Compton Electron Detector for the MOLLER Experiment

MOLLER Collaboration Meeting

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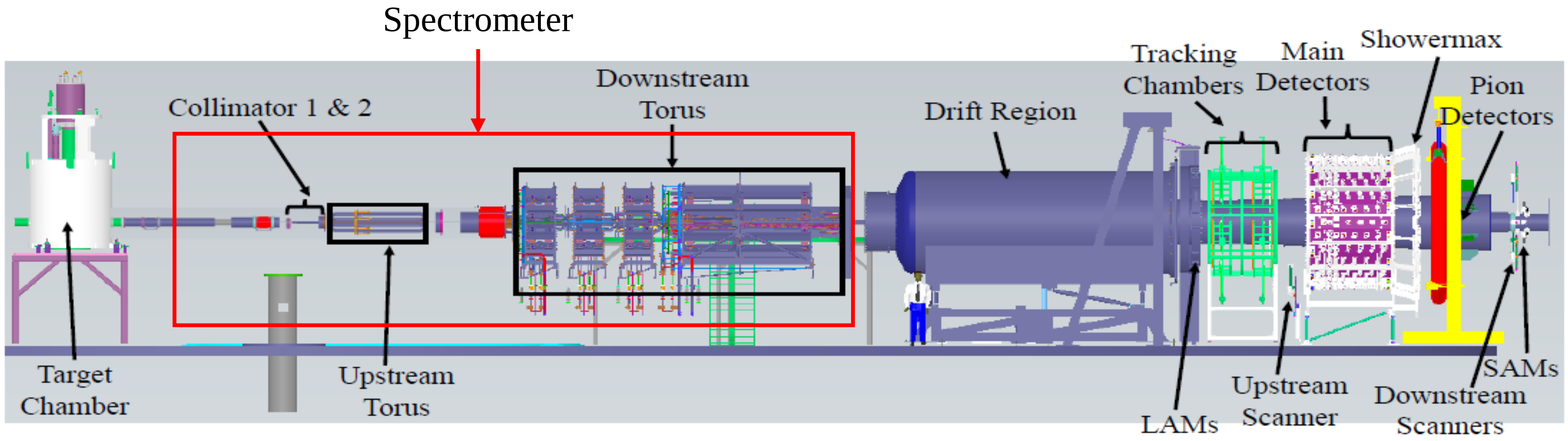
MOLLER Experimental Setup



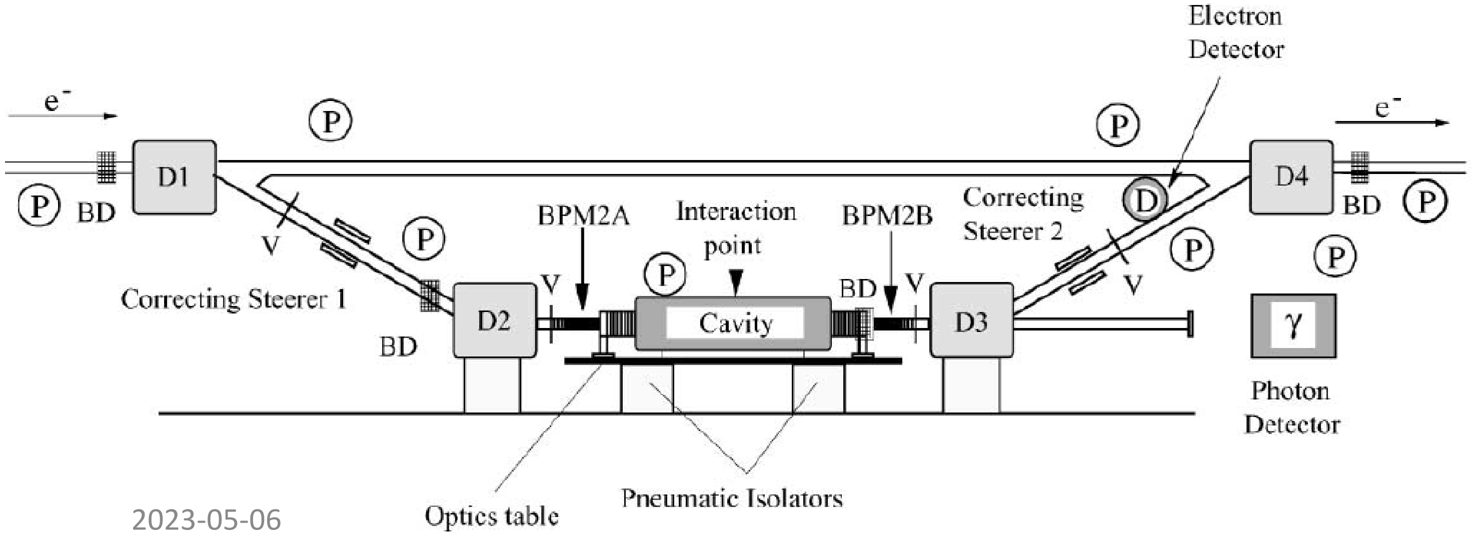
Parameter	Value
Incoming electron Energy, E [GeV]	≈ 11.0
Scattered electron Energy, E' [GeV]	2.0-9.0
Scattered angle, θ_{lab} [mRad]	5-19
$< Q^2 >$ [GeV]	0.0058
Max. beam current [μA]	70
Cross section scatter area, σ [μbarn]	≈ 60
Møller event rate @ 65 μA [GHz]	134
Beam polarization P_{beam}	$\approx 90\%$
Measured A_{PV} [ppb]	32
$\delta(\sin^2\theta_W)_{stat}$	0.00023

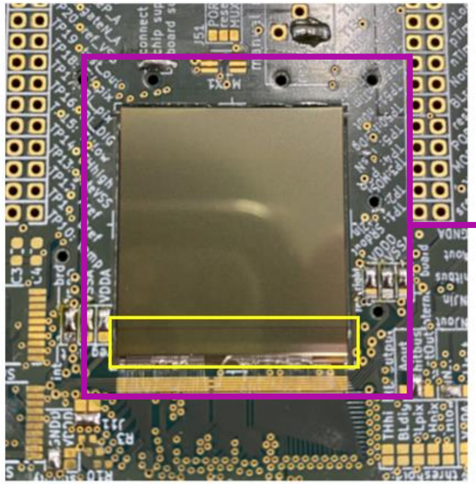
$$A_{meas} = P_e\left(f_p A_{PV} + \sum_b A_b f_b\right) + A_{beam} + A_{inst}$$

The experiment requires the measurement of the polarization of the electron beam to better than 90 ± 0.5 % in order to meet experimental goals

Compton Polarimetry

- Uses Compton Scattering to measure electron polarization as a function of scattered photon/electron energy
- Electron energy is related to recoil momentum
- Magnetic fields in dipole D3 will deflect electrons based on their momentum
- Higher photon energy after scattering $\rightarrow$ lower electron energy $\rightarrow$ larger bend radius in D3
- Therefore, position of deflected beam relative to un-scattered beam line can be used to calculate electron beam polarization
- Requires a detector to accurately measure 'deflection' of electron beam with respect to un-scattered beam
- Use HVMAPS to precisely locate deflected electron path

