Development of a Novel Magnet for the HAICU Hydrogen Fountain

Undertaken at TRIUMF and UBC

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Motivation for a Novel Bitter Coil

- Atomic Hydrogen can be trapped via its magnetic moment (very small!)
- Doppler laser cooling limit is ~10mK
  - Too high energy for atomic fountain techniques (expansion)
- Create a large trap depth with high field gradients
  - Higher catching efficiency
  - Ideal trapping volume for compression
- Provide 3 dimensional optical access
- Remove cryogenic risks

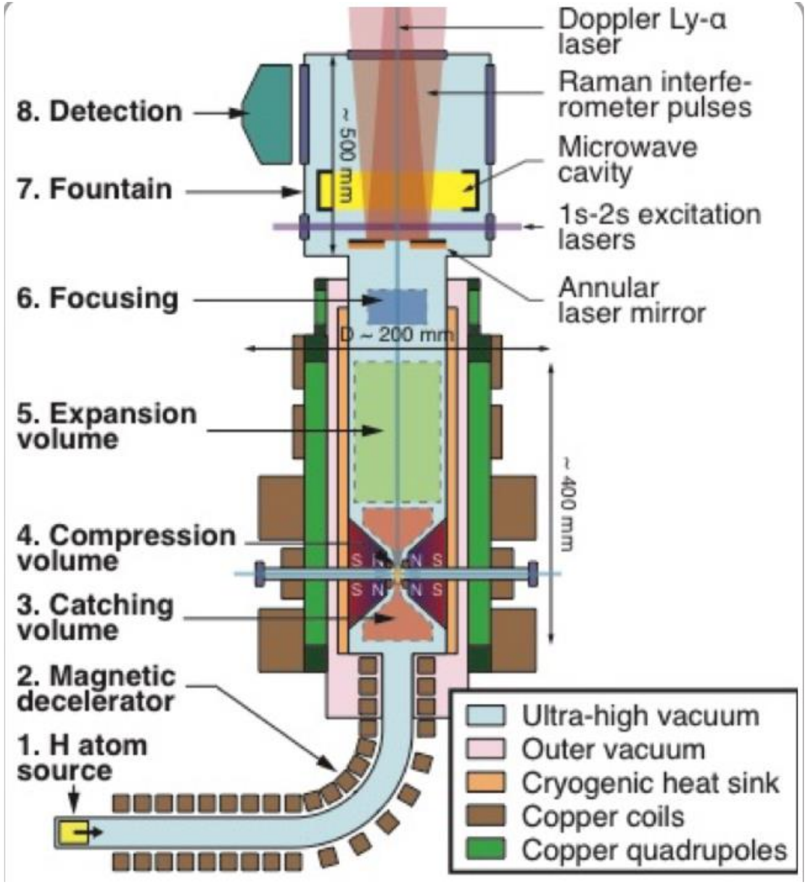
What is HAICU?

- **Hydrogen-Antihydrogen Infrastructure at Canadian Universities**

  - Next generation of ALPHA - reduce systematic errors [B-field gradient and Transit line broadening]
  - A proposed H experiment using H as a proxy
  - Atomic fountain - interferometry and Raman spectroscopy
  - A space for implementing and developing new atomic cooling techniques (Laser Cooled Magnetic Expansion Cooling)
  - Led by Prof. Makoto Fujiwara and Prof. Taka Momose

