Update on Cryogenic Silicon Suspension Activities at Glasgow

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Overview

- Motivation for this work
- Initial suspension design
- Suspension support structure
- Procedural assembly
- Cryogenic setup
- Cryostat interfacing + issues
- Results
- Lessons learned
- Future work

Motivation for this work

- At detection band frequencies of ≈10-200 Hz, current generation detectors are limited by thermal motion of the test masses and their suspension elements
- The equation for thermal displacement noise states [1] [2]:

$$x(\omega) = \sqrt{\frac{4k_B T}{m\omega}\left(\frac{\omega_o^2 \phi(\omega)}{\omega_o^4 \phi^2(\omega) + (\omega_o^2 - \omega^2)^2}\right)}$$

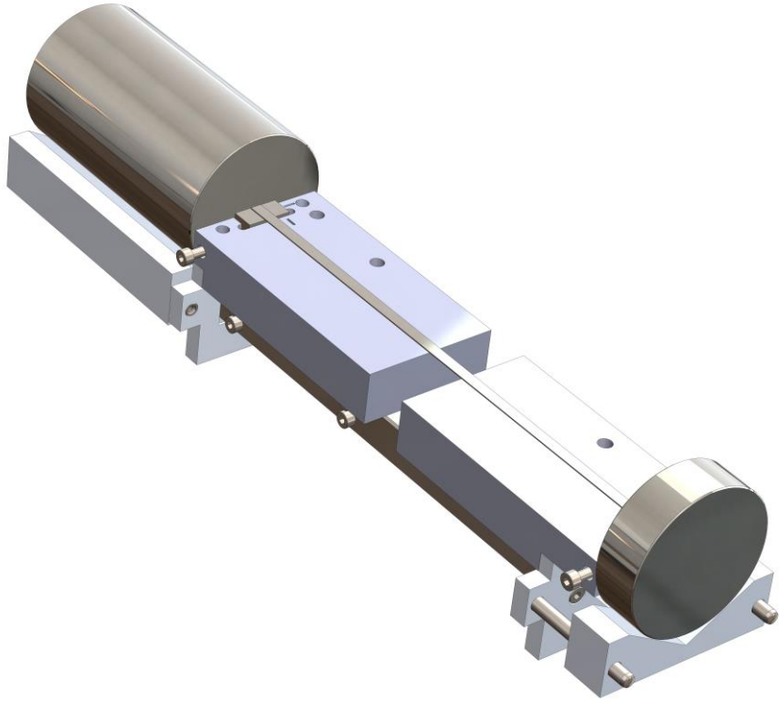
- Previous worked tackled reduction in thermal noise with low loss materials, but it is clear to see, reduction of temperature is a way of directly improving thermal noise but this is a technical challenge.
- Due to broad peak in mechanical loss of fused silica at 40K and poor thermal conductivity, need to find a new material
- Silicon!

[1] H. B. Callen, “Irreversibility and Generalised Noise”, Physical Review 83, 34, (1951).
[2] H. B. Callen, “On a Theorem of Irreversible Thermodynamics”, Physical Review 86, 702, (1952).

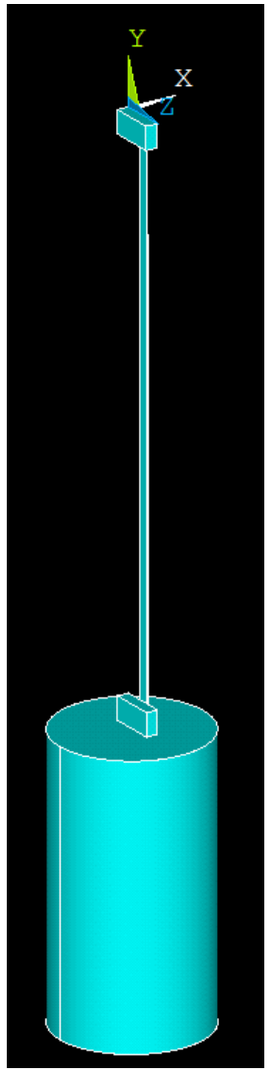
Initial suspension design

- Stage 1 – multi-material
  - What can we realistically build?
  - CTE mismatches
  - Glue
  - Timescales
- Stage 2 – Quasi-monolithic silicon
  - Hydroxide catalysis (HC) bonded
  - Polishing and cleaning
  - Tight tolerances
  - Not trivial!

