Electron Detectors for the MOLLER Experiment

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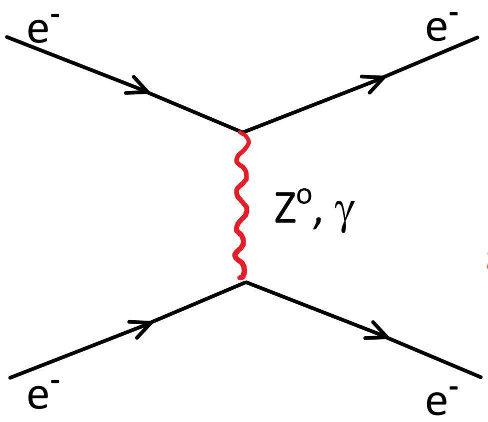
Overview

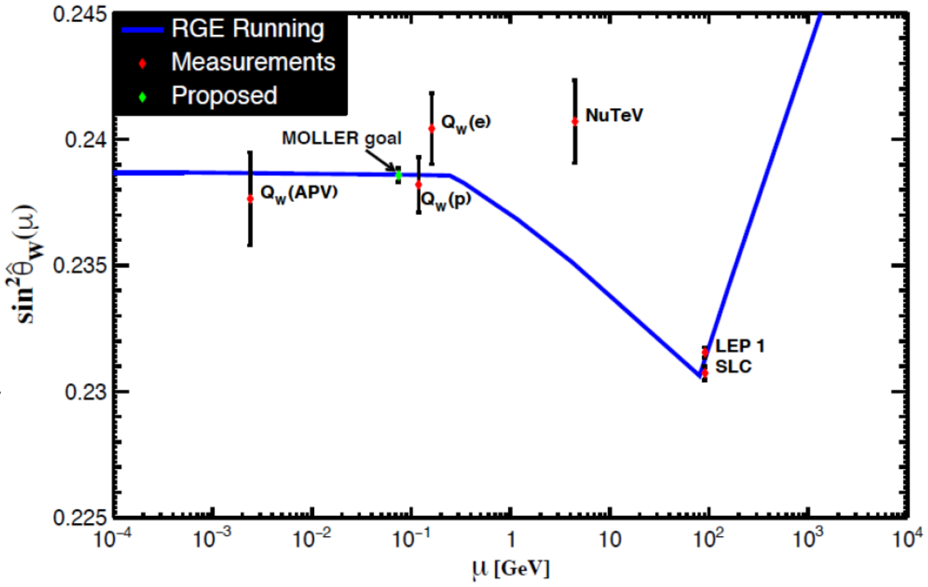
- The MOLLER Experiment
- Main Integrating Detectors
- Compton Polarimeter
- HVMAPS
- HVMAPS for the Main Detectors
- HVMAPS for the Compton Polarimeter

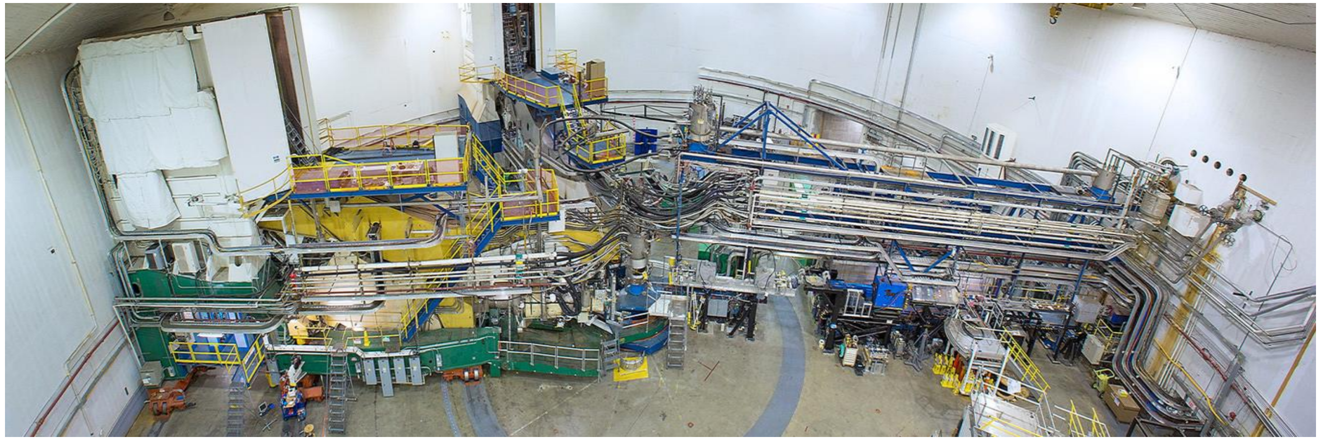
Key points of MOLLER

Measurements:

- A_{PV} is due to EM and weak neutral currents
- Measure A_{PV} in Moller scattering to an uncertainty of 0.8 ppb
- Weak charge of the electron (0.0435) to within 2.4%
- Weak mixing angle to ± 0.00028
- Probe into possible new physics beyond the Standard Model

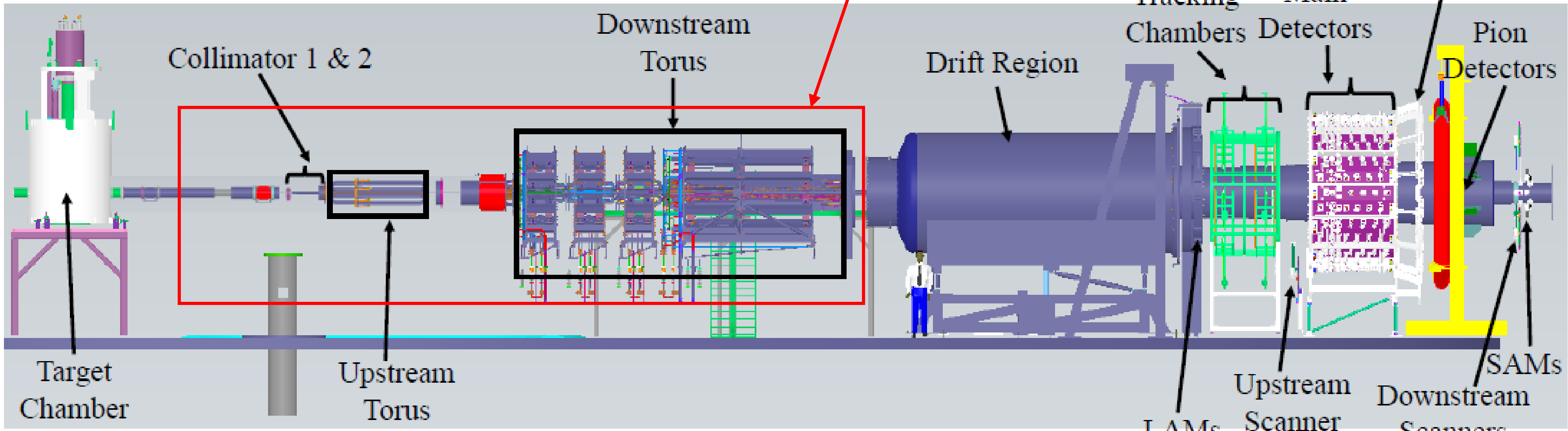






- Scheduled to begin in 2025
- Conducted in Hall A of JLab, Virginia
- Will use JLab's CEBAF, with 1920 Hz helicity flip rate
- CEBAF produces a longitudinally polarized electron beam at 11 GeV with 65 μA beam current