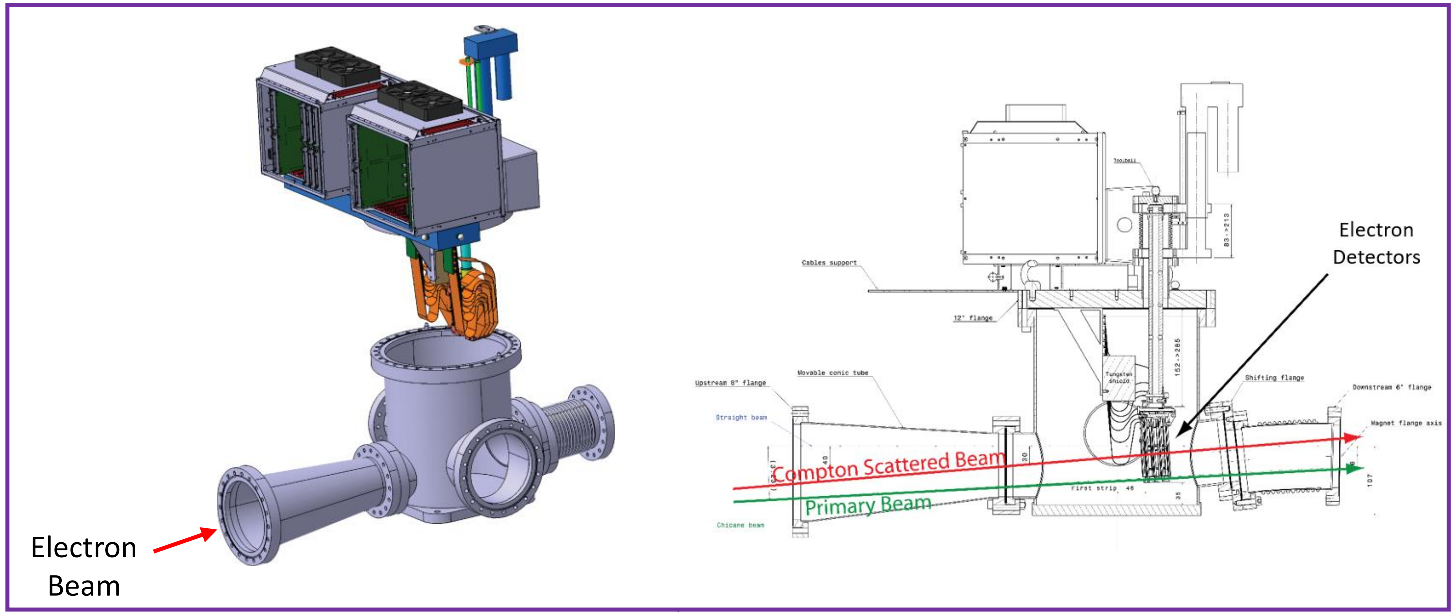


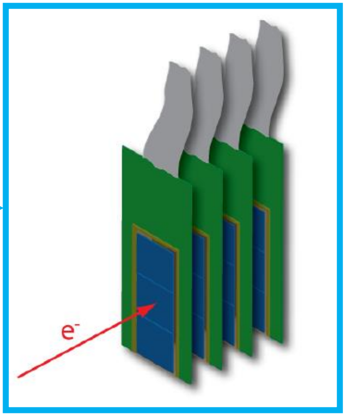


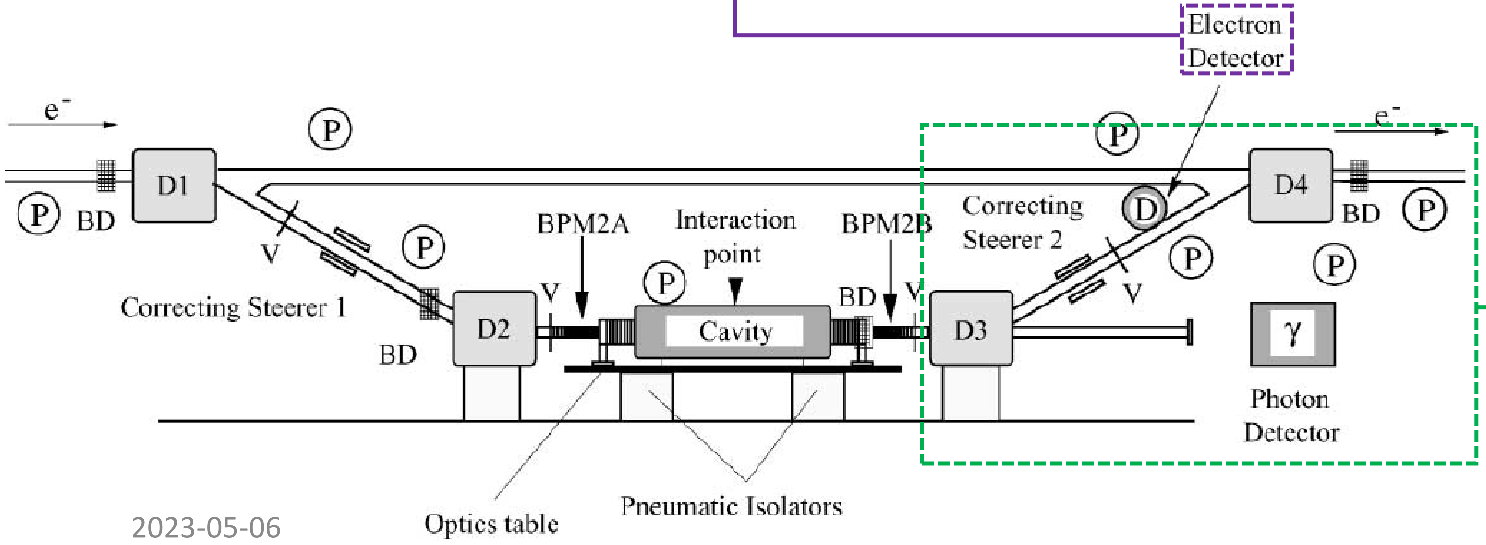
HVMAPS (MuPix 10) with periphery section highlighted in yellow

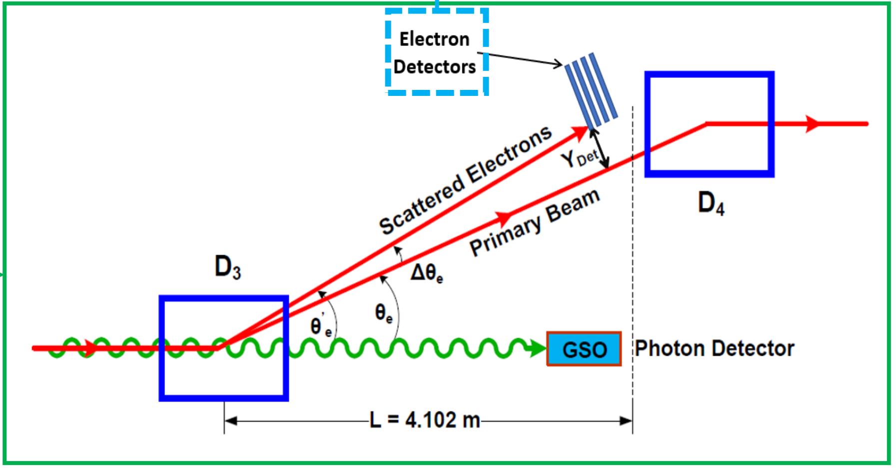
Compton Polarimetry

- 4 detector planes with HVMAPS
- 2 x 2 cm^2 detectable area per HVMAPS
- 3 HVMAPS per plane, for a total detectable area of 2 x 6 cm^2 on each plane