Aluminium fuse end, glue and silicon



Hydroxyl catalysis bonding jig



Proposed final suspension design

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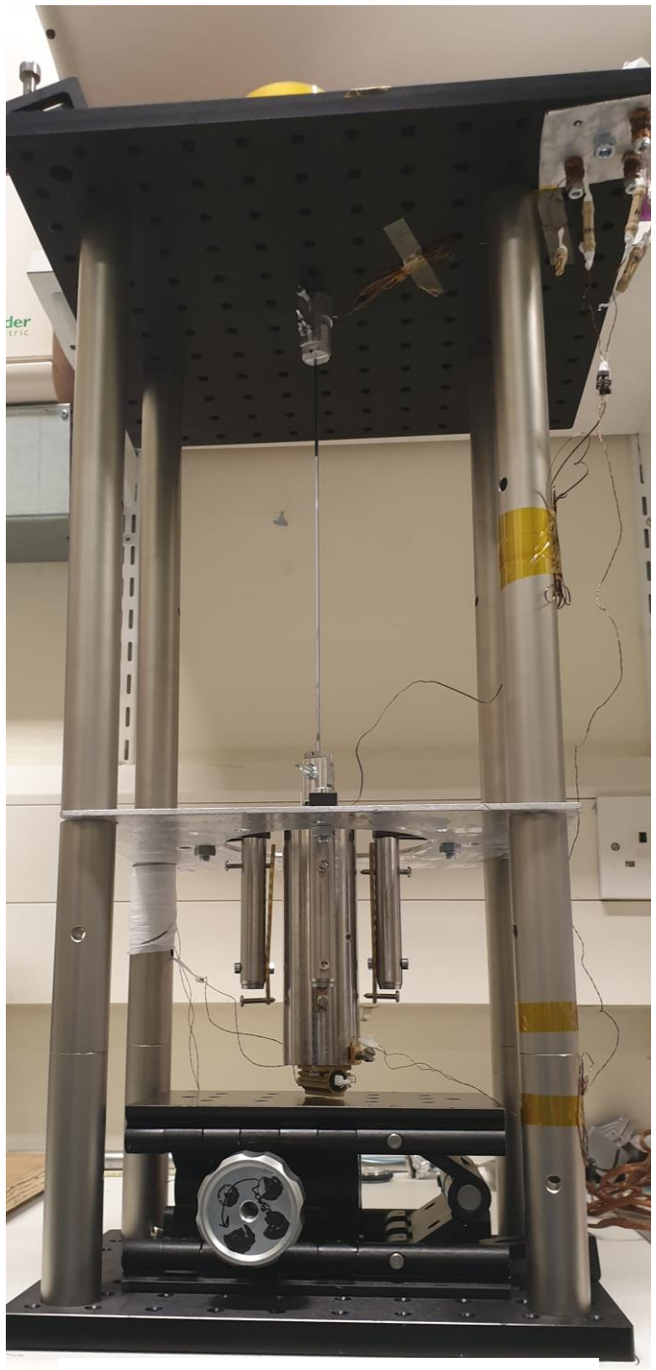
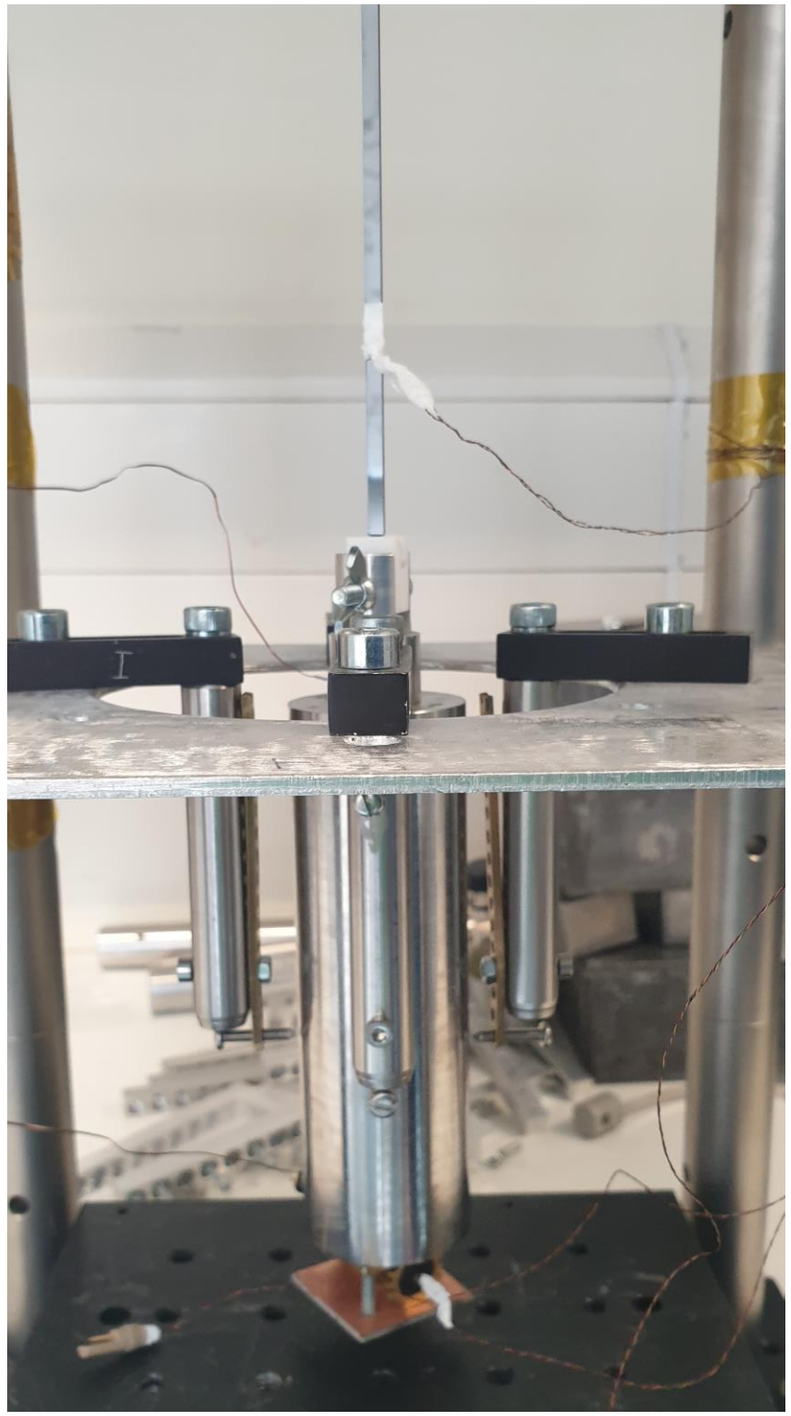
Suspension support structure