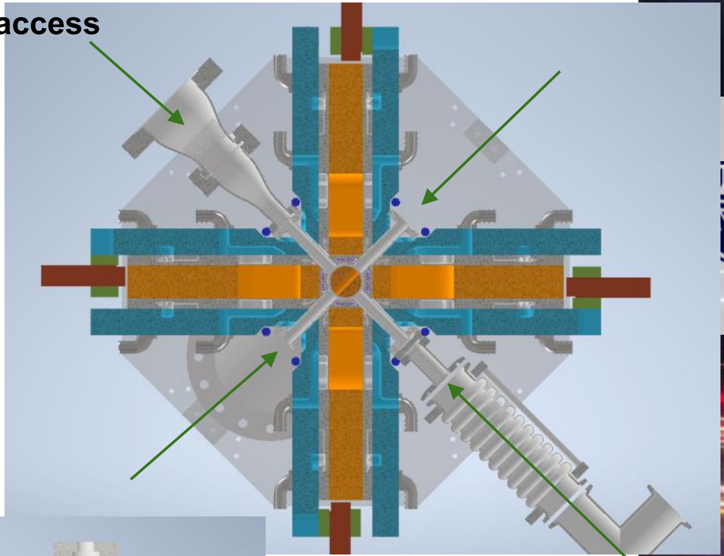
Prototype design

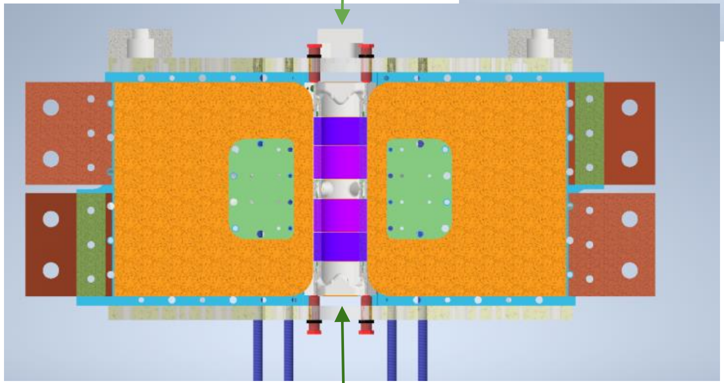
- Hydrogen Zeeman decelerator
  - Momose group @ UBC
- Magneto-optical trap
  - Chukman So et al. @ TRIUMF
- Optical system
  - UBC, TRIUMF and SFU
  - Lyman-α and probe lasers (243nm etc.)
- Detection
  - MCP and SiPM
  - Andrea Capra and Lars Martin @ TRIUMF



The Magnetic trap (phase 0)

- ❑ Ioffe-Pritchard trap style
- ❑ Mirror coils (4 magnets [purple]) for axial trapping
- ❑ Quadrupole (4 magnets [orange]) for radial trapping
  - ❑ 0.6T @ 2160A
- ❑ Trap depth of 0.15T
- ❑ 3-axis optical access
  - ❑ Laser cooling (121nm) [green arrows]



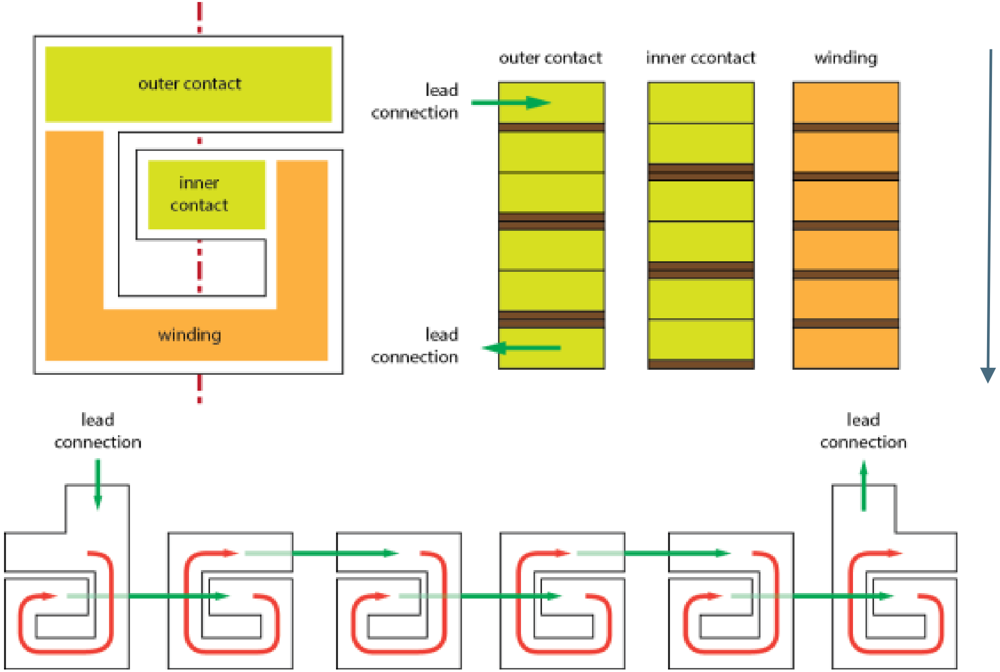


Designed by
Chukman So

Quadrupole

- ❑ Bitter type coil design
  - ❑ No cyrogenics
  - ❑ More optical access
- ❑ Water cooled (2L/s)
  - ❑ 196 coolant holes (9.04W/s per hole)
  - ❑ 100 PSI of water
- ❑ 22 copper layers
  - ❑ 20 PFA layers (0.05” thick)
  - ❑ 2 PEEK layers with RVT
  - ❑ 2 3D printed distribution blocks
    - ❑ Viton™ gasket
  - ❑ 2 Stainless steel compression blocks