MOLLER Experimental Setup

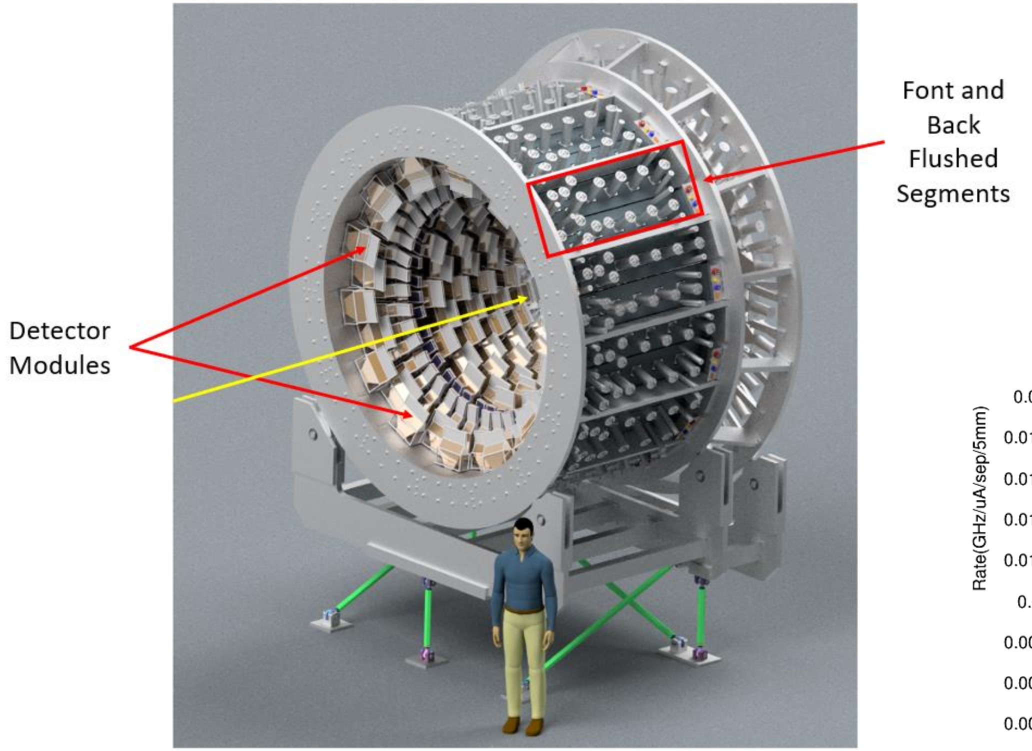


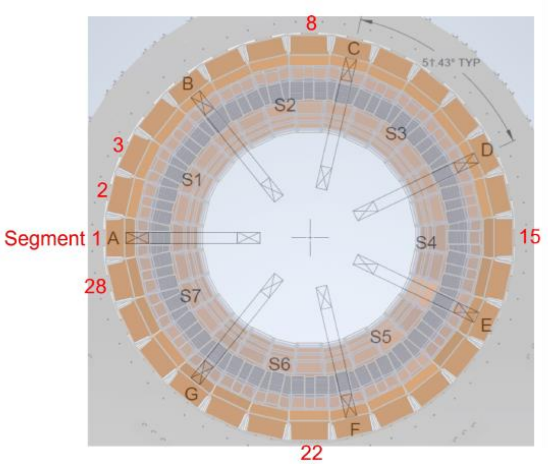
$$A_{meas} = Pe\left(f_p A_{PV} + \sum_b A_b f_b\right) + Ab_{eam} + Ai_{nst}$$

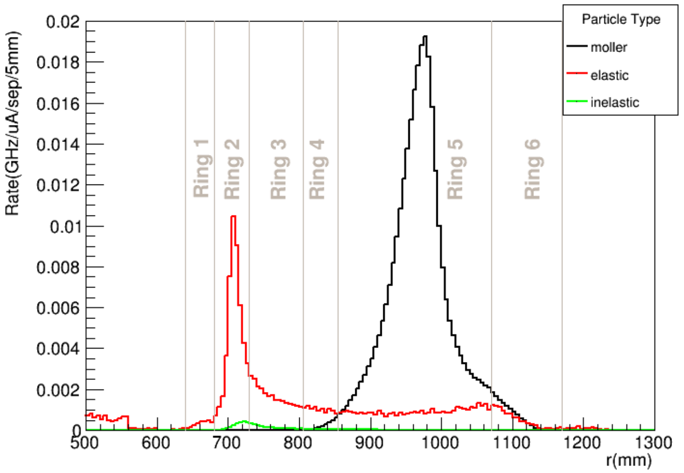
$$A_{PV} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \left[mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{4\sin^2\theta}{(3+\cos^2\theta)^2}\right]Q_W^e$$

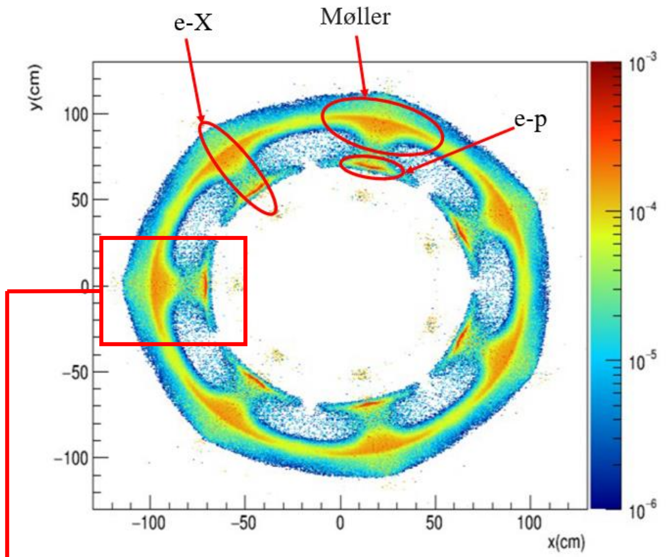
Parameter	Value
Incoming electron Energy, E [GeV]	≈ 11.0
Scattered electron Energy, E' [GeV]	2.0-9.0
Scattered angle, θ_{lab} [mRad]	5-19
$< Q^2 >$ [GeV]	0.0058
Max. beam current [μA]	70
Cross section scatter area, σ [μbarn]	≈ 60
Møller event rate @ 65 μA [GHz]	134
Beam polarization P_{beam}	$\approx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