Stage 1 build

Ribbon attachment



Stainless steel mass and end stops

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Procedural assembly

- Development of procedures covering:
  - Handling, gluing and curing ribbon in fuse ends
  - Transporting of cured ribbon
  - Installation of ribbon into suspension structure
  - Hanging of mass + testing
  - Locking up and transportation of suspension
  - Interfacing with cryostat
- Developing new procedures for HC bonded suspension

Ensure gloves are worn, where necessary wear ESD wristband also.

- Ensure the lab is clear of any major obstructions between the desk and the cryostat head.
- Ensure the cryostat head is clear and all cables are tidied/taped clear of aluminium standoff plate.
- Ensure all temperatures sensors, heaters and other electronics are attached before hanging mass – including 6x sensors to LEMO bobbins.
- Check all cables on suspension are tidied/taped clear of any interference with suspension or ribbon interface.
- Check positions of fuse ends and mass are aligned correctly.
- Use the aluminium ribbon to aid in alignment.
- Lock up mass tight. Tighten bottom stops first, then top.

Hanging the mass

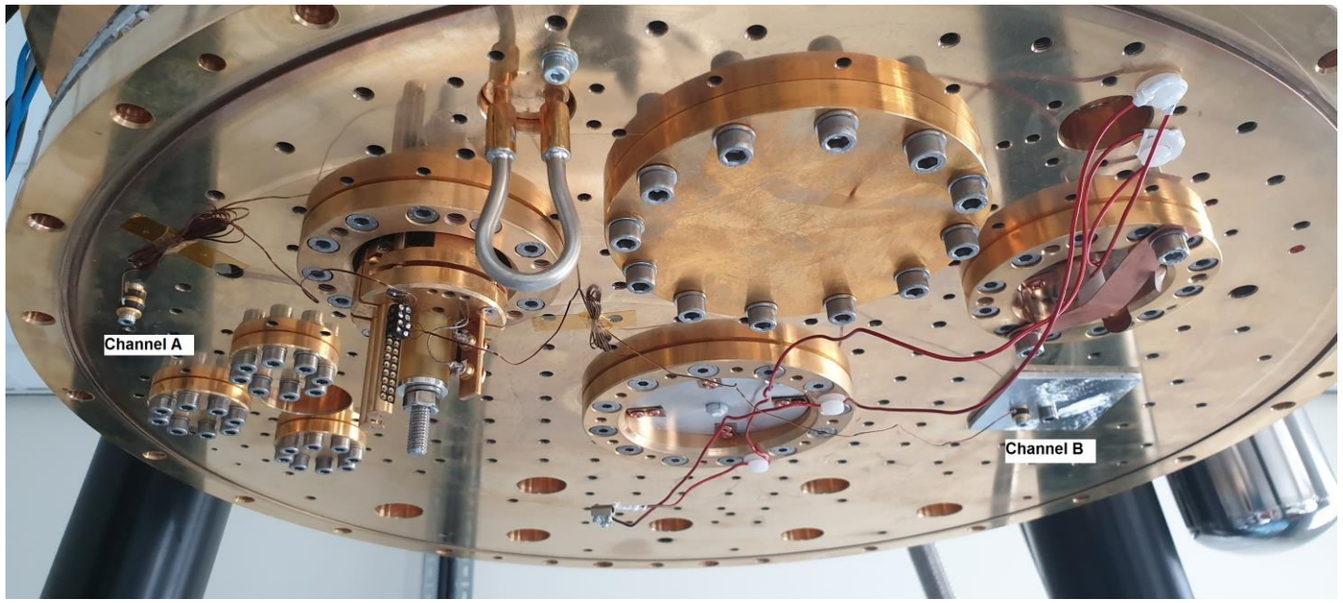
- With the mass locked, install the ribbon. This is a 2-person job.
  - The person holding the ribbon concentrates solely on the top fuse end. The second observer checks for ribbon clearance at the bottom and is in charge of the securing bolts.
  - Start by taking the ribbon in through a wire-free clearance – the back may be best. Without touching the ribbon, grip the rounded ends of the top fuse end. Concentrating solely on the top, while the second observer watches for clearances, insert top fuse end into top fuse end on the ceiling.
  - Second person inserts bolt through.
  - Once bolt inserted, first person adds wing nut to top bolt (a few threads are sufficient)
  - If bottom fuse end is not automatically in correct place, rotate the mass (not the ribbon) until alignment is sufficient for bottom fuse ends to marry.
  - If height is not correct, slowly adjust lab jack to correct position for bottom bolt.
  - One person inserts bolt and holds, while the other wing nuts.
- Now retract all end stops, top stops first, then bottom, with 1 complete turn of the screw.
- Don safety glasses. Slowly retract lab jack to let ribbon hang – this will allow the mass to settle centrally.
- Check all 8 end stops – slowly retract all top stops first, then bottom stops to free the mass.
- At this stage, minimise the mass movement by gently contacting mass and bringing it to rest