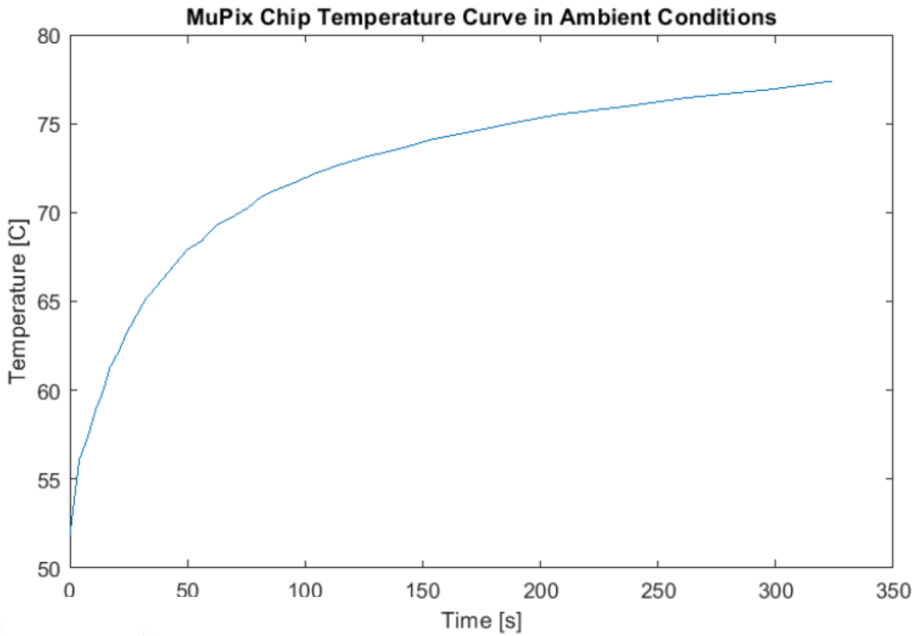


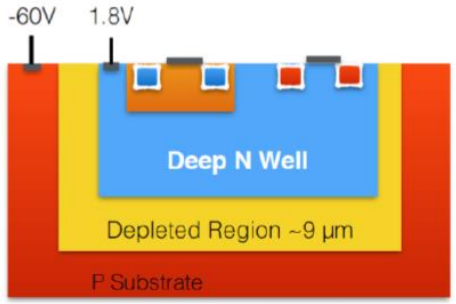


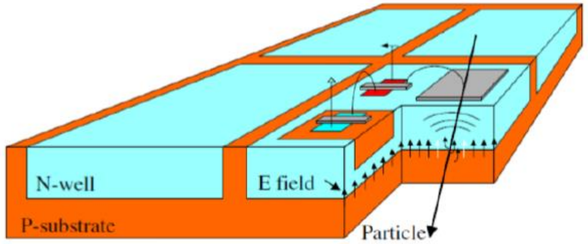


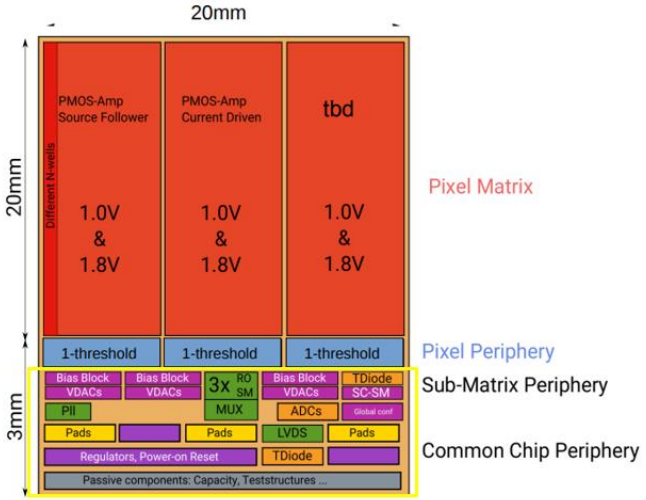
HVMAPS Electron Detectors

- Hybrid pixel sensors based on HV-CMOS technology
- Each pixel dimension is 80 x 80 μm^2, spread across a 250 x 256 grid
- Overall size of detectable area = 2 x 2 cm^2
- Can be as thin as 50 microns (low material budget)
- Readout electronics, filters and amplifiers all integrated into the chip.
- Timing resolution of 16 ns with peak detection rate of 30 MHz
- Generates about 1W of heat during peak operation
- Operating temperature should not (ideally) exceed 70 degrees Celsius