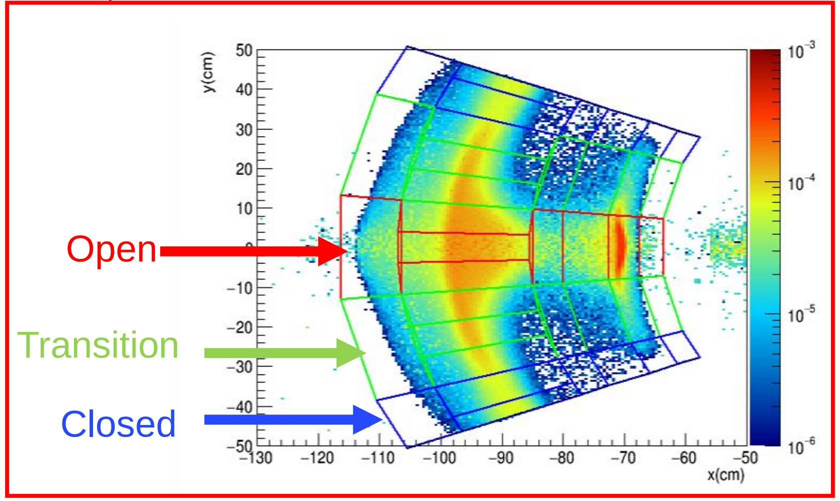
Scattered Electron Profile



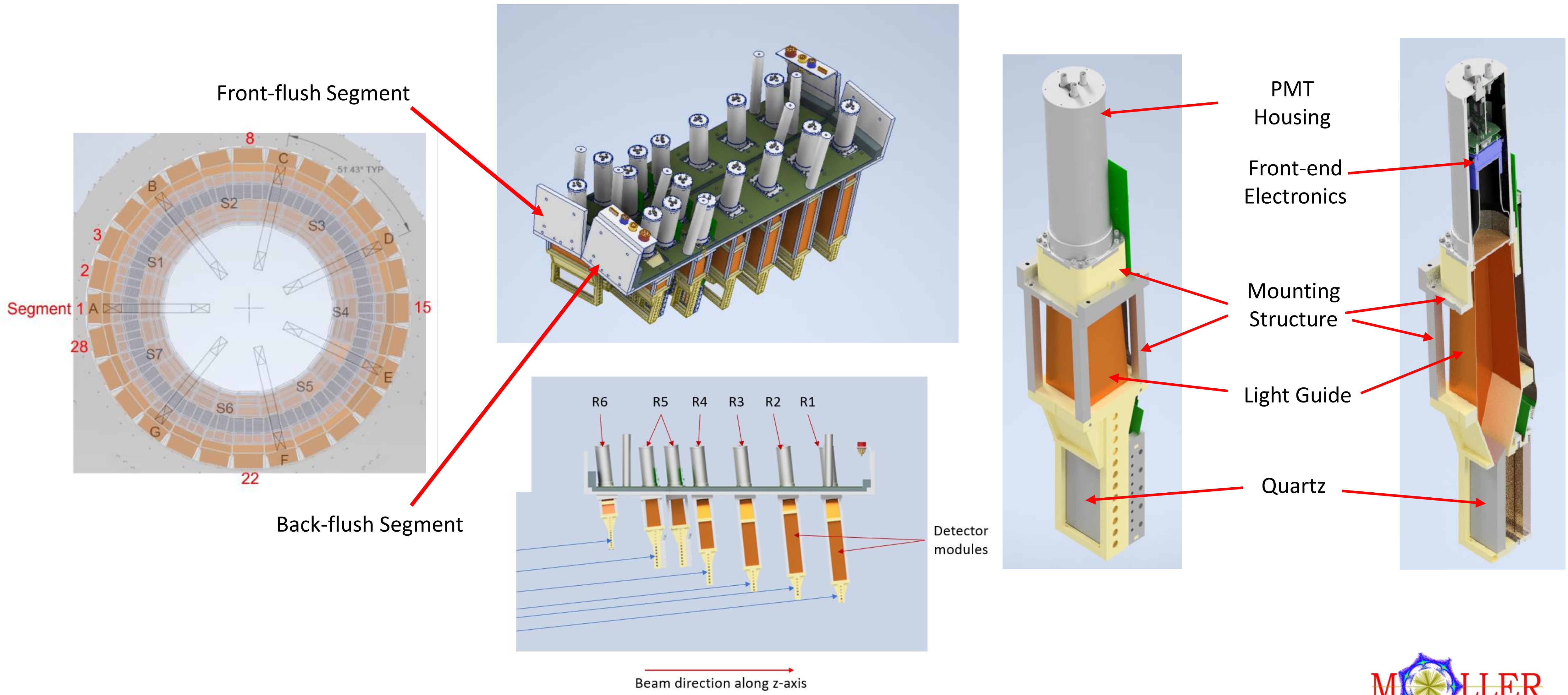








Main Detector Segmentation



Recalling the Asymmetry Measured by MOLLER

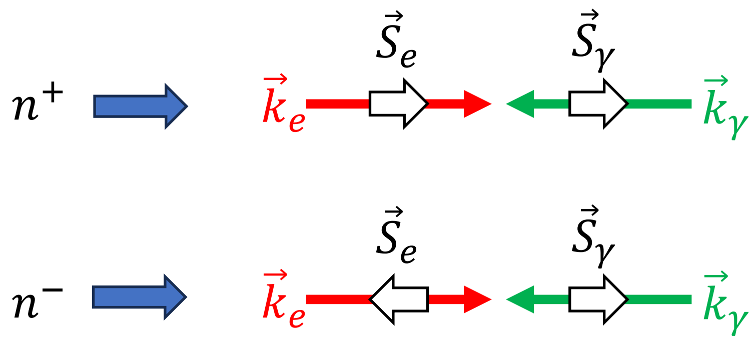
$$A_{meas} = P_e \left(f_p A_{PV} + \sum_b A_b f_b \right) + A_{beam} + A_{inst}$$

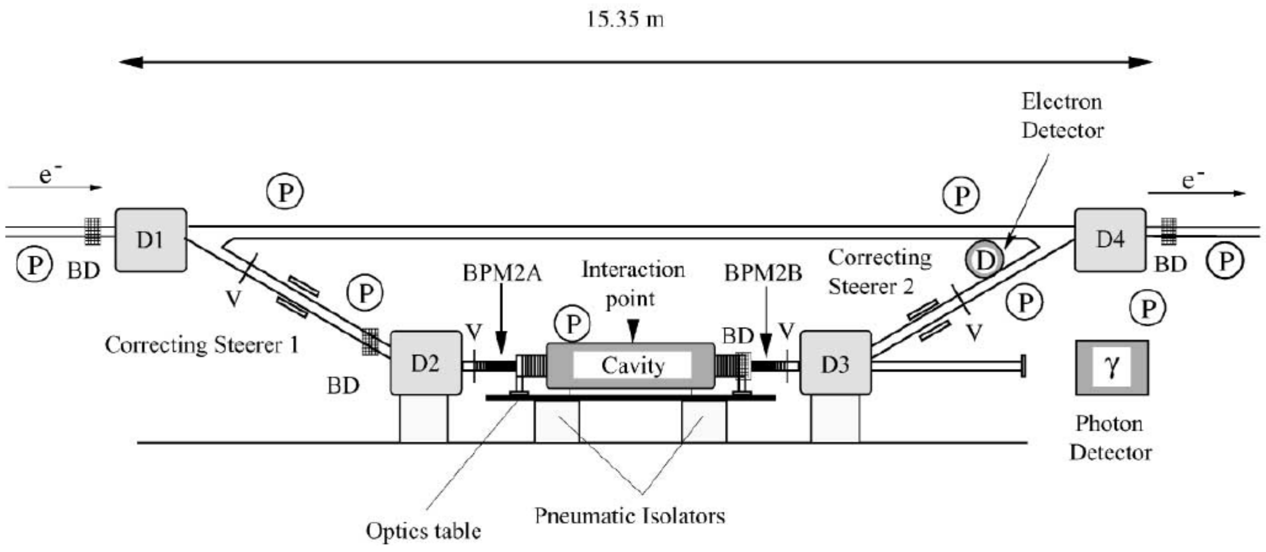
Beam Polarization

- CEBAF produces a highly polarized longitudinally polarized electron beam at 11 GeV with 65 μA beam current
- For MOLLER, beam helicity flip rates of 1.92kHz will be needed
- Three polarimeters present: Mott, Moller and Compton polarimeters

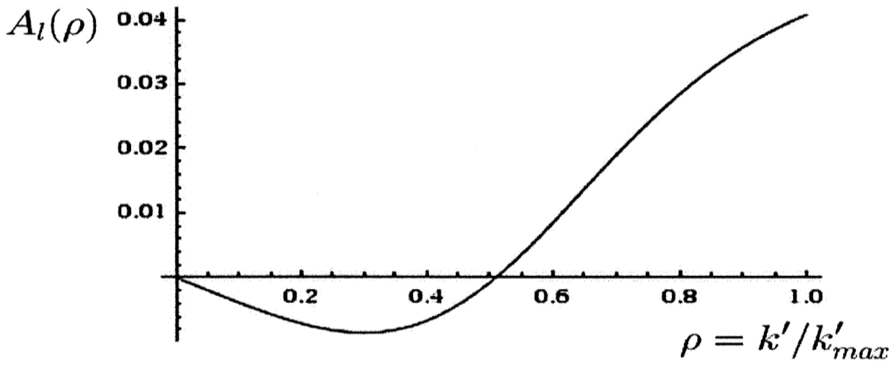
The experiment requires the measurement of the polarization of the electron beam to better than 90 ± 0.5 % in order to meet experimental goals

Compton Polarimetry





$$A_{exp} = \frac{n^+ - n^-}{n^+ + n^-} = P_\gamma P_e A_l \qquad P_e = \frac{A_{exp}}{P_\gamma A_l}$$



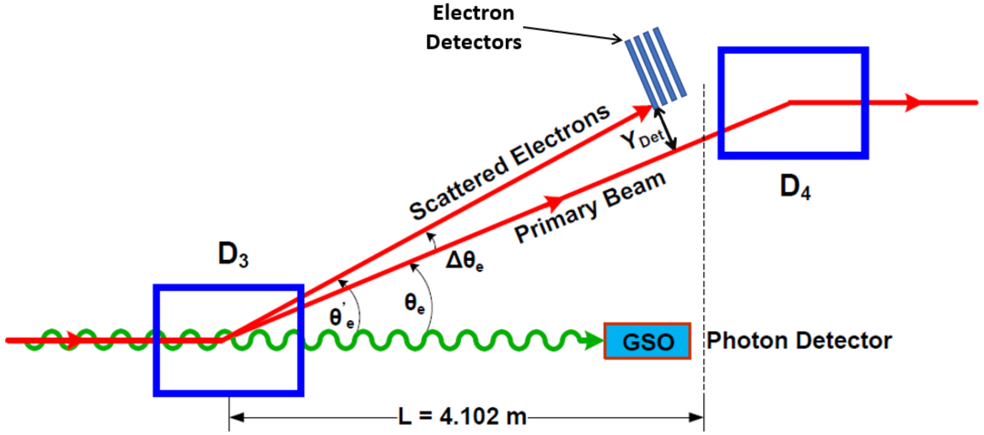
- A_{exp} : Experimental asymmetry measured from detectors
- P_e : Electron polarization
- P_γ : Photon polarization
- A_l : Theoretical Compton asymmetry (known)