Cryogenic setup

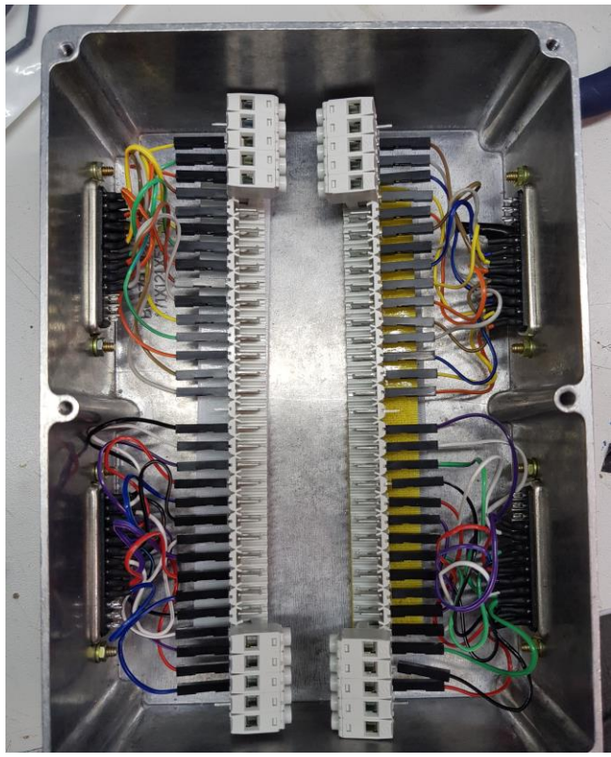
- Leiden Cryogenics cryostat
- Cryogen-free (closed-loop helium)
- Large experimental space:
  1000 mm x Ø 504 mm (≈ 0.2 m^3)
- Optical windows and large sensor capacity for characterisation