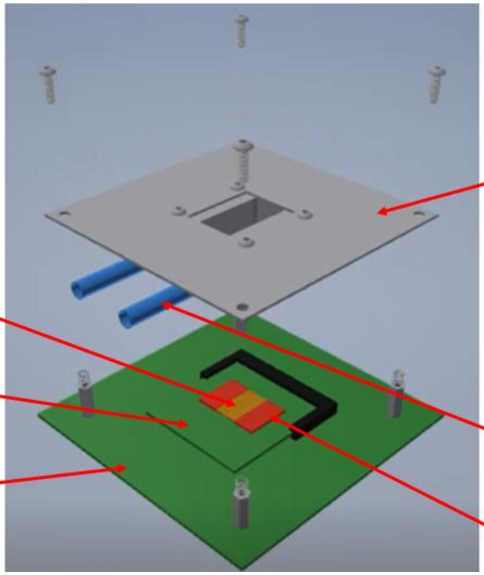


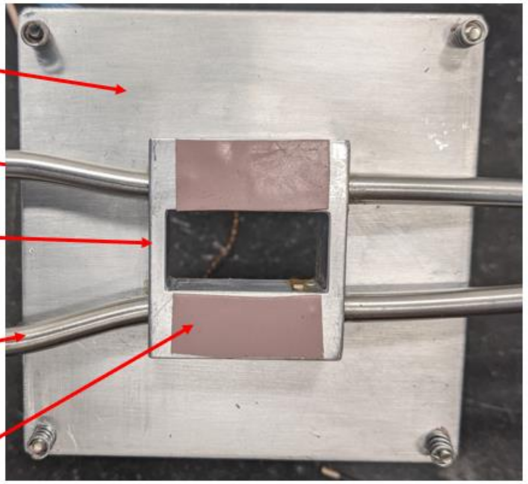


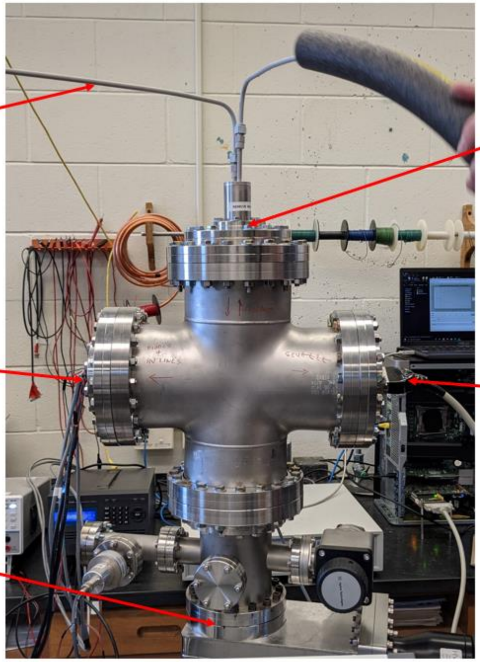


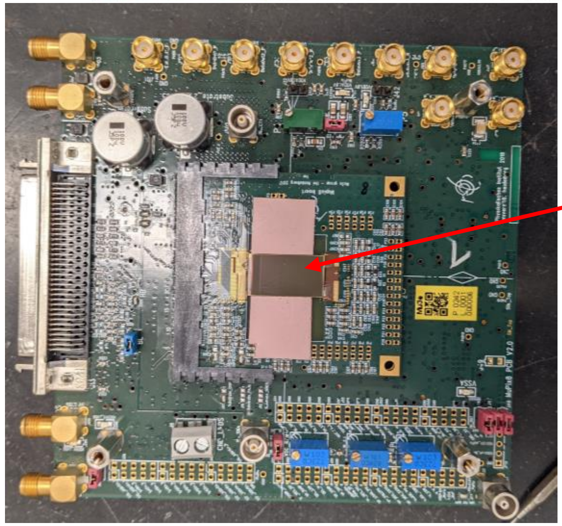


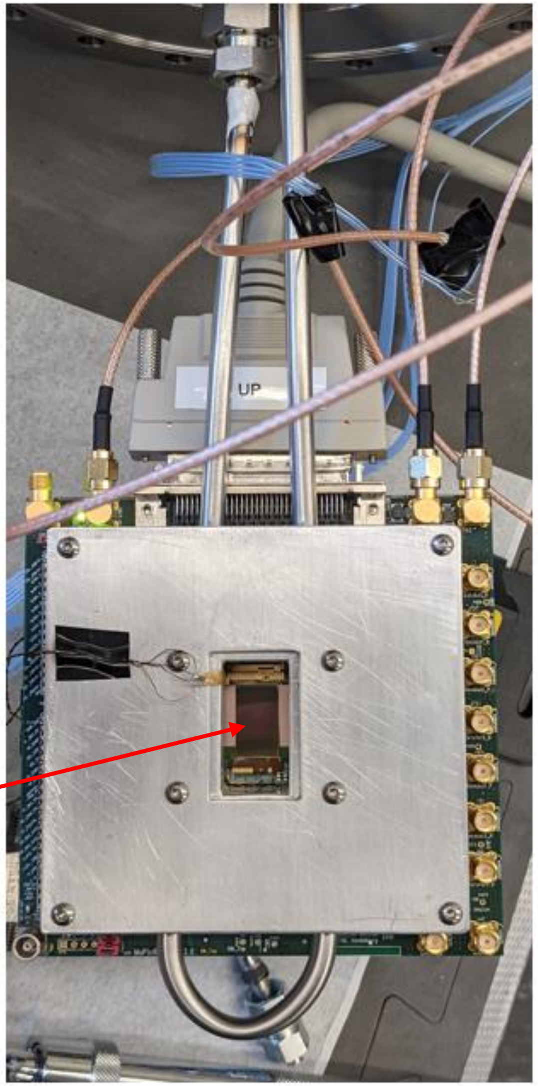
MuPix 8 Thermal Performance Testing





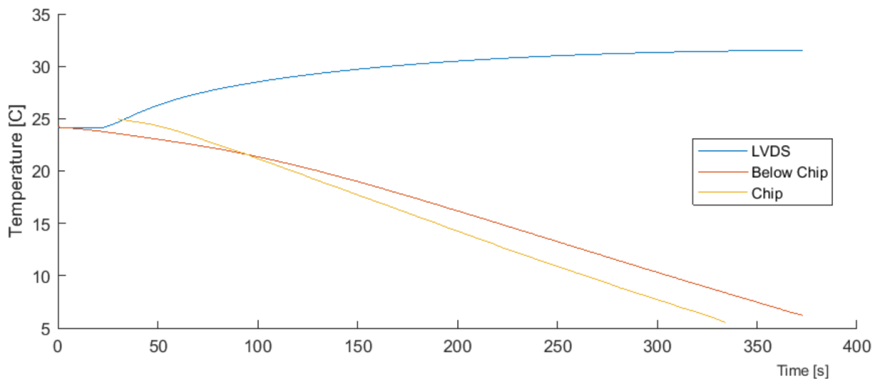




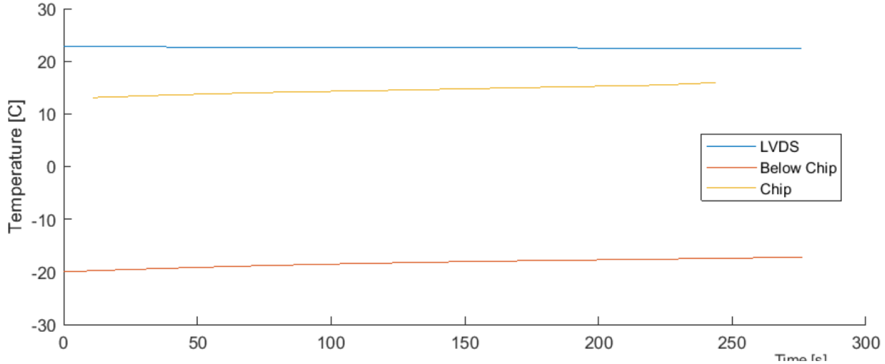


MuPix 8 Thermal Performance

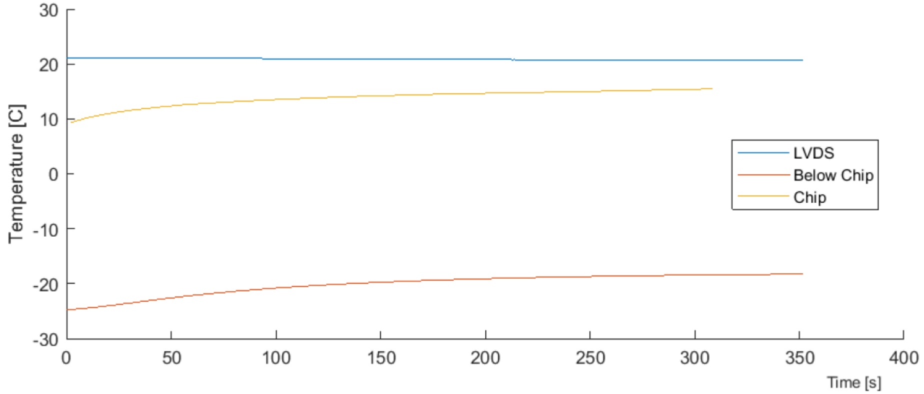
Readout + coolant flow started



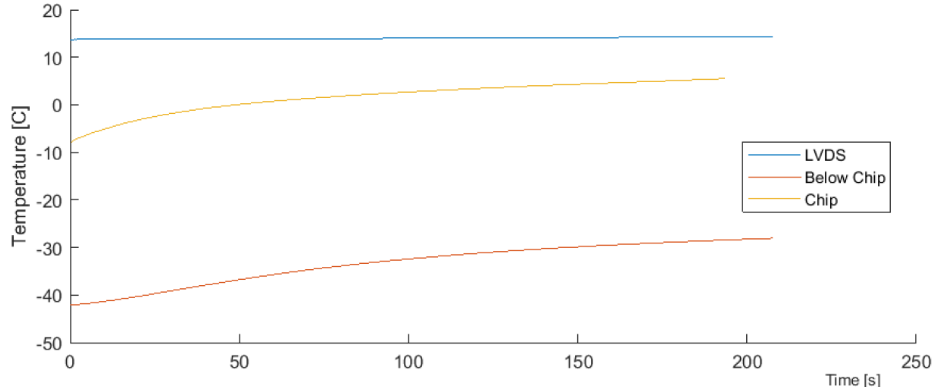
~8 min. DT, constant coolant flow temperatures stabilize



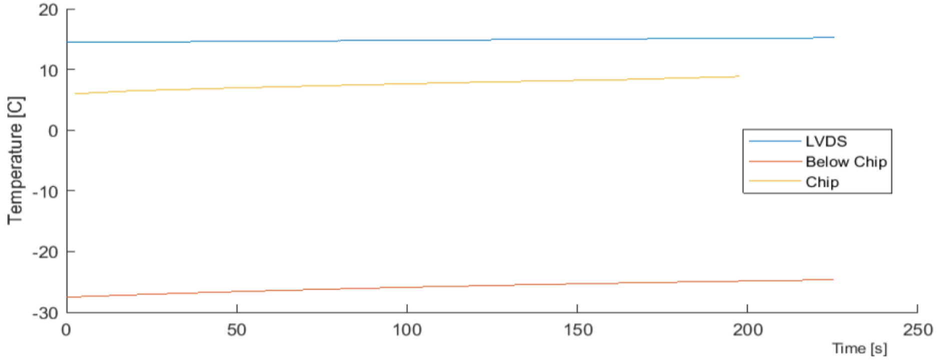
~8 min. DT, coolant flow briefly interrupted