Quadrupole



Water direction

Red indicates the direction of the current

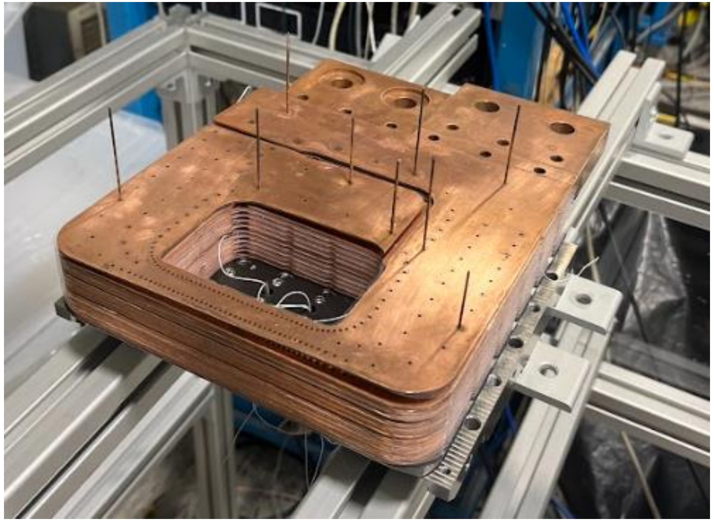
Quadrupole - Testing

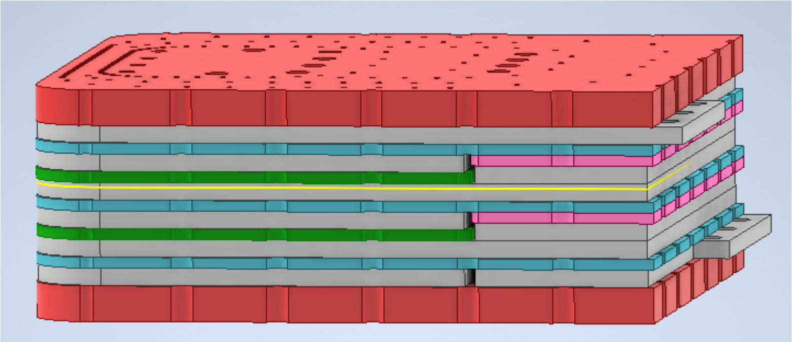
- 3D printed stainless steel block
  - 10 inlet/outlets to 196 holes
- Flow testing for blockages
- Dealing with porosity
  - Sealed with Loctite 294
- PEEK provides a poor seal
  - RTV is applied in a thin layer providing a significant improvement

Top image - 3D printed block (machined by the Calgary machine shop), orange is RTV
Left image - Seepage through the porosity

Quadrupole - Construction

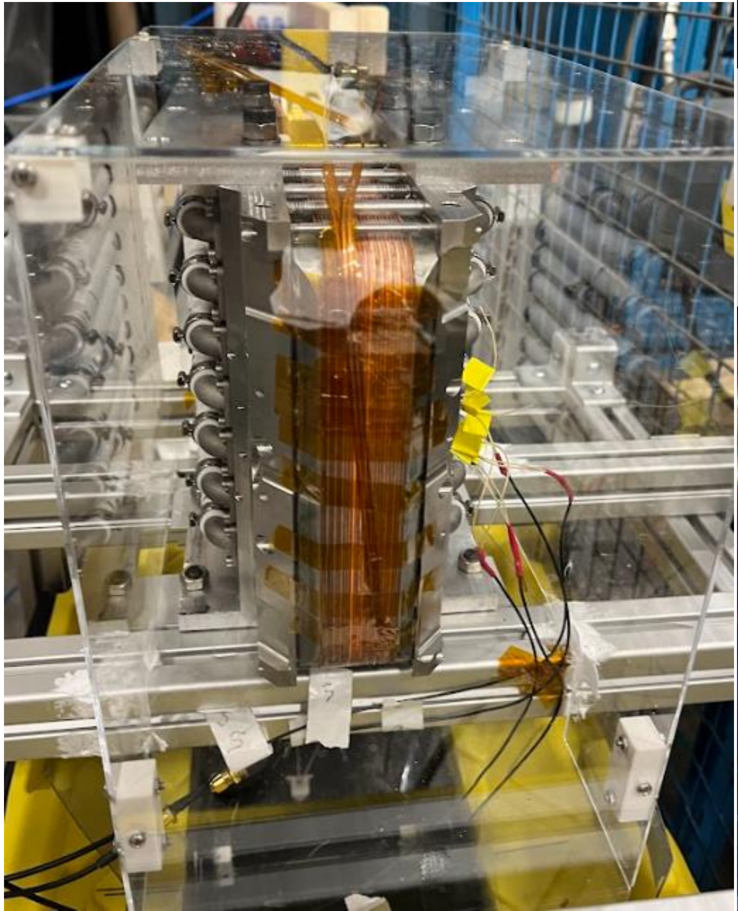
- 22 copper layers
  - 2 layers with copper tabs for the busbars
  - 20 alternating layers
- 20 PFA layers
  - 4 different patterns to form the sheets into a coil - Pattern A [Pink], Pattern B [Blue], Pattern C [Green], Pattern D [Not seen]
- 7 Thermistors placed on the internal cavity and face
  - Epoxied to the copper sheets (layers 10-12)