Disassembled cryostat

Cryostat cold plate

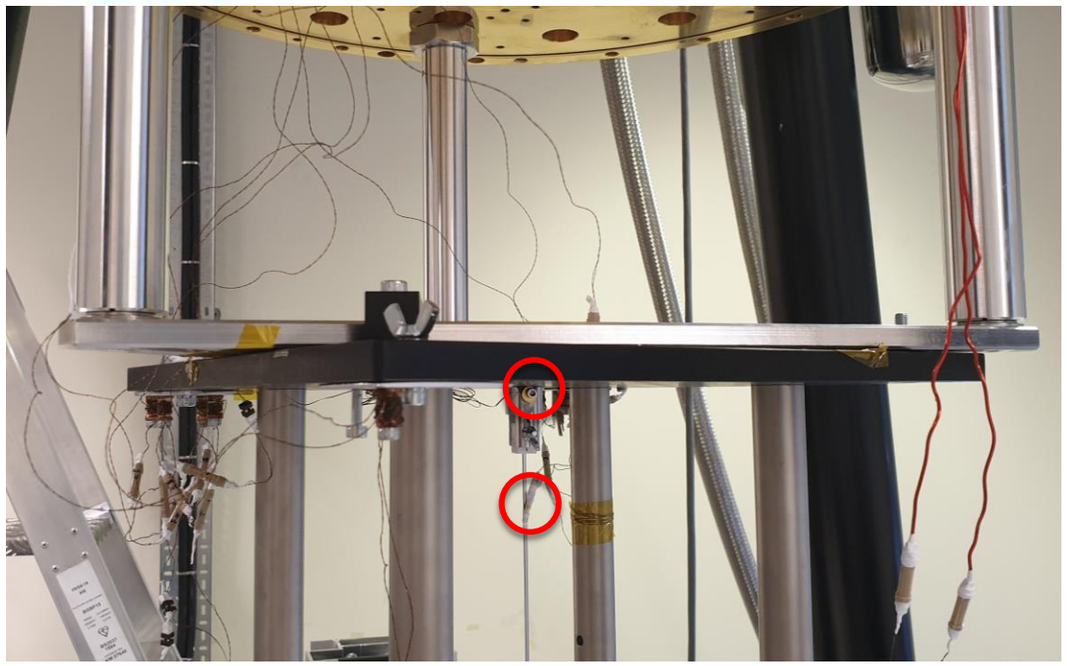


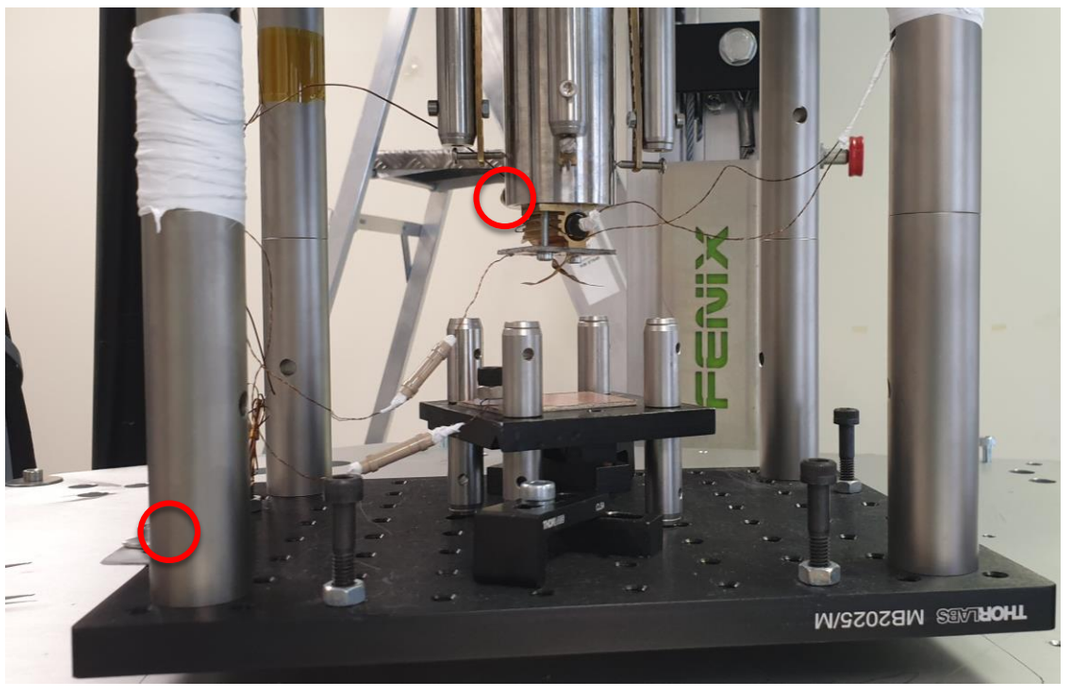
Closing up cryostat – 50K shield shown with lifting pincers