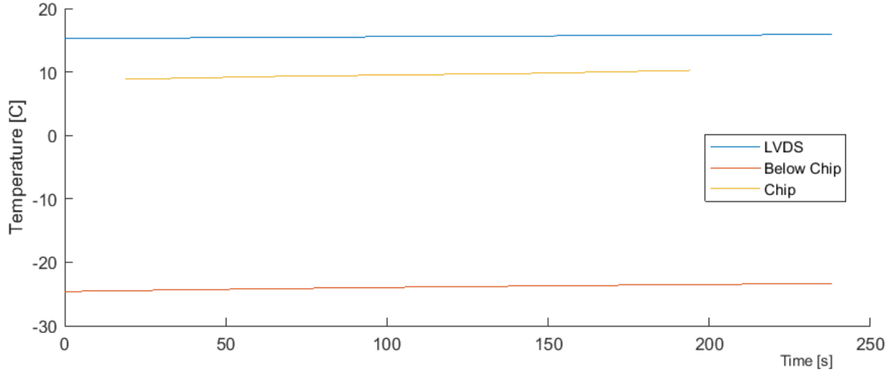
HVMAPS + coolant flow restarted



~8 min. DT, constant coolant flow temperatures stabilize



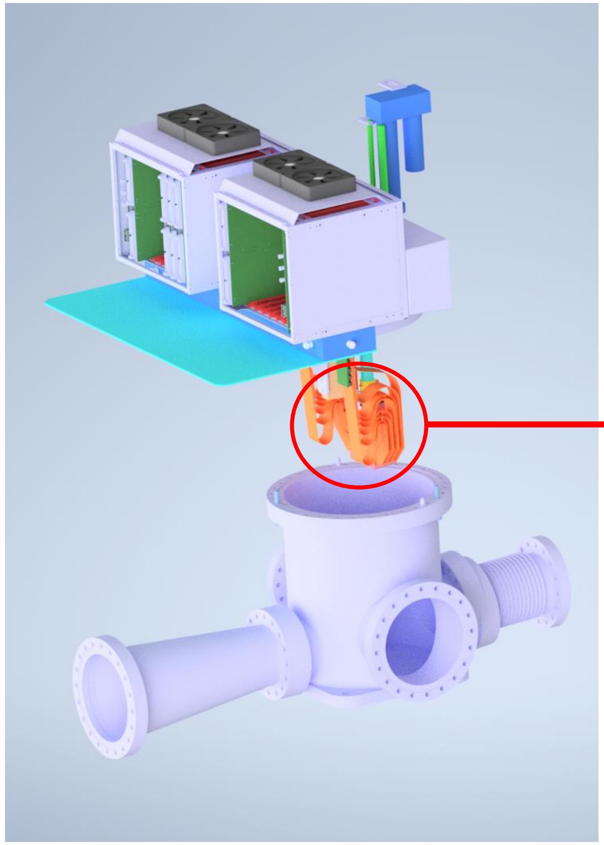
~8 min. DT, constant coolant flow temperatures stabilize

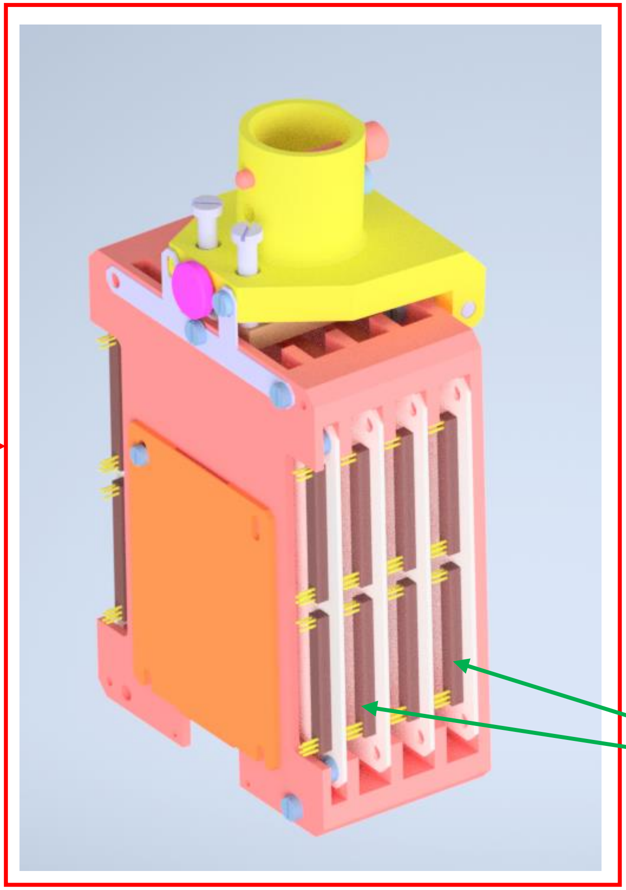


Design Intent and Challenges

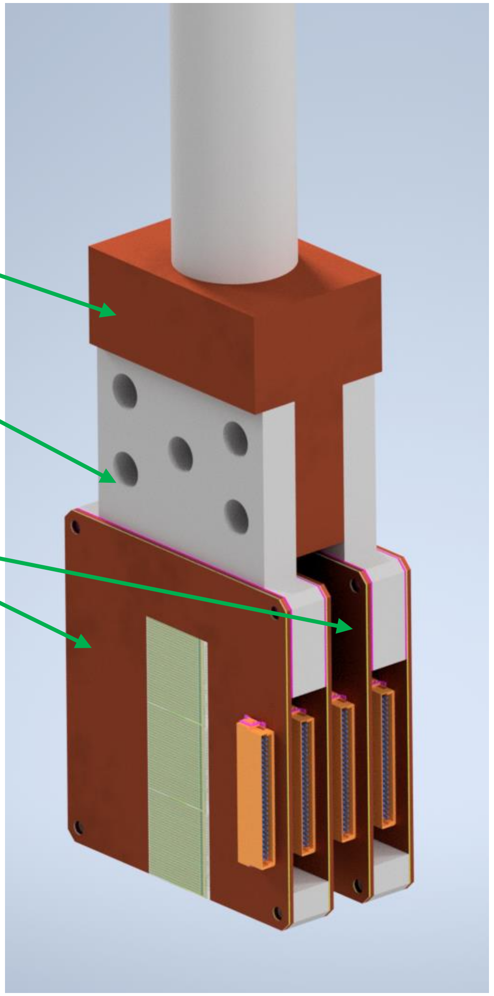
- Detector planes will be under vacuum, thus complicating cooling options
- Directly cooling the HVMAPS via forced convection on chip surface not possible
- Best method would be to **conduct** the heat away from the HVMAPS to a sink
- Design and implement an integrated cooling and mounting structure to conduct heat away from the HVMAPS to a liquid-cooled heat exchanger
- Generous use of copper (high thermal conductivity) and thermal pads between interfaces