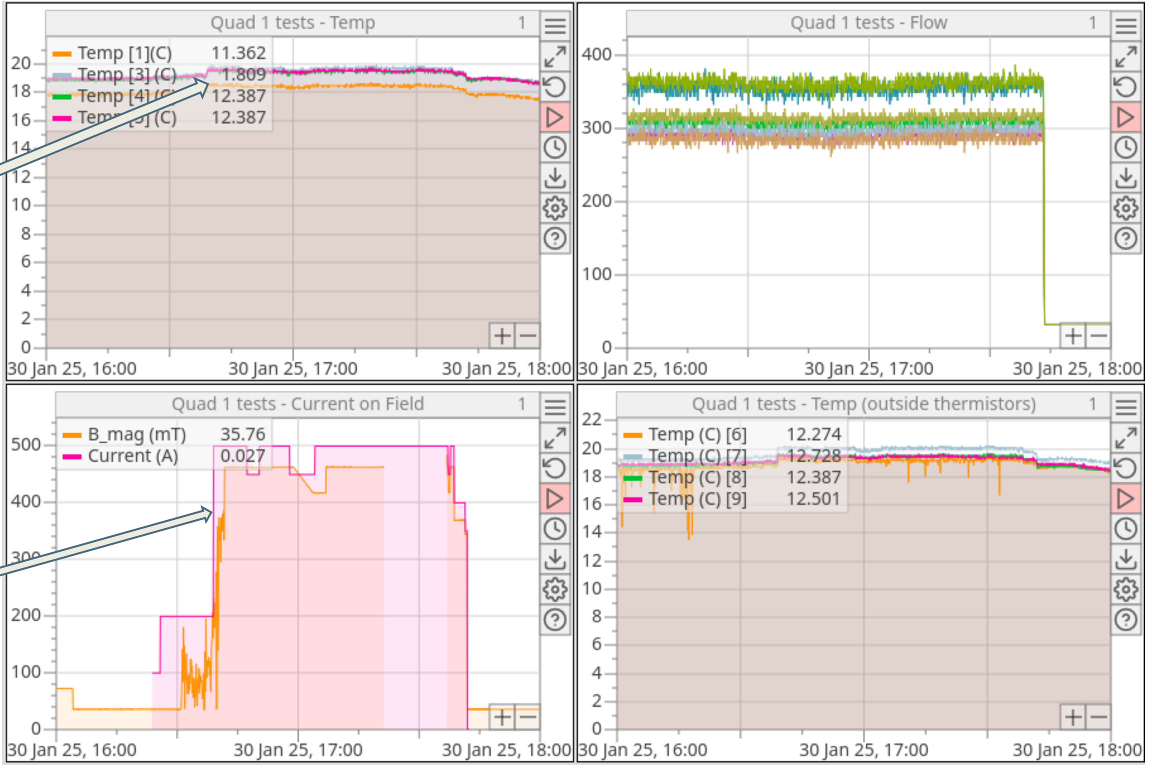
Quadrupole - Commissioning

- Testing structure
  - Hold the 25KG magnet
  - Stop water leakage (prone to leaks)
  - Meet safety standards
- Water manifold
  - Monitor flow rate to each section
  - 2L/s
- Temperature monitoring
  - Internal and external thermistors
- B-field
  - Static (long term stability)
  - Mapping (comparison to simulation)