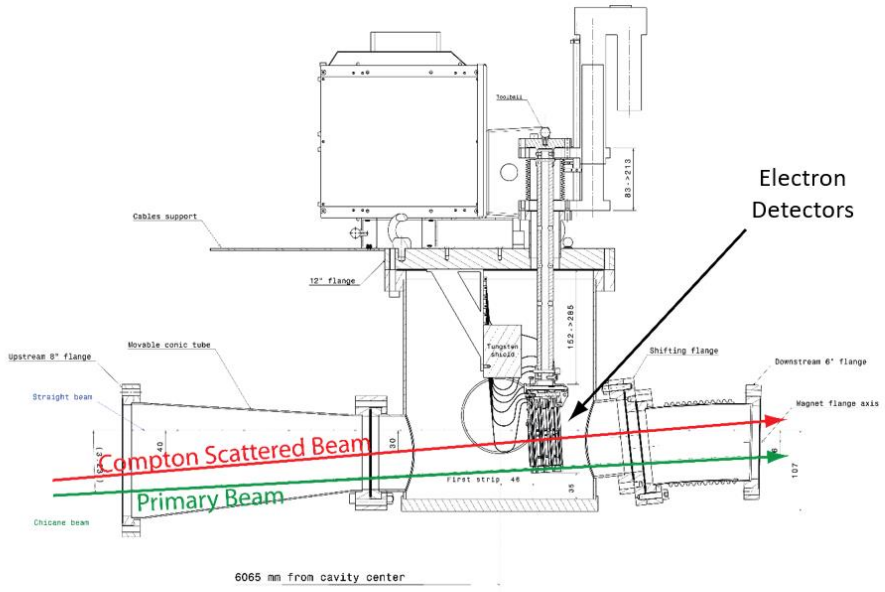
Compton Polarimeter

- Deflection at HVMAPS detectors is used to measure beam polarization
- Electron loses momentum to photon via. Compton scattering
- Higher photon energy means lower electron energy
- Greater loss of electron energy means greater bend radius by dipole D3:

$$r = \frac{\gamma v m}{Be} = \frac{p}{Be}, \qquad \gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

- Uses 4 planes of HVMAPS (3 per plane) to measure electron deflection from primary beam





Need for electron detectors for MOLLER

Main Detectors

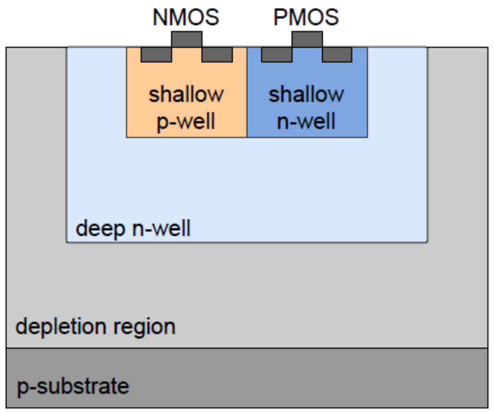
- Electron detectors needed to monitor event profile in the main Moller region at given beam currents
- Also used to simultaneously observe the evolution of the beam profile as beam currents change
- Can be used as a tracking detector on the Ring-5 plane as well

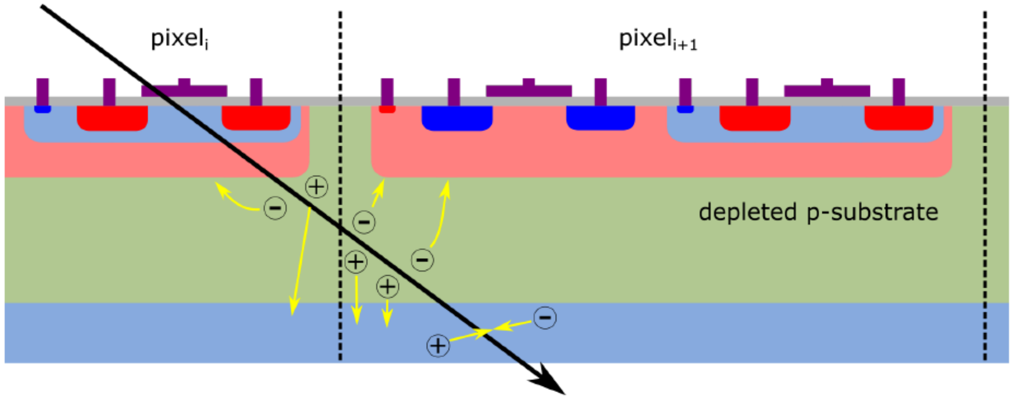
Compton Polarimeter

- Developing new electron detectors in parallel with diamond-strip detectors
- Need high (spatial) resolution electron detectors to accurately measure deviation of Compton-scattered electrons compared to un-scattered electrons
- New detectors may replace/complement existing diamond-strip detectors

High Voltage Monolithic Active Pixel Sensors (HVMAPS)

- Based on CMOS technology
- Monolithic pixel sensors: sensor and readout ASICs are integrated on the same chip (as opposed to hybrid sensors, where they are two separate layers)
- Particle detection, corresponding signal generation, amplification and signal processing are all done on the same die
- Pixels can be fabricated to be very small, allowing for high spatial resolutions for particle tracking
- Multiple chips can be combined to form a detector plane
- Can be manufactured to be very thin, so low material budget
- High radiation tolerances

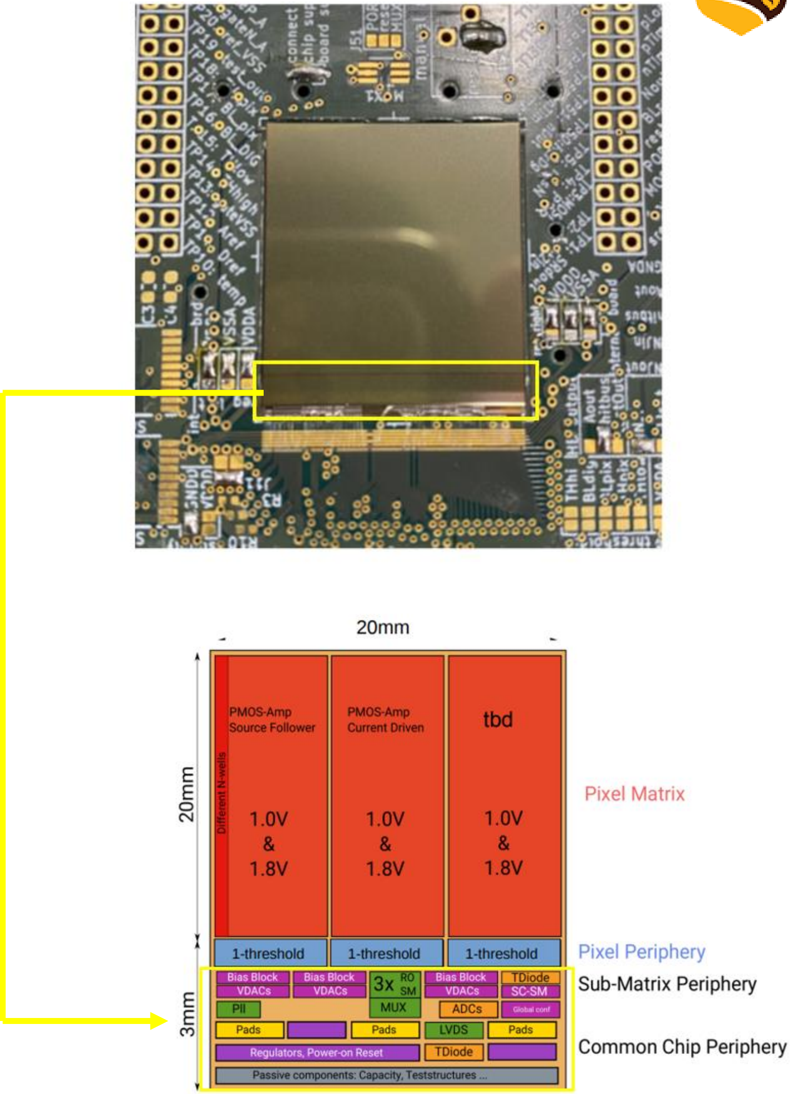




Source: Weber, Alena Larissa. *Development of integrated circuits and smart sensors for particle detection in physics experiments and particle therapy*. Diss. 2021.