Existing vs. New Detector Assembly



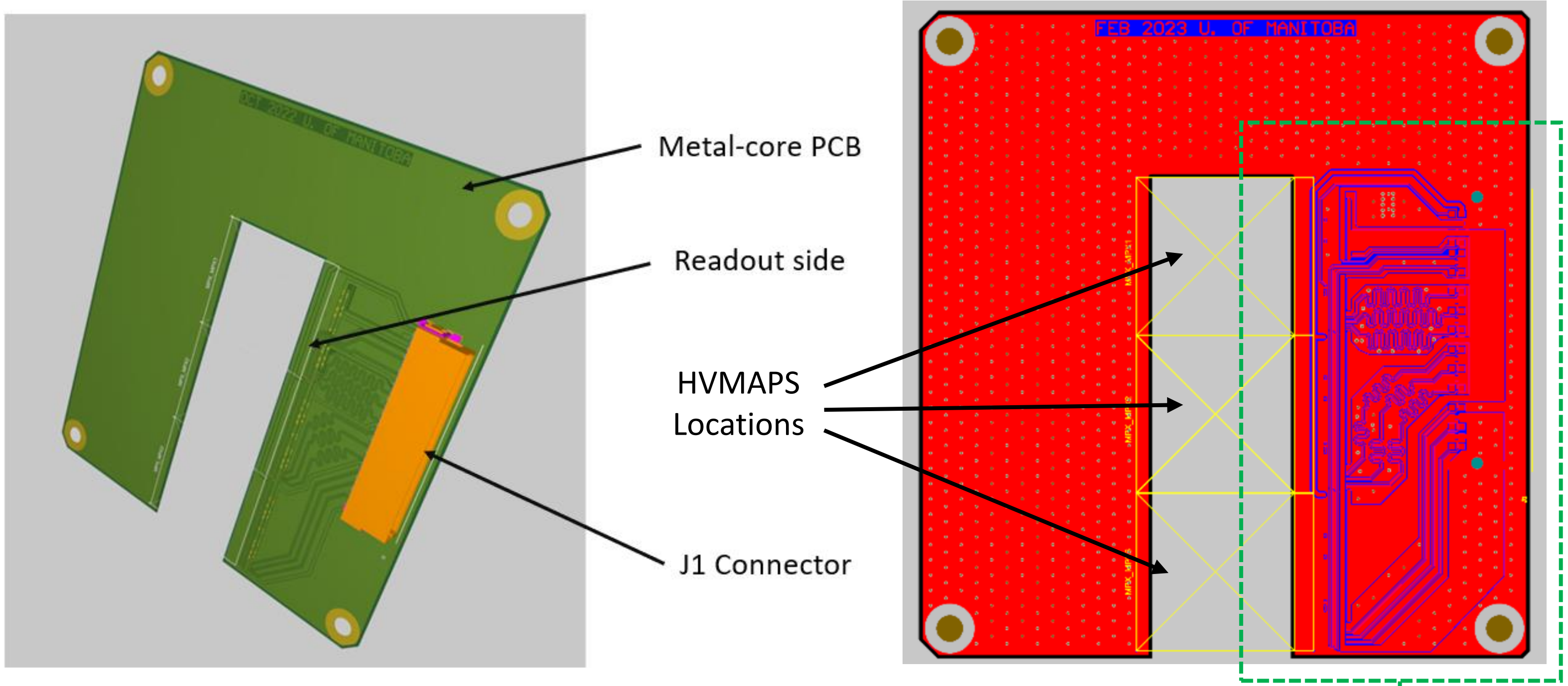


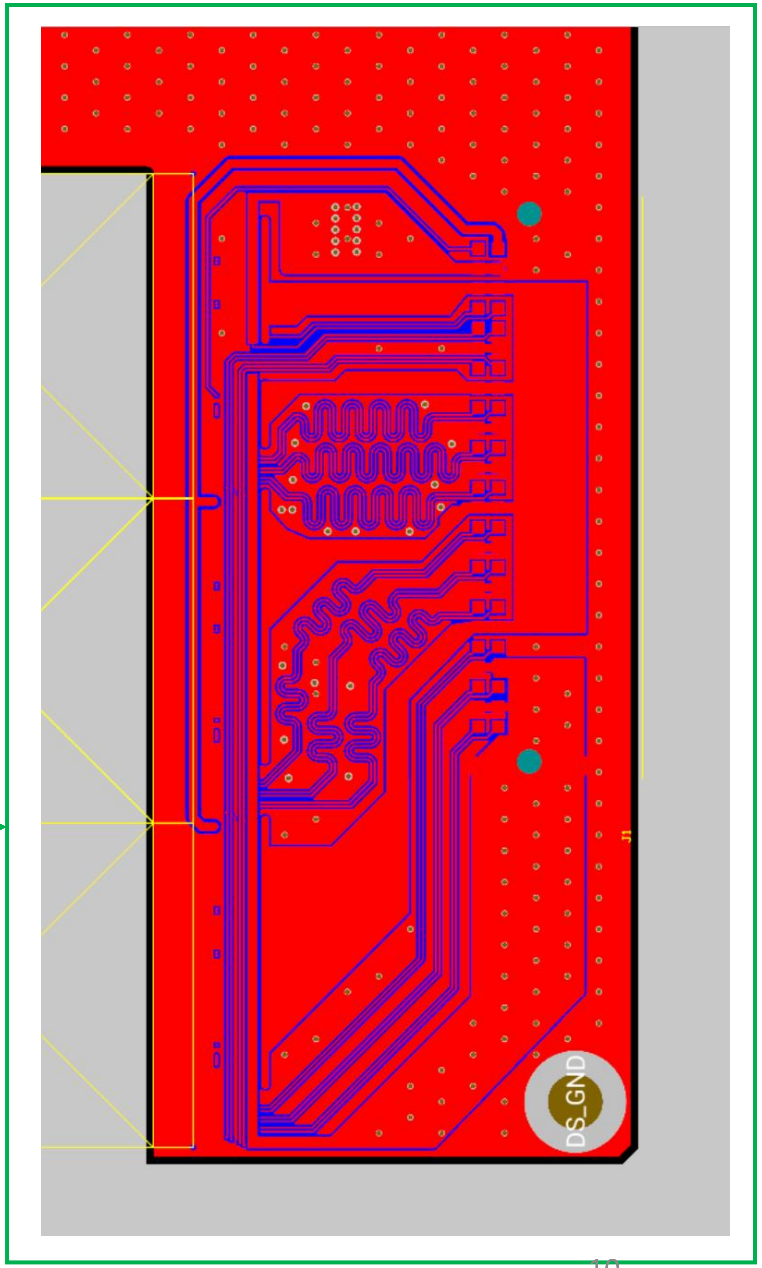
Existing microstrip detector planes



New HVMAPS detector planes

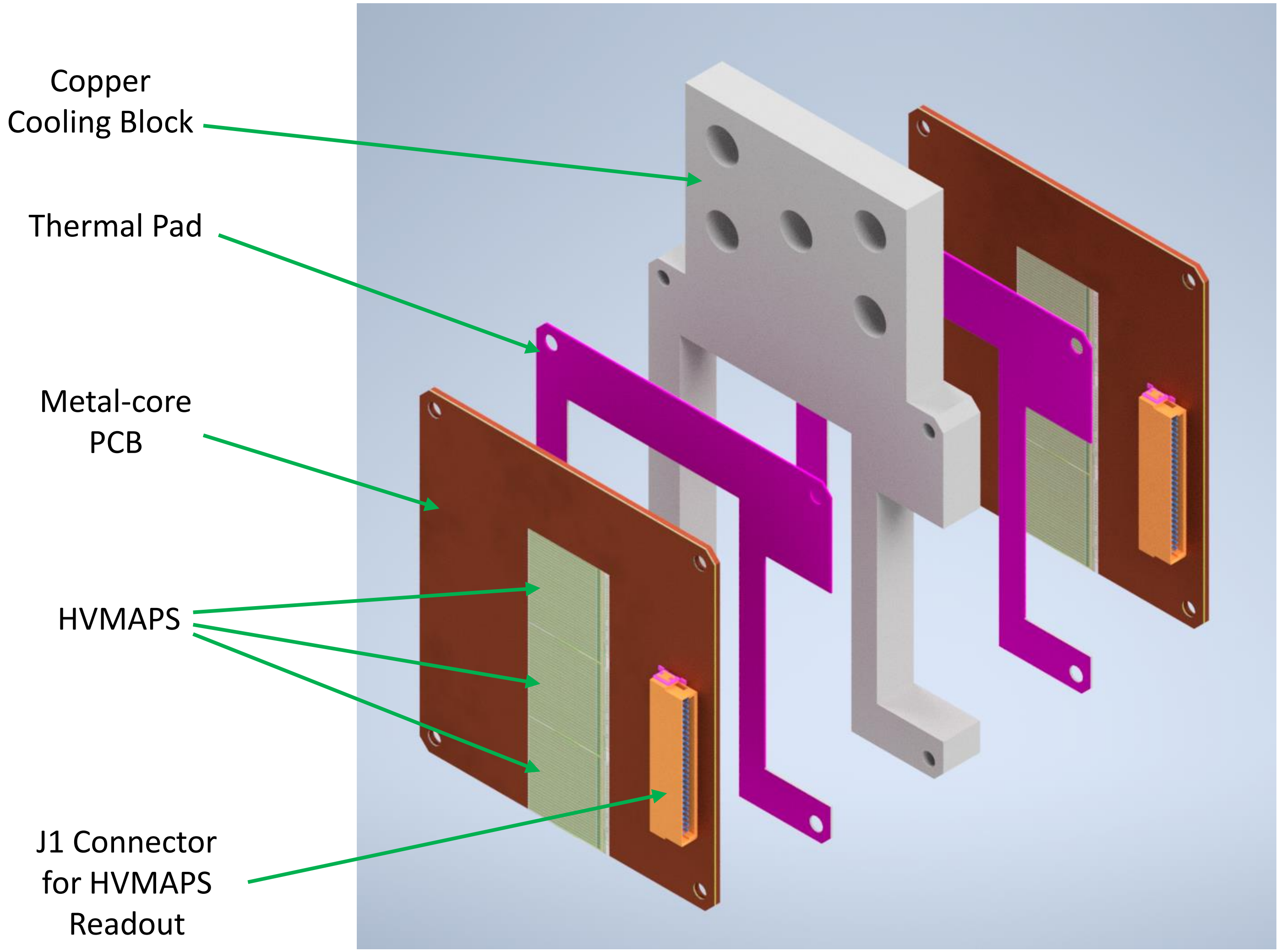
Metal-core PCB for HVMAPS





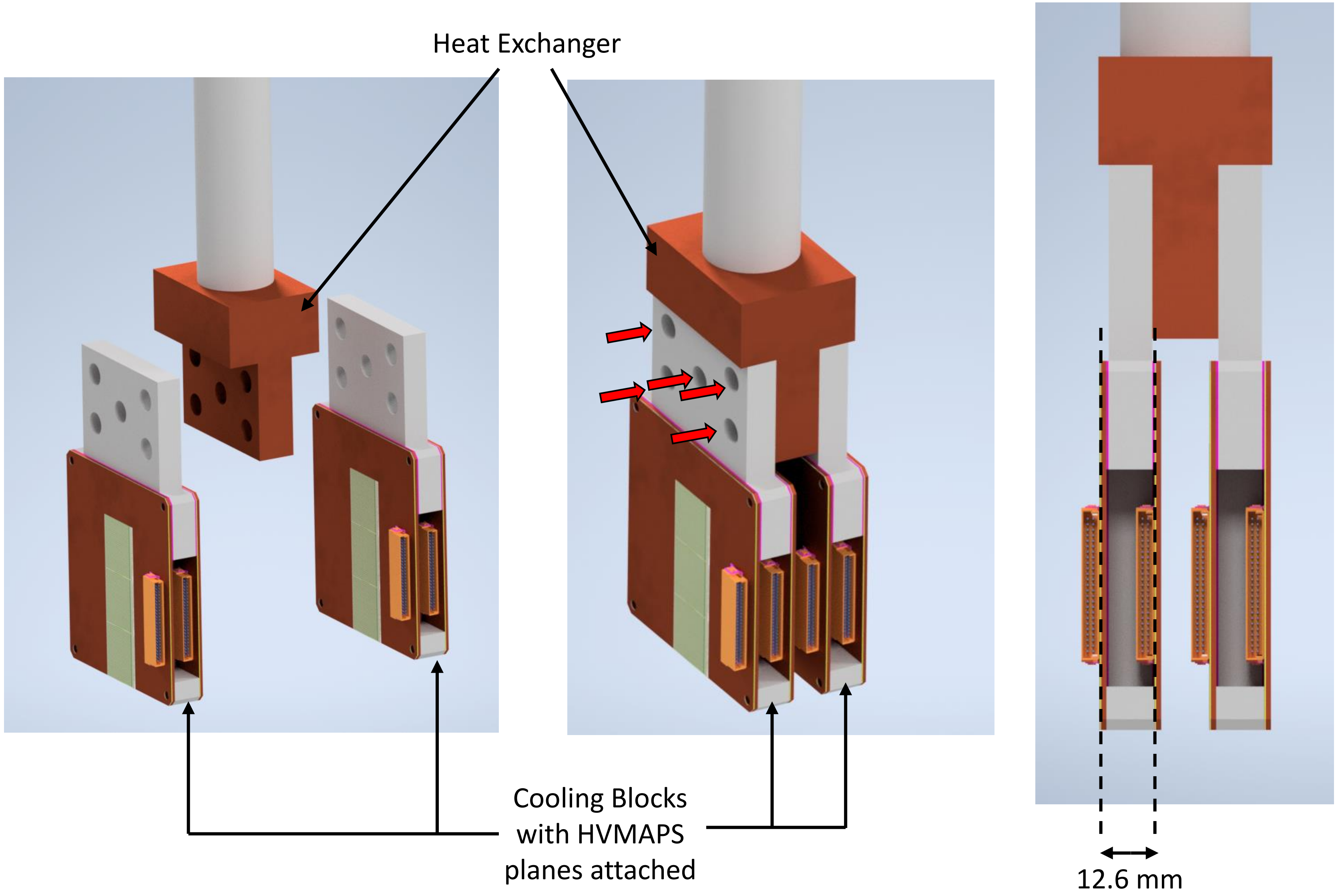
- PCB designed by Dr. Jie Pan, University of Manitoba
- HVMAPS will be glued and wire-bonded to the PCB
- Metal-core PCB will help conduct heat produced by the HVMAPS away for dissipation
- Exploring the idea of using thermal pads to improve thermal conduction between metal-core PCB and HVMAPS