Quadrupole - Commissioning

Temperature increase of 1C @ 500A



Field changes with applied current

Future endeavours for our HAICU

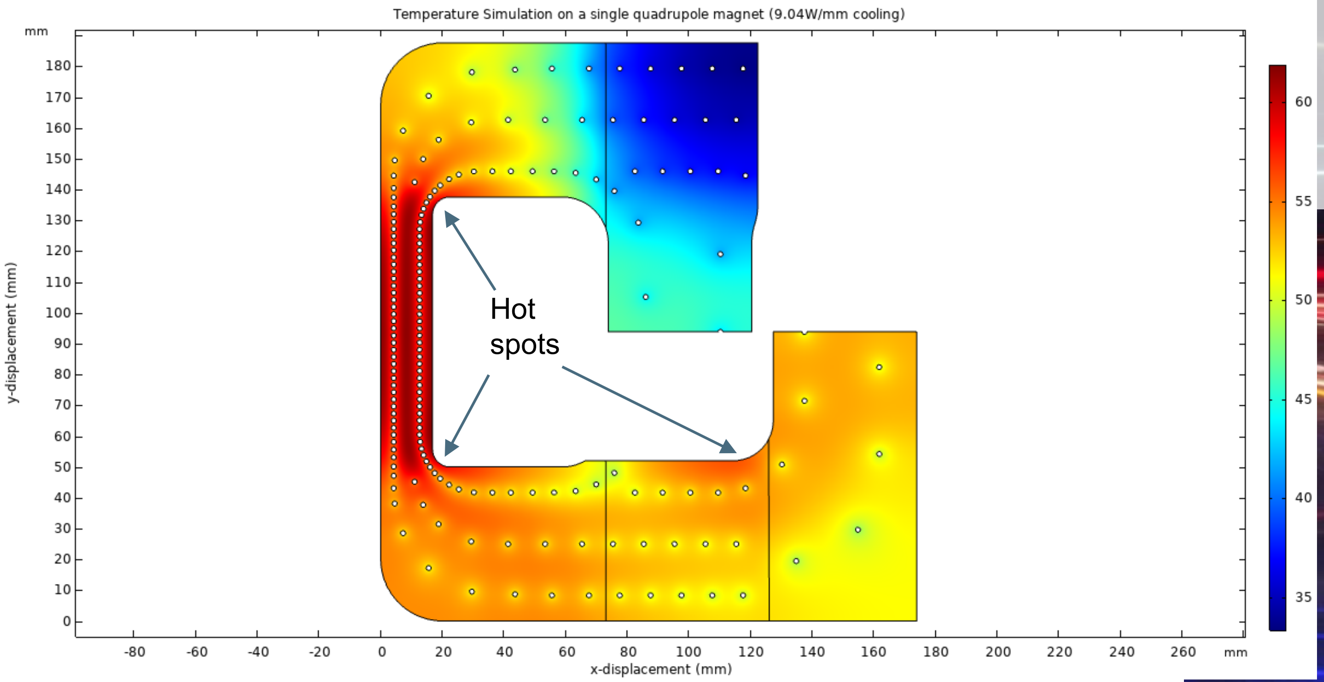
- ❑ Phase 0
  - ❑ Trap and detect H (ionisation)
  - ❑ Laser cool (1D)
  - ❑ Learn the needs for future renditions
- ❑ Phase 1 and onwards
  - ❑ Laser cool (3D)
  - ❑ Laser Cooled Magnetic Expansion Cooling
  - ❑ 2S population pumping
  - ❑ 2S - beyond spectroscopy

Thanks for listening!
Any questions?

Supplementary slides

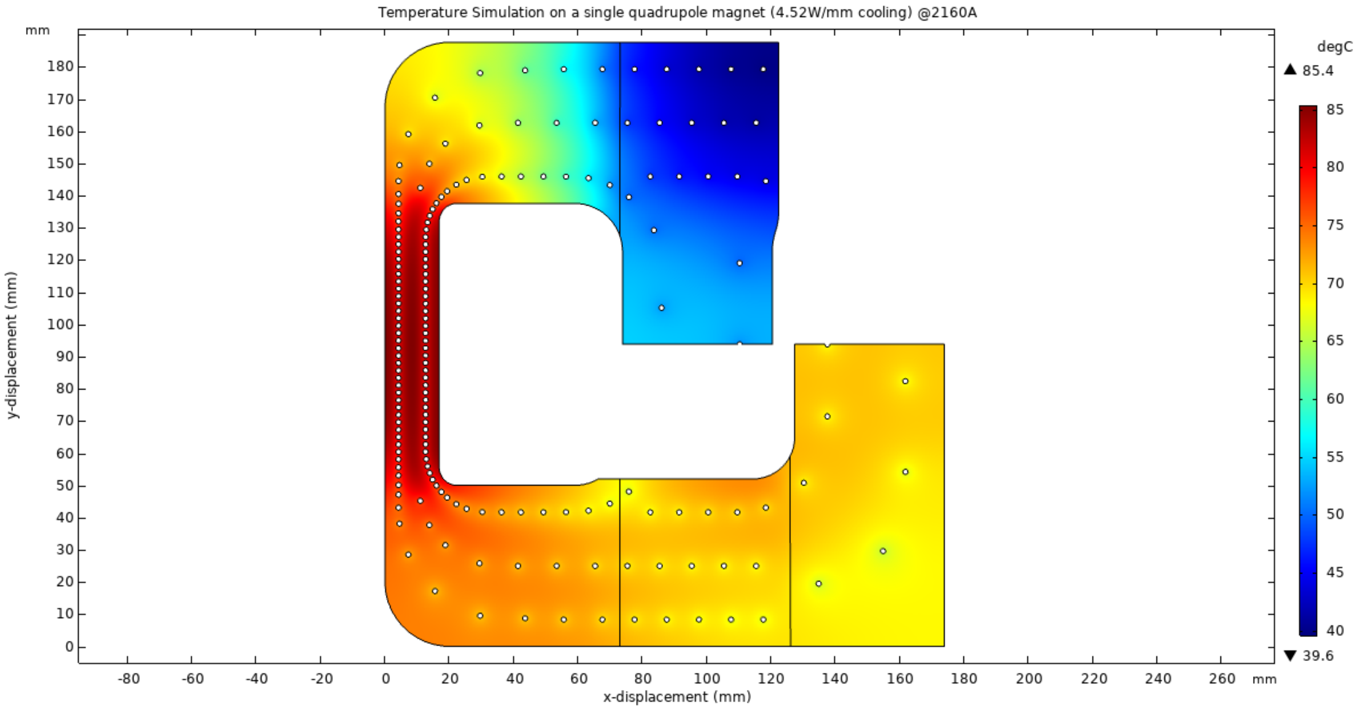
Quadrupole simulation -Thermal (full flow)