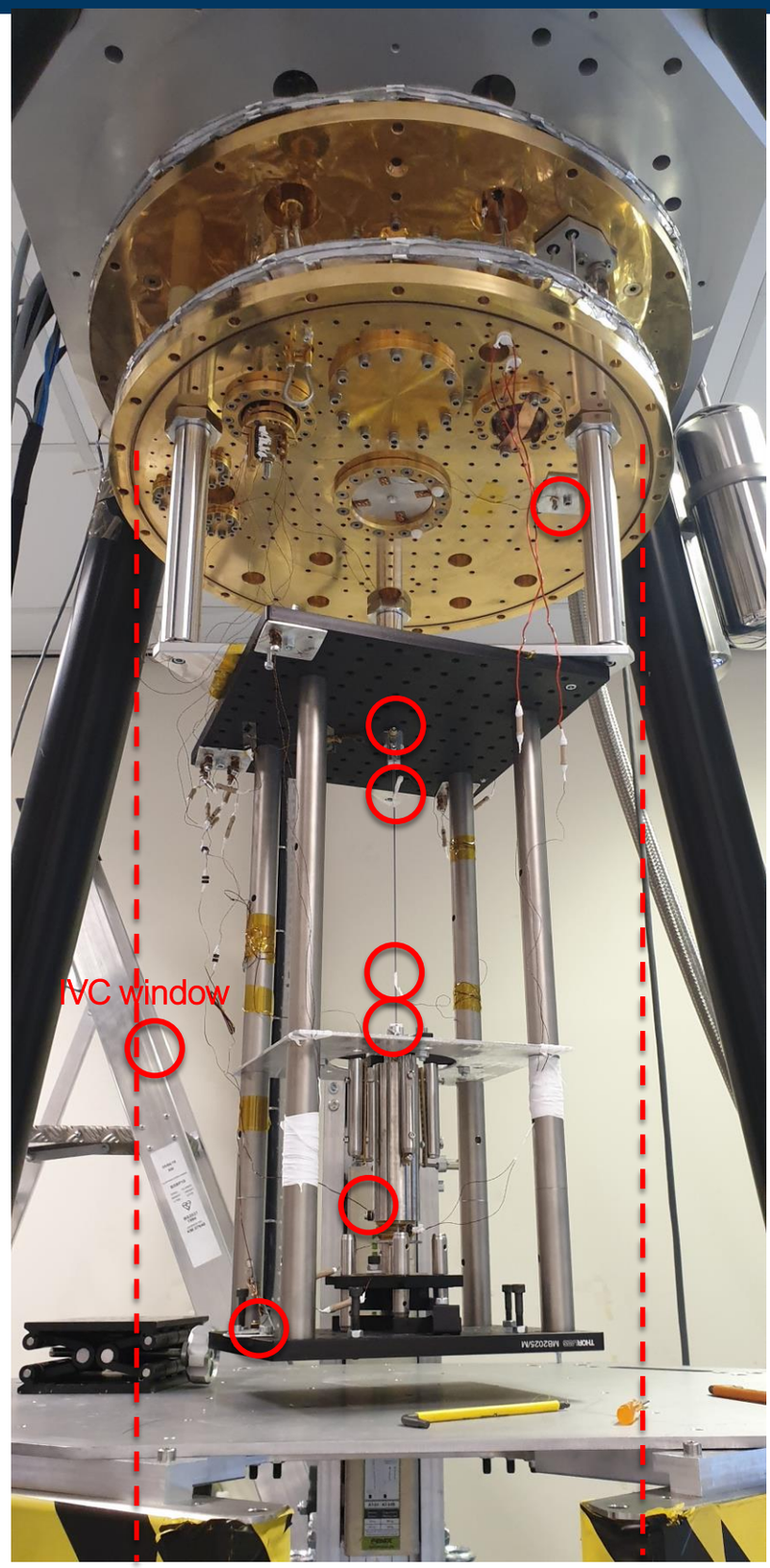


Custom plug and play sensor box

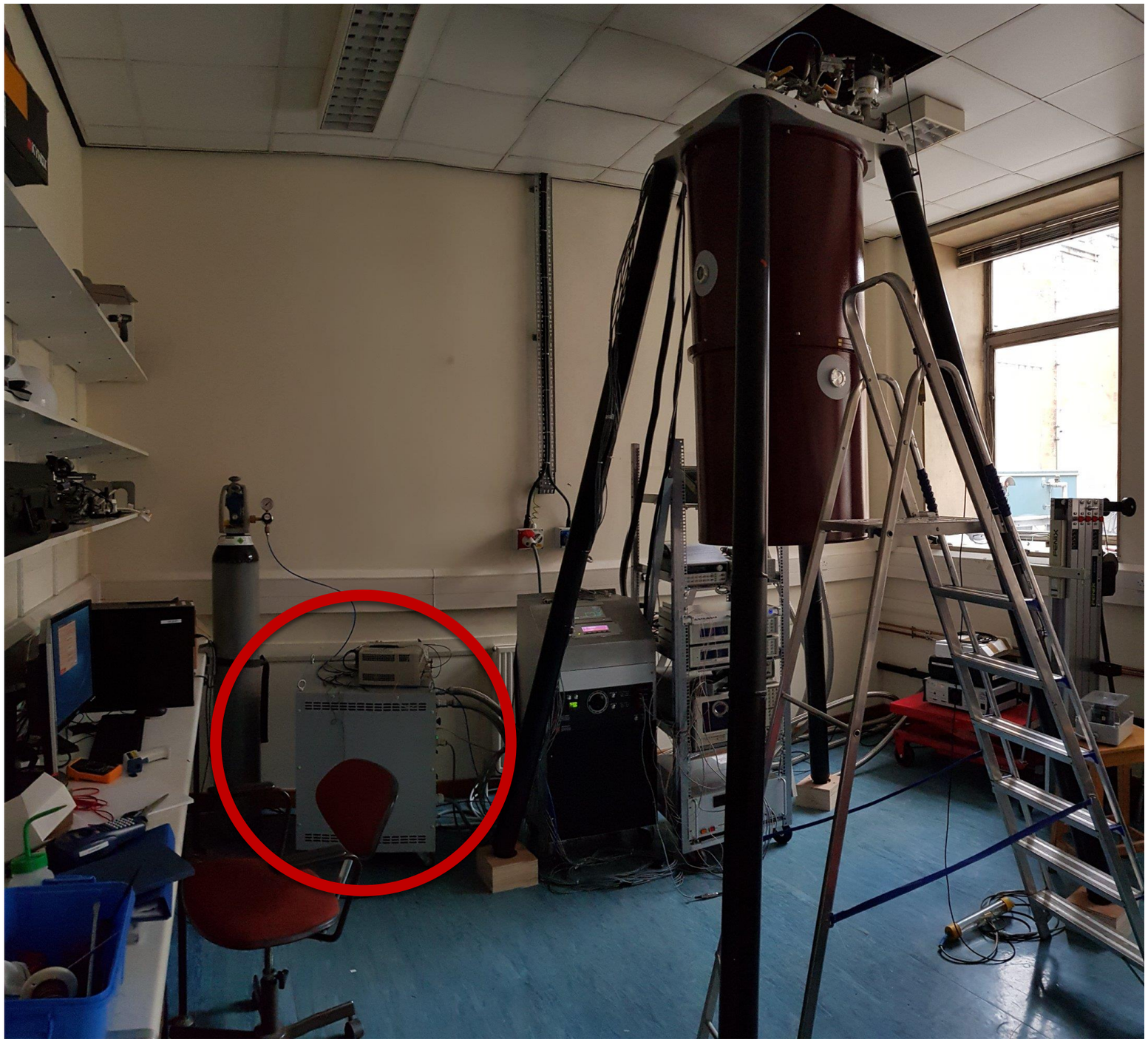
Cryostat interfacing







Cryostat issues

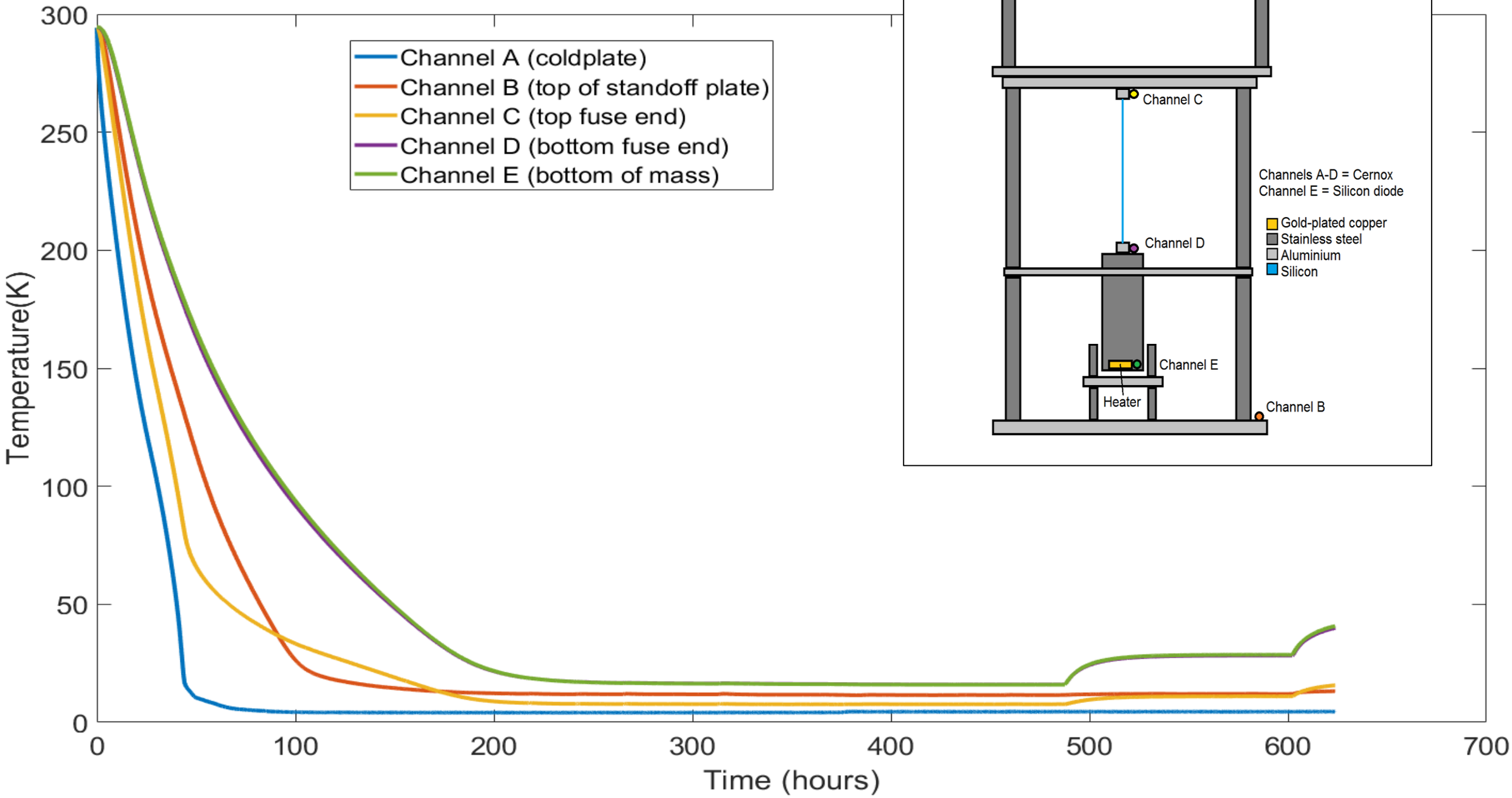


Results – many iterations

Suspension	Ribbon (775um thick, 0.20-0.25 m long)	Fuse end material	Glue	Result	Comments
1	Offcut, unpolished	Aluminium	Araldite	Failed - unknown	Basic sensor setup, ribbon landed intact
2	Offcut, polished	Aluminium	Eccobond 286	Failed - bottom	Moved sensor, aluminium standoff plate inserts. Turned off over Christmas, failed on warmup.