New HVMAPS Mounting and Cooling Assembly



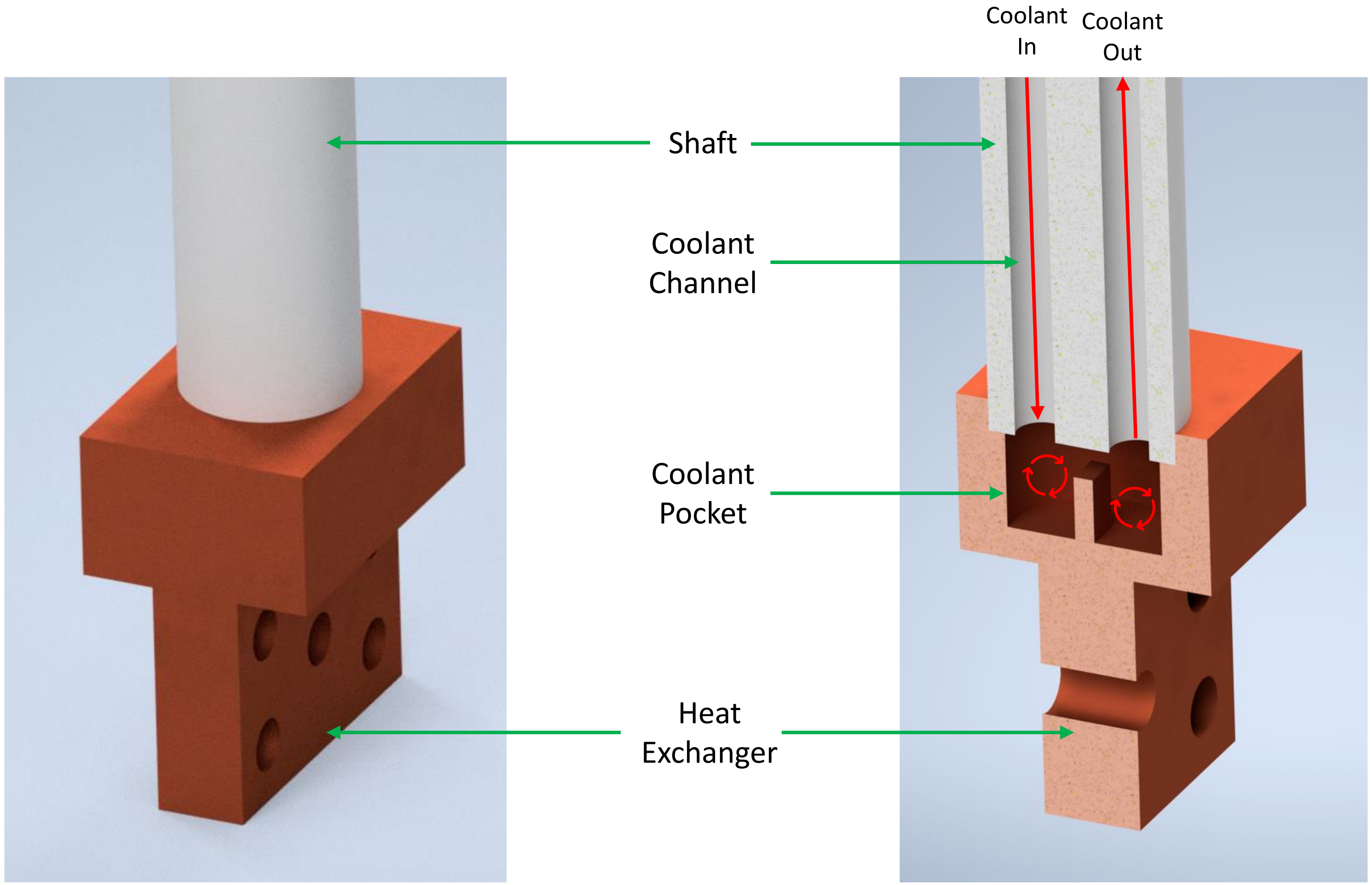
- Each detector plane consists of 3 HVMAPS wire-bonded to a metal-core PCB
- 1 J1 connector to read out data from each plane
- Two planes will be attached to one cooling block, interfaced together using thermal pads
- Gentle, yet firm pressure required to compress thermal pad between detector plane and cooling block for maximum thermal conduction
- Cooling block will be a single piece of machined copper (different color used in figure for ease of visibility)