- 30C water
- 65C max temperature at full flow
- 2160A at optimal
- Each hole is required to remove 380.6W



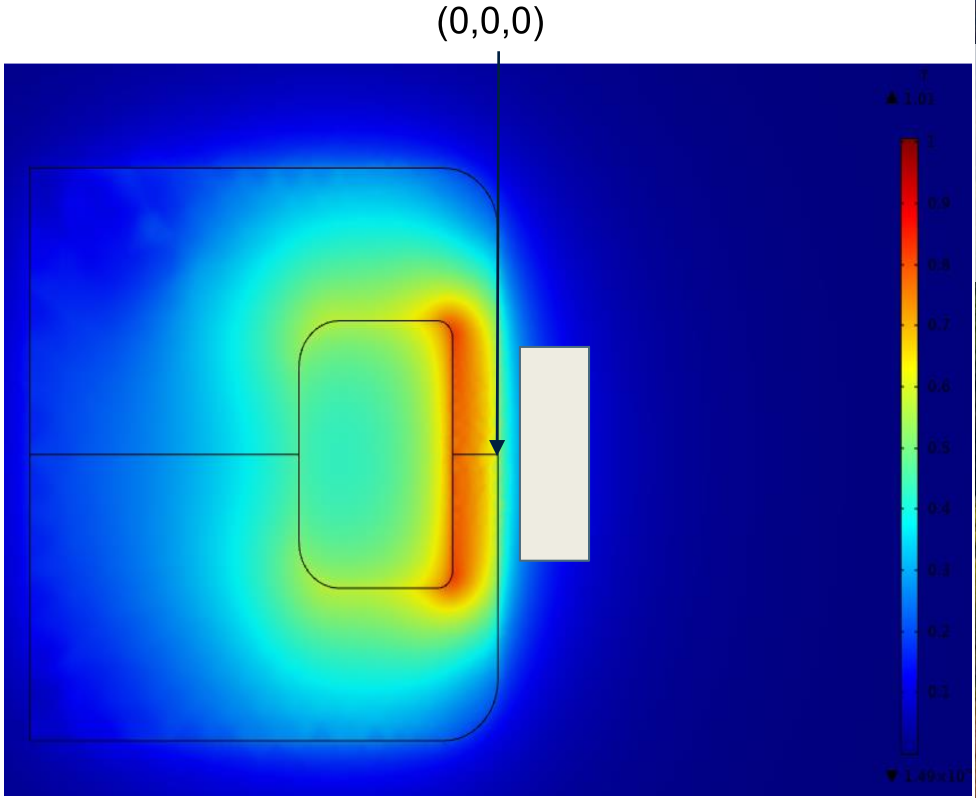
Quadrupole simulation -Thermal (half flow)

- 30C water
- 85.4C max at half flow rate
- 2160A at optimal
- Materials chosen to withstand 250C