HVMAPS (P2Pix)

- For MOLLER, we will be using a version of the HVMAPS known as P2Pix
- Each chip will be approx. 20 x 23 mm^2 in size, with a detectable area of 2 x 2 cm^2
- Detectable area will have an array of 250 x 256 pixels (64,000 pixels in total), with each pixel being 80 x 80 μm^2
- 100 microns thick, therefore optimizing ease of handling and material budget
- Peak detection rate of 30 MHz, with timing resolutions of 16 ns
- Requires -ve (60-100)V bias voltage
- Generates about 1 W of heat during peak operation
- To improve noise performance and longevity, chips should ideally stay below 50 degrees Celsius



Implementation of HVMAPS for MOLLER

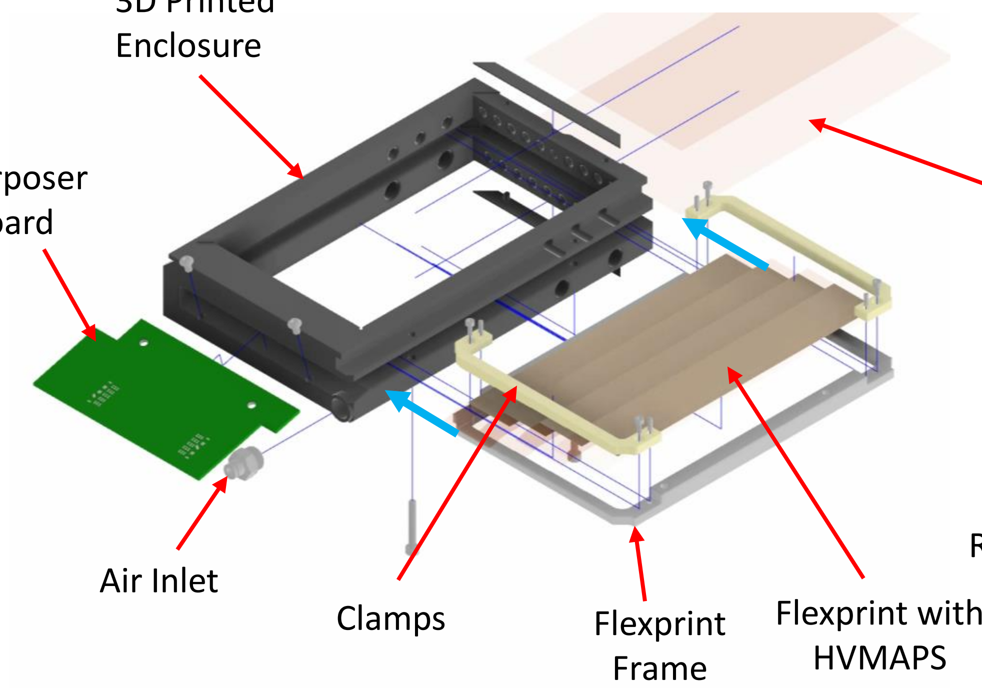
Main Detector Ring 5 Module

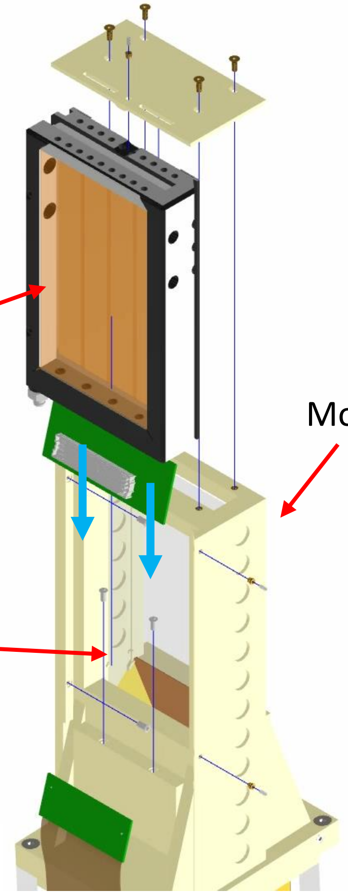
- Position a plane of HVMAPS behind each Ring 5 quartz tile to monitor event profile in the main Moller region
- Each Ring 5 quartz will have an array of 28 HVMAPS (7 x 4) attached perpendicular to the quartz
- Separate enclosure containing the HVMAPS will be mounted to the Ring 5 quartz trays
- ~28 W of heat produced by each HVMAPS plane of each module; need to flow chilled air over HVMAPS to keep them cool
- Kapton film on enclosure will help protect HVMAPS, as well as aid air flow across them

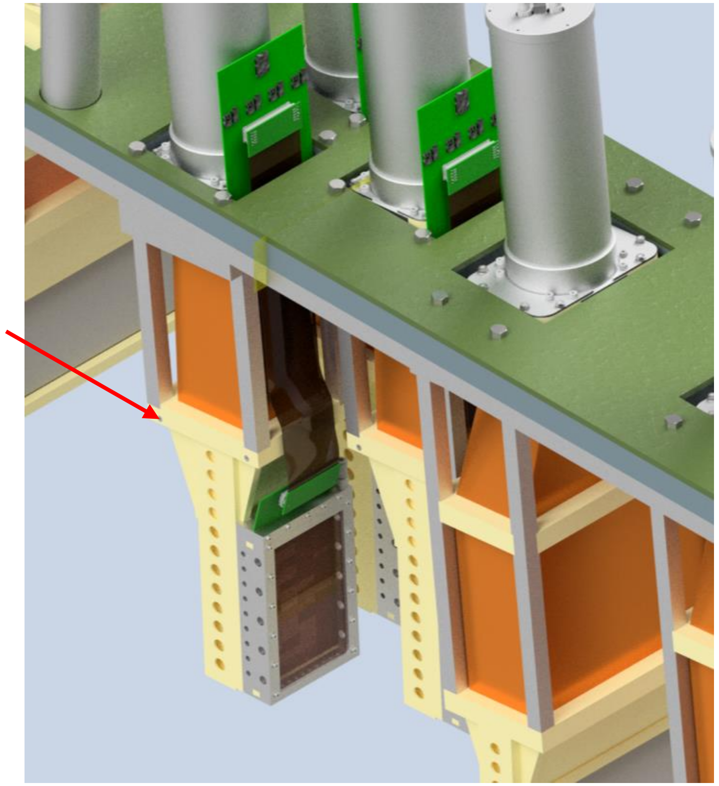
Compton Polarimeter

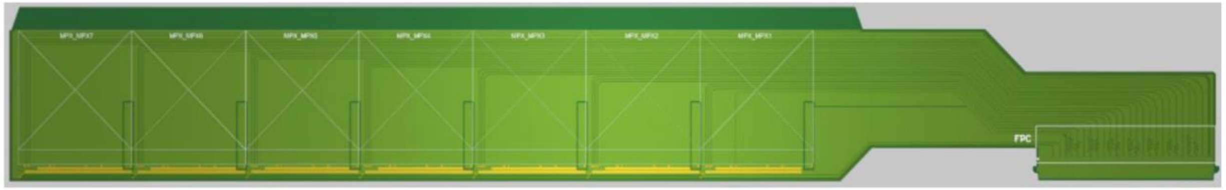
- Design 4 planes of detectors using HVMAPS with each plane having a 6 x 2 = 12 cm^2 detectable area
- Each plane will have 3 HVMAPS bonded to a metal-core PCB
- Detectors will be under vacuum, so need to implement cooling system to keep HVMAPS below 50 degrees Celsius
- (~12 W of heat generation expected)
- Integrate the cooling structure into the mounting structure and assembly
- Use conduction as main method of heat transfer away from source (HVMAPS)