3	Offcut, polished (re-used from suspension 2)	Aluminium	Eccobond 286	Failed - unknown	Cryo-switch used, ambient sensor fitted, ribbon shattered at bottom of IVC
4	Offcut, polished (re-used from suspension 1)	Aluminium	Eccobond 286	Survived	Ribbon later failed likely due to shock contact with cryostat from member of staff. Short circuit in heater system.
Lab shut down					
5	Offcut, polished (re-used from suspension 1/4)	Aluminium	Eccobond 286	Failed - bottom	Leak valve fitted, 2x sensor fitted to ribbon, sensor reshuffled, ambient sensor removed (capacity)
6	Full, polished	Aluminium	Eccobond 286	Failed - top	New OVC o-ring, vacuum issues
7	Offcut, unpolished	Macor	Eccobond 286	Failed - top	Macor fuse ends, vacuum issues
8	Full, unpolished	Macor	Eccobond 286	Survived	Sensors reshuffled, backing pump seals replaced (fixed), major compressor issues discovered. Compressor died.

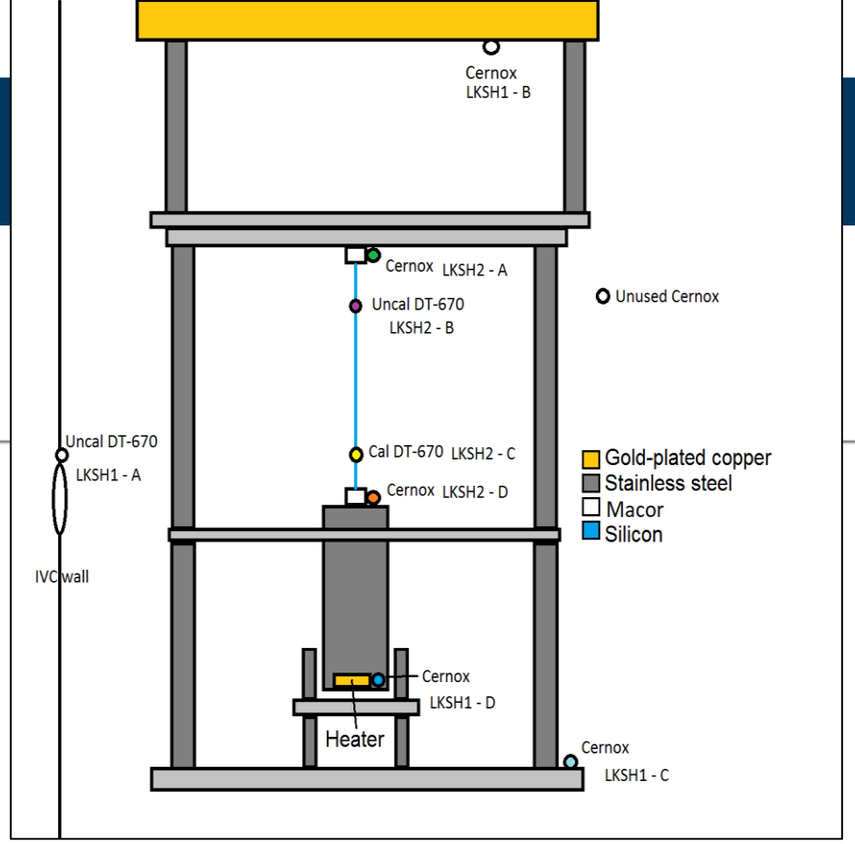
Notes: ‘Offcut’ ribbons are typically 1.60 -1.76 mm in width, ‘Full’ ribbons are 3.5 mm wide
‘Unpolished’ means the ribbon edge was left in it’s laser-cut condition, ‘polished’ ribbons were lapped and super-polished along ends of ribbon inserted into fuse ends

“Typical” cooldown with heating applied