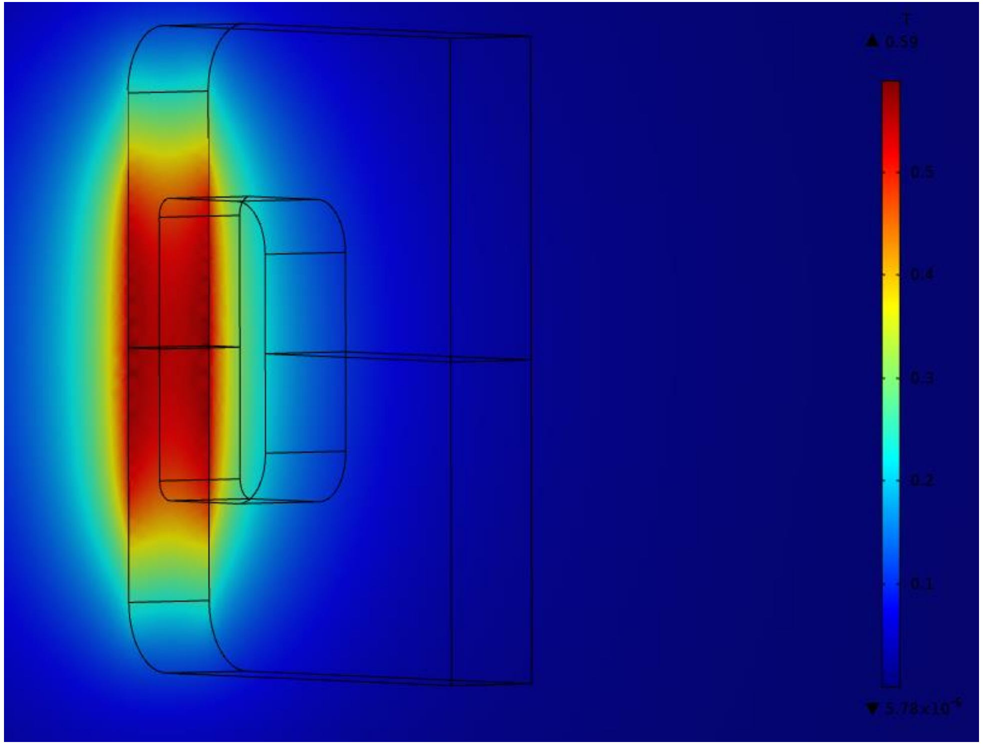
Quadrupole simulation - B-field

- ❑ Each pole generates a strong "valley" like background field in the trapping volume [white square]
- ❑ This geometry in quadrature and with an imposing coil geometry creates a trap depth of ΔB = 0.15T, or T = 200mk for H.



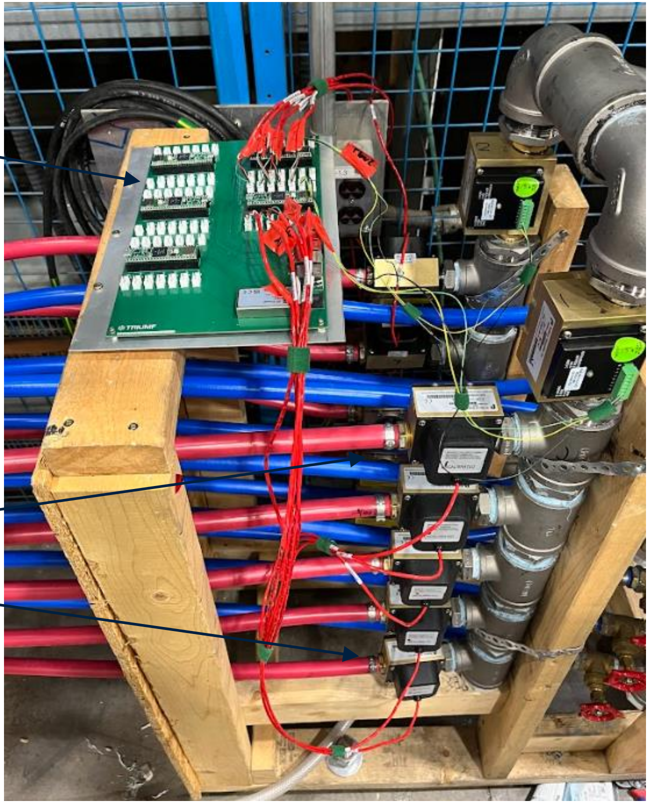
Quadrupole simulation - B-field

- Field on the magnet surface
- Edge effects leads to higher current density → magnetic flux



Quadrupole - testing (Manifold and water)

Flow monitoring board
(Designed by G.Wankling)