HVMAPS Enclosure for Ring 5 Modules





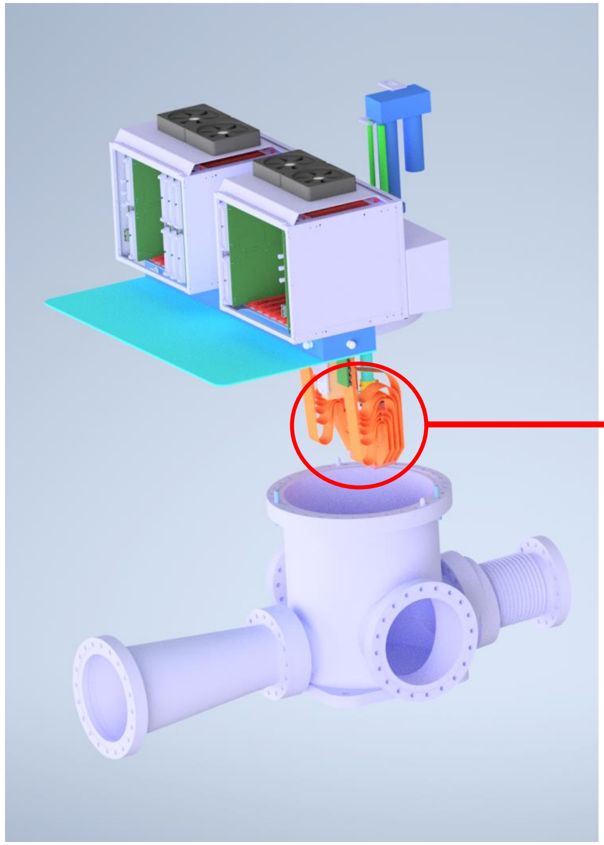


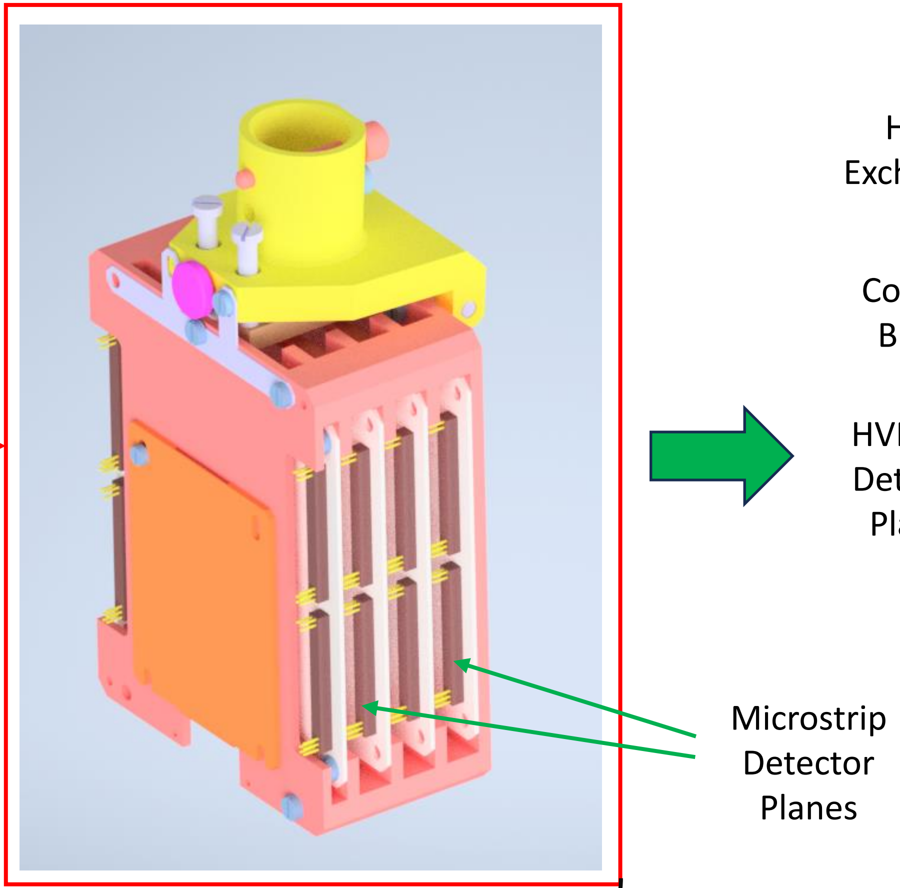


Flexprint (by Jie Pan)

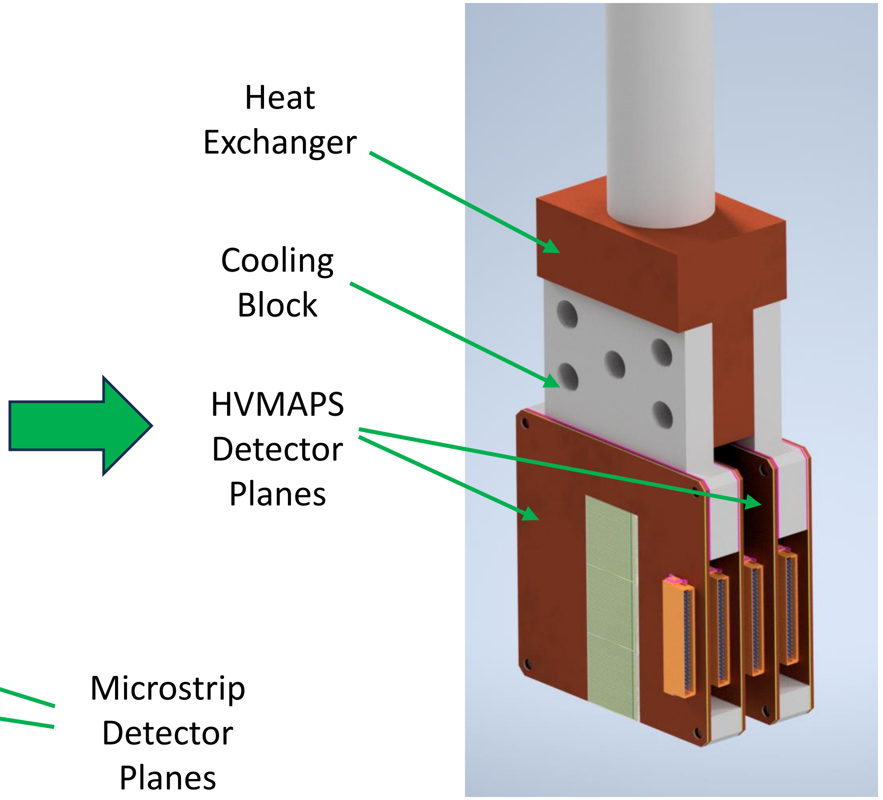
CAD by Kristofer Isaak, University of Manitoba