Cooling Blocks and Heat Exchanger



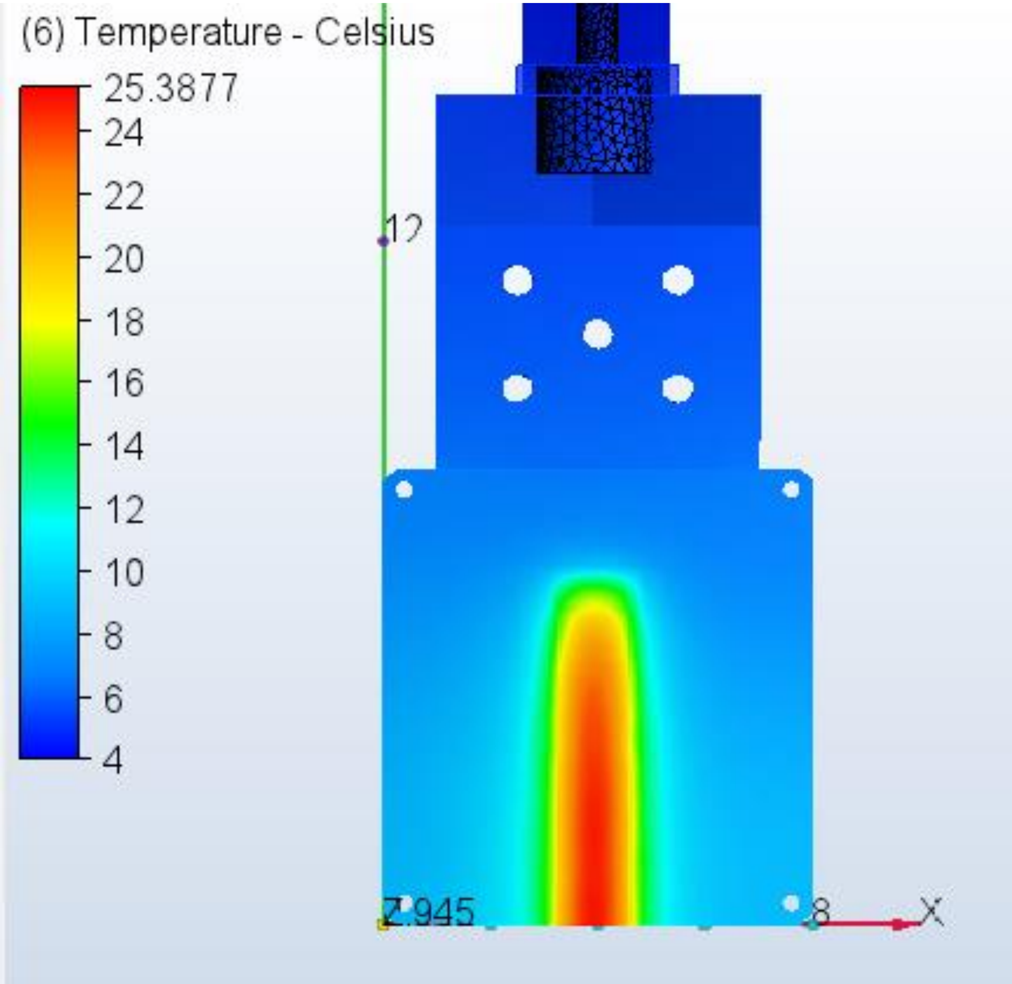
- Both cooling blocks will be attached to either side of the copper heat exchanger using 5 fasteners (red arrows)
- Applies a clamping pressure of 4000 psi between mating heat-exchanger components
- Maximizes conduction between components
- Heat exchanger will be machined out of a single block of copper
- Distance between two adjacent HVMAPS planes is 12.6 mm

Heat Exchanger and Shaft

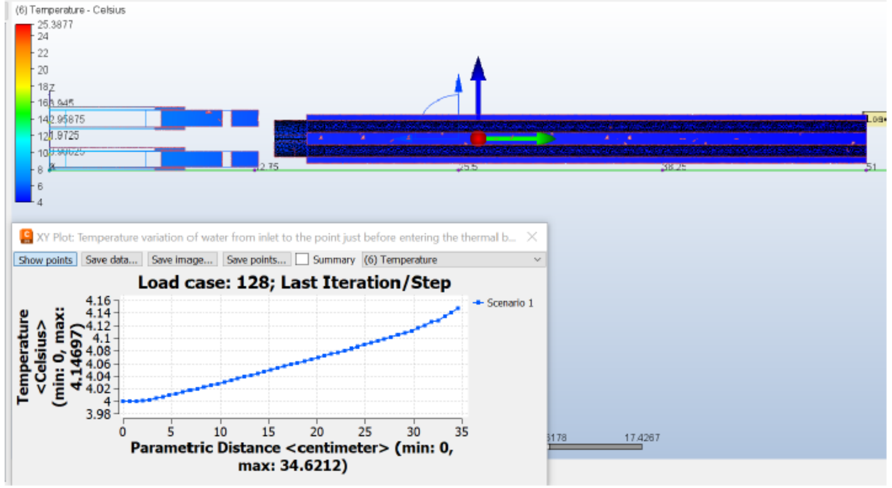


- Shaft holding the assembly in beam line will be attached to a linear translation stage to move detector planes up and down
- Translation stage attached via a feed-through
- Shaft will be a copper rod with coolant channels bored along its length
- Will be using LCW (Low Conductive Water) as coolant
- Pocket is designed to make the flow of coolant turbulent, thereby increasing heat transfer to coolant
- Shaft and heat exchanger will be brazed to prevent possible leaks

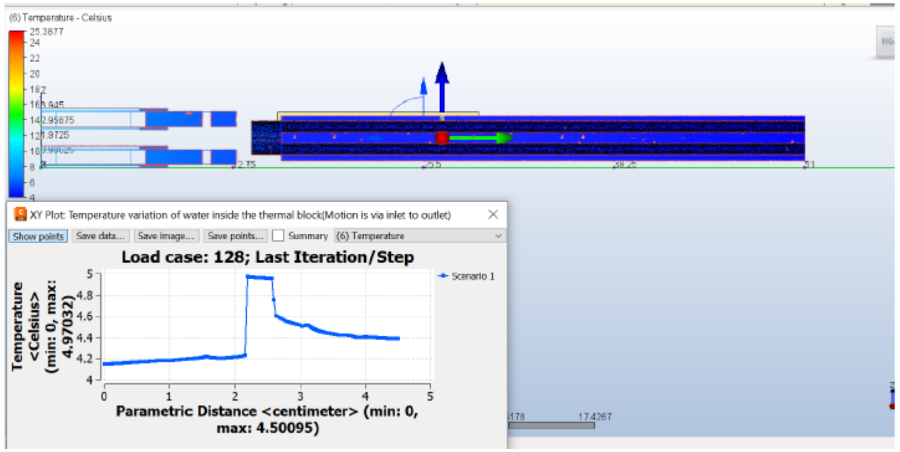
CFD Simulations (by Shefali)



Temperature distribution of overall assembly



Temperature variation of coolant as it moves closer to the heat exchanger



Temperature variation of coolant inside the heat exchanger

Still working on…

- An updated assembly including thermal pads on the top/bottom of the periphery side of the HVMAPS to further improve cooling efficiency
- Use simulations to optimize size/geometry of cooling block to minimize electron scattering inside block
- Modifications to align detector planes at a fixed angle (normal to beam line)
- Assembling a prototype to study the performance of current cooling setup inside a vacuum with HVMAPS operating at maximum capacity

Summary

- Studied thermal performance of prior version of HVMAPS (MuPix 8) in a vacuum
- Designed integrated mounting and cooling assembly to replace current strip detectors with HVMAPS
- Simulations show that the current integrated design is capable of maintaining the HVMAPS at < 30 C
- Design will undergo gradual modifications to increase efficiency of cooling system

Thank you