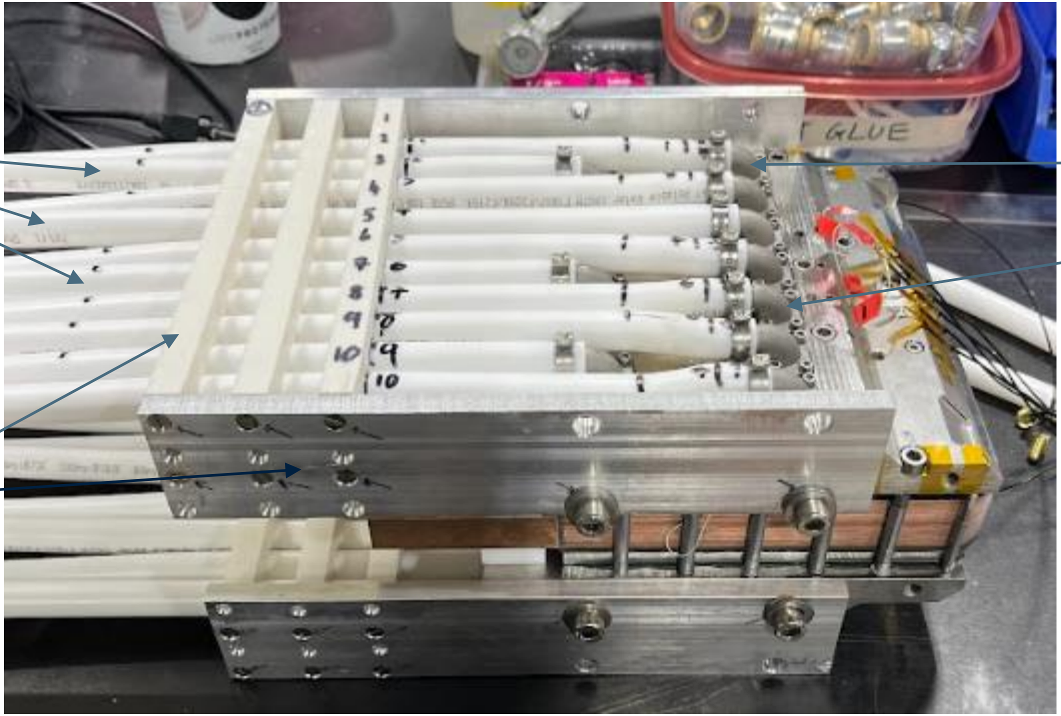


Water outlet (10 out)
(Constructed by J.Ewins and A.Kimovska)

Quadrupole - testing (Manifold and water)

PEX ⅜” tubing

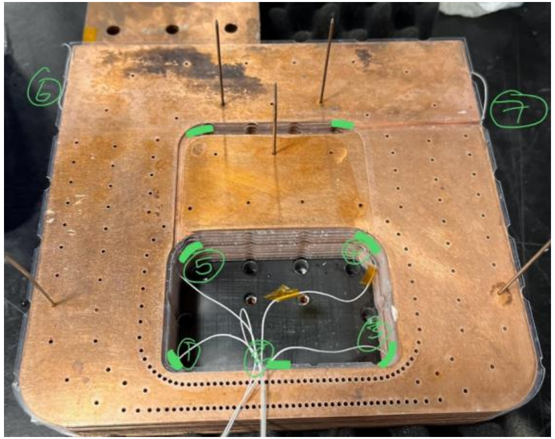
Support for tubes
(3D printed)
Designed by C.So

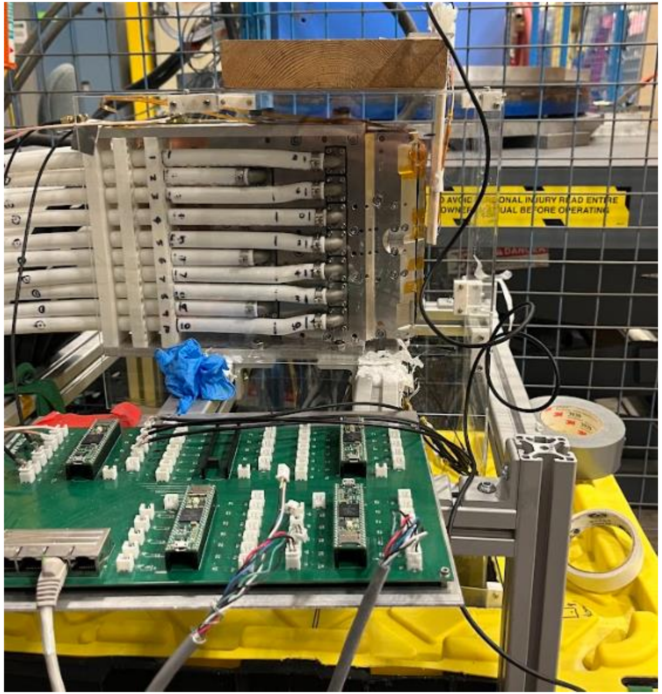


3D printed
stainless steel
elbow. Viton™
for the interface
gasket

Quadrupole - testing (Temperature)

- 7 internal and 4 external thermistors are placed
  - Multilayer NTC Thermistors - P12011CT-ND
- Teensy microcontrollers
  - Voltage dividers
  - Ethernet communication
- Python frontend → Midas





Board designed by G.Wankling

Quadrupole - testing (B-field)

- Static
  - TMAG5273 Hall effect sensor (will be replaced)
  - Arduino Nano microcontroller → USB connection → Python frontend → Midas
  - Placed (approx.) in trap center
- Mapping
  - Magnetic mapping robot (Marco Marchetto)
- Current and voltage monitoring
  - Sorensen SGX series
  - Onboard readout → Ethernet → Python frontend → Midas