HVMAPS for the Compton Polarimeter



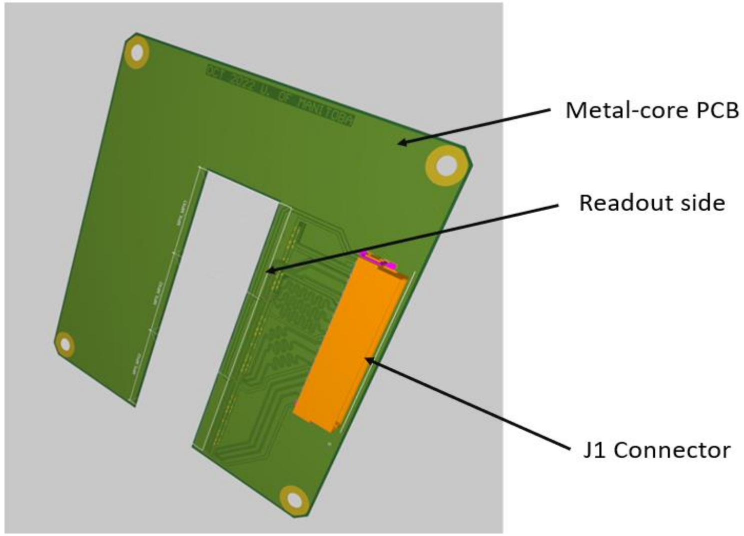


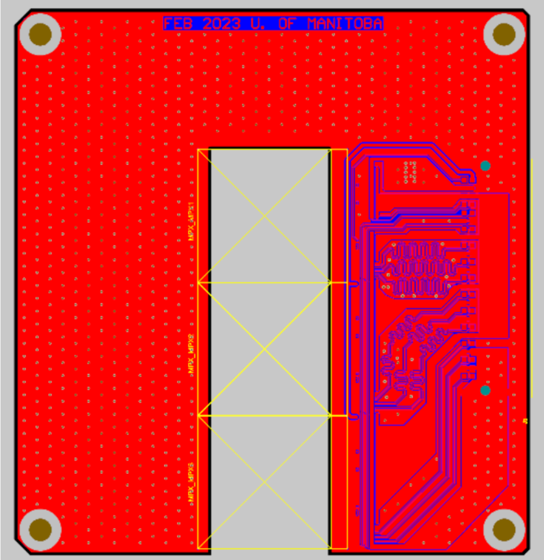
Existing microstrip detector planes

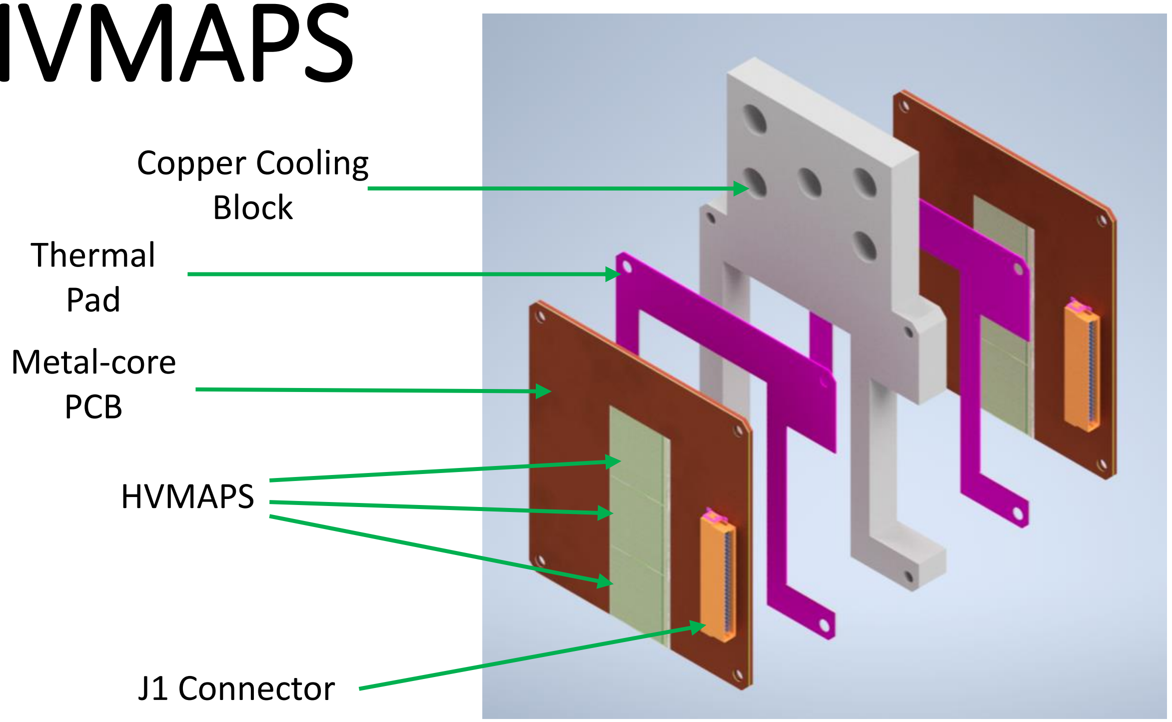


New HVMAPS detector planes

Metal-core PCB for HVMAPS

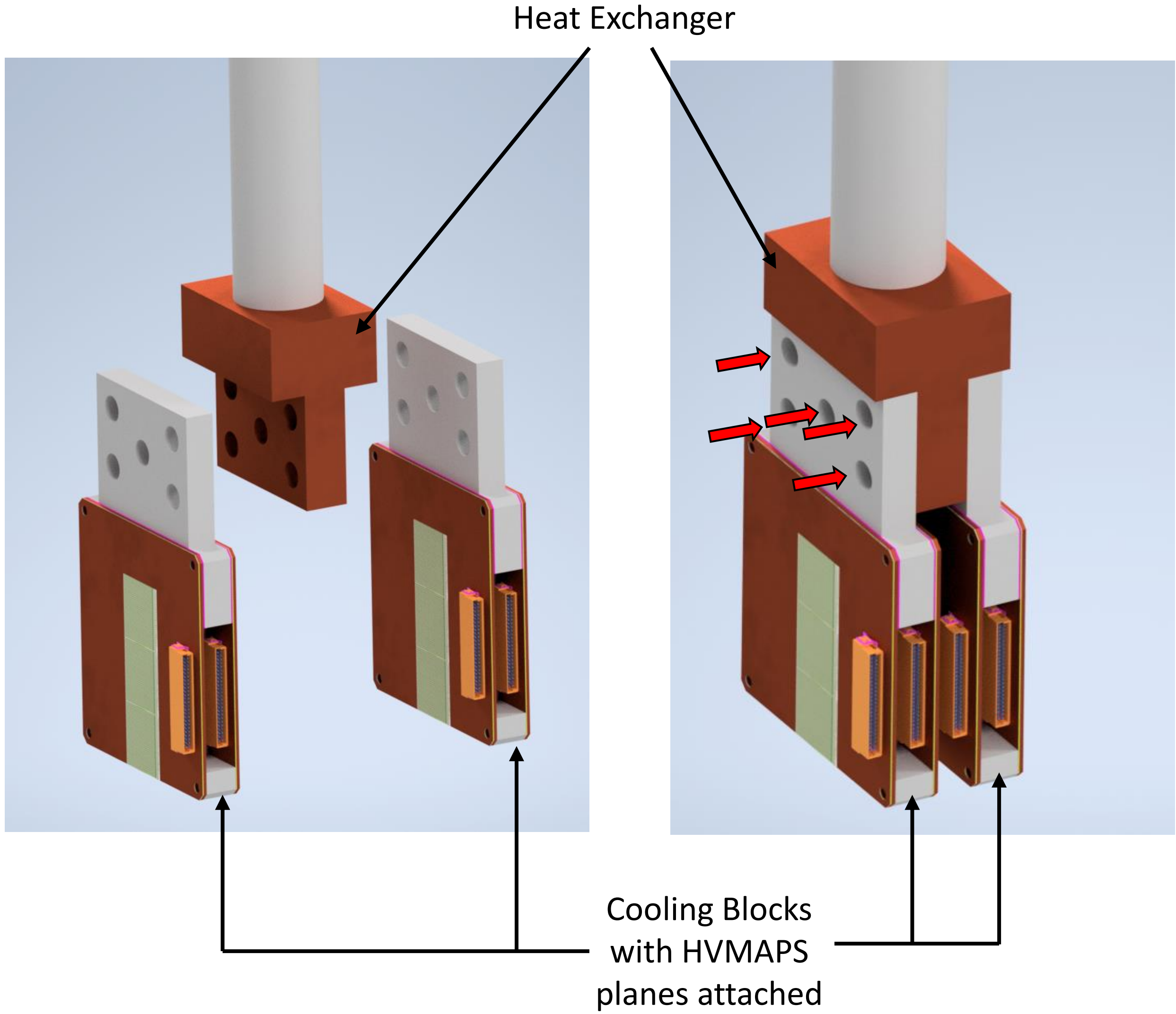


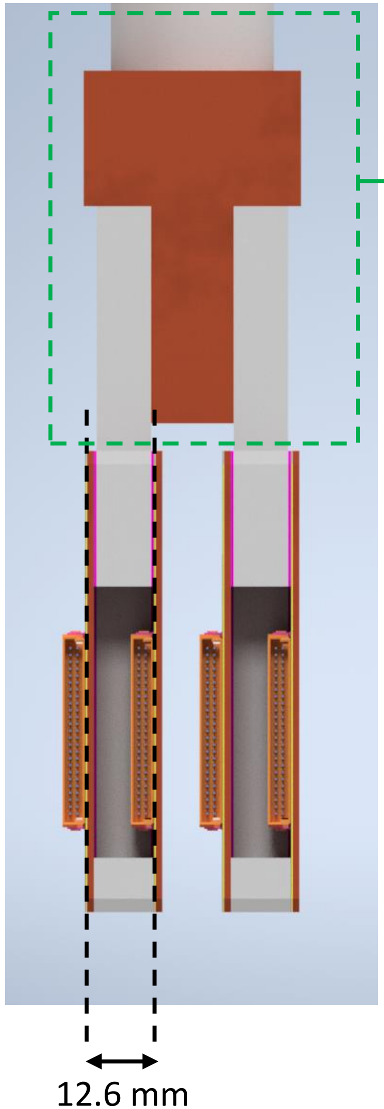


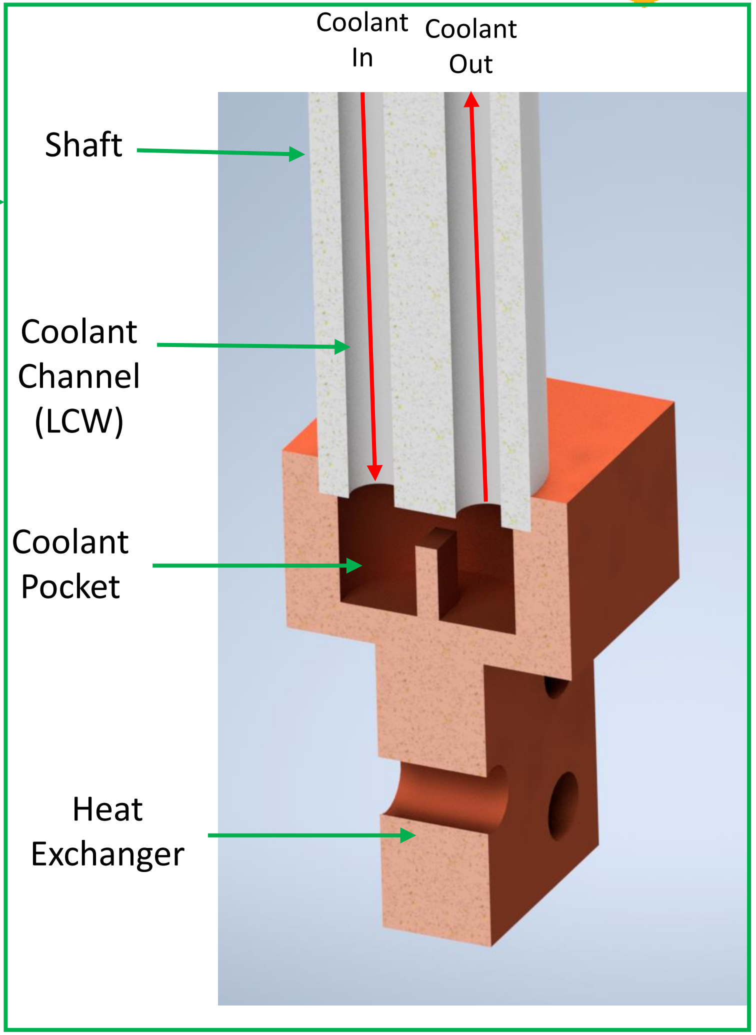


- PCB designed by Jie Pan, University of Manitoba
- HVMAPS will be glued and wire-bonded to the PCB
- Metal-core PCB will help conduct heat produced by the HVMAPS away for dissipation
