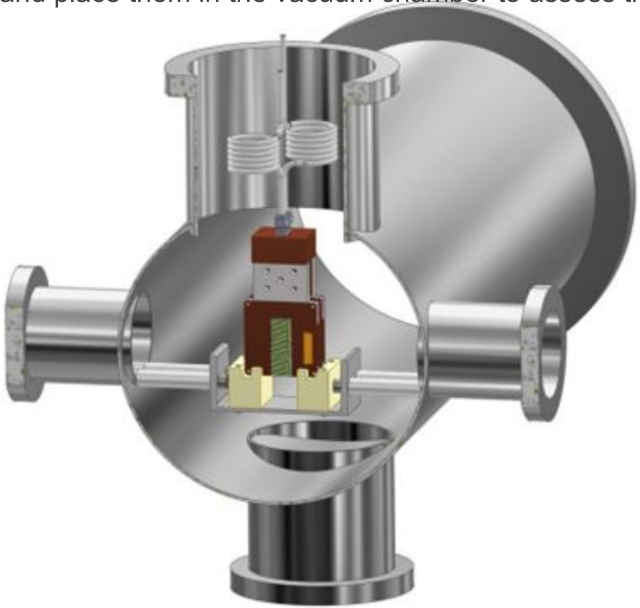


The placement of the sensors/inputs is mentioned in above pictures.

Vacuum Chamber Assembly

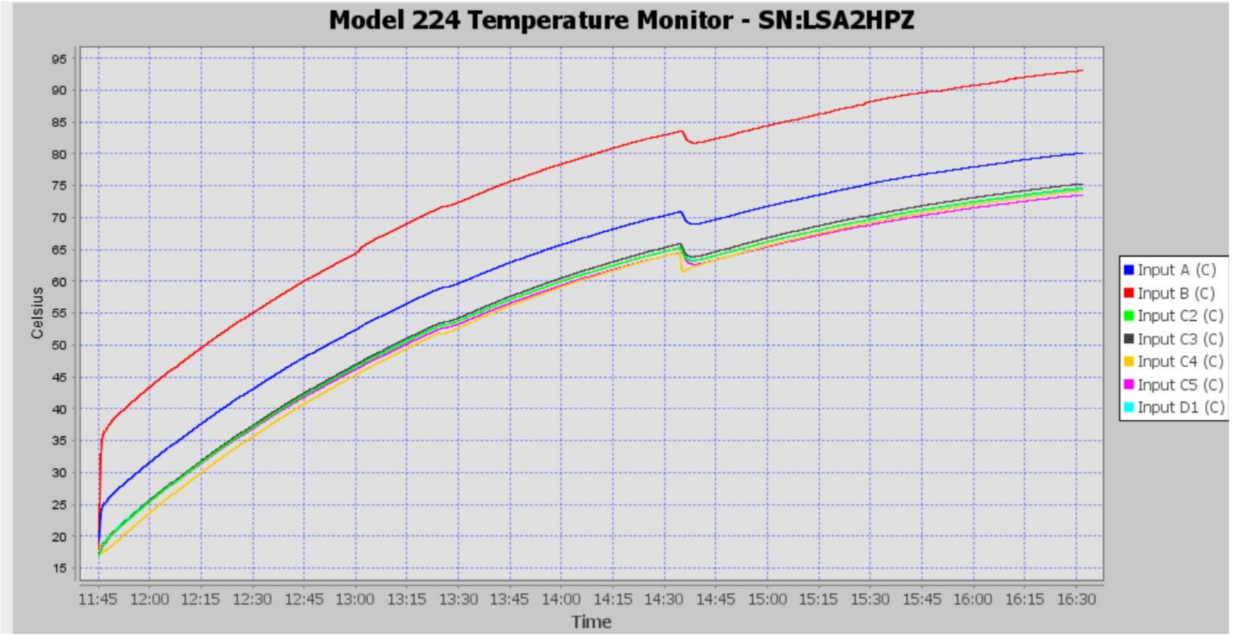
We assembled four e-detector planes using this dummy chip and heater configuration, and place them in the vacuum chamber to assess the heating.

Vacuum chamber existing in UoM, Winnipeg.



CAD of the vacuum chamber with prototype of e-detector setup placed inside it.