- Exploring the idea of using thermal pads to improve thermal conduction between metal-core PCB and HVMAPS

Cooling Blocks and Heat Exchanger

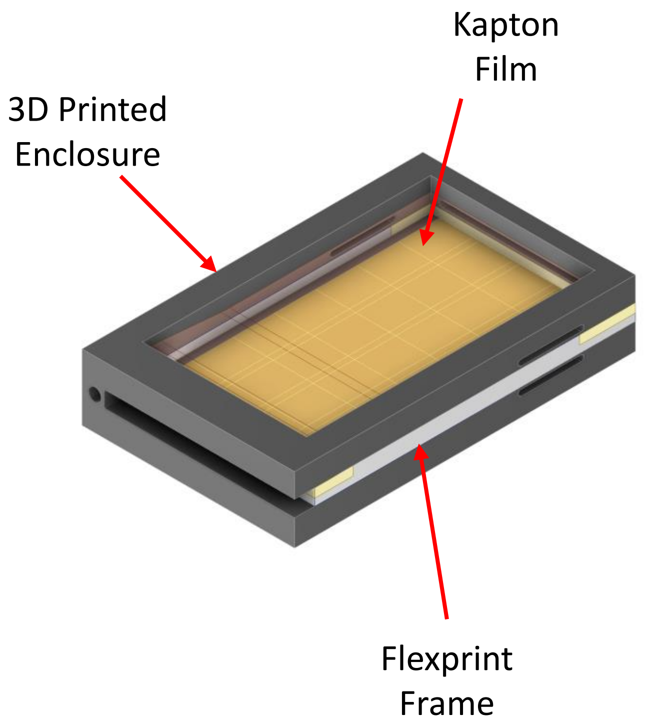


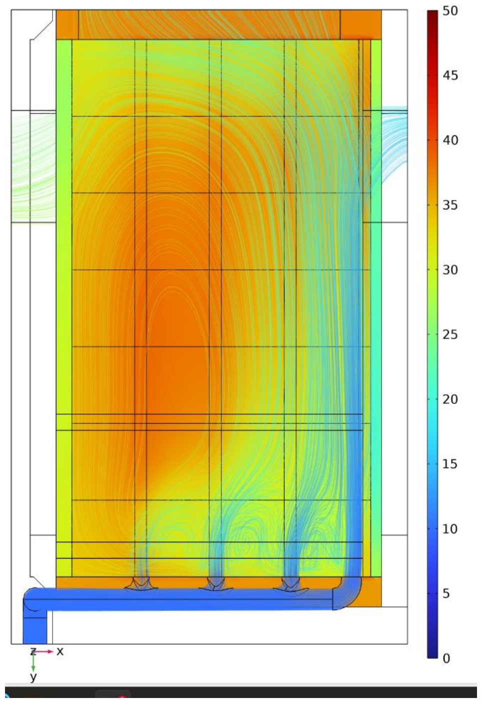




Thermal Simulations

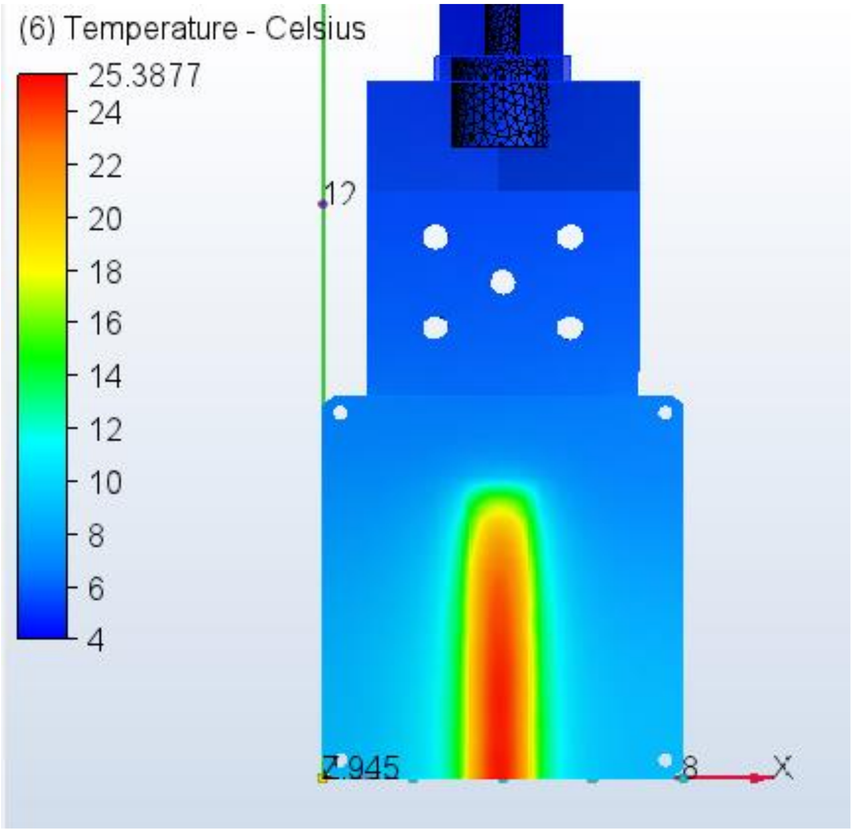
Ring 5 HVMAPS Enclosure





Temperature distribution of Ring 5 HVAPS enclosure
(Kristofer Isaak, U of Manitoba)

Compton Electron Detector Plane



Temperature distribution of Compton HVMAPS planes
(Shefali Prabhakar, U of Manitoba)

Thank you. Questions?