First Analysis inside the vacuum chamber without coolant:

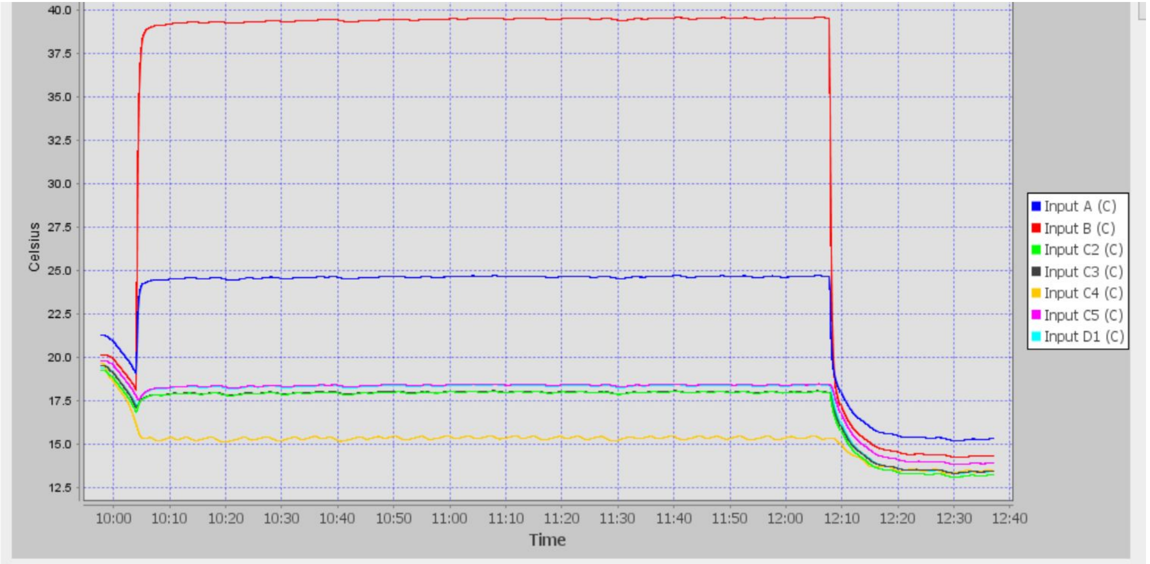


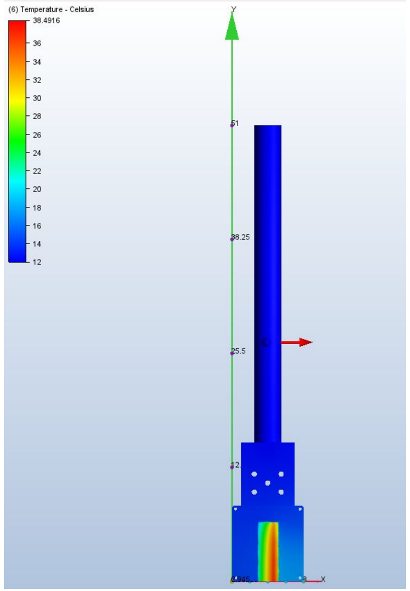
- Power supplied: 12W

Comparison of the Lab Measurements with the CFD Simulations:

Our aim is to compare the temperature gradient at various positions of the prototype functioning inside the vacuum with the computationally modeled thermal simulations of the same model.

Power: 12 W , Temperature of the Coolant: 12 degrees Celsius.





Comparison of the Lab Measurements with the CFD Simulations:

Power(W)	Temp. of the Coolant (°C)	Experimental Results (°C)	CFD Simulation Results (°C)	Difference(°C)
6	4	20.8	17.3	2.8
6	8	24.1	21.3	2.8
6	12	27.7	25.2	2.4
6	16	33	29.2	3.7
12	4	33.5	30.5	3
12	8	36	34.4	1.6
12	12	39	38.4	0.5
12	16	47	42.5	5
15	4	43	37.1	5.9
15	8	46	41.1	4.8
15	12	49	45.1	3.8
15	16	55	49.1	5.9

All the tests were performed under the supervision of **Laheji Mohammad**, Postdoc in the MOLLER group.

Conclusion and next steps:

- HV-MAPS are required to perform the measurement with more precision as it provides better spacial resolution and less noise to signal ratio.

- Cooling is necessary for in vacuum operation of these detectors as we saw nearly 95 degrees celsius rise without the coolant.

- The simulations performed on CFD are in close to the data collected during Lab tests.

- The next steps are to bond the real HVMAPS chips to the PCB and run the similar tests within a beamline facility.

Thank You for Listening!

I am in the process of concluding my Master’s at the University of Manitoba, I'm open to future opportunities. Contact: prabhak2@myumanitoba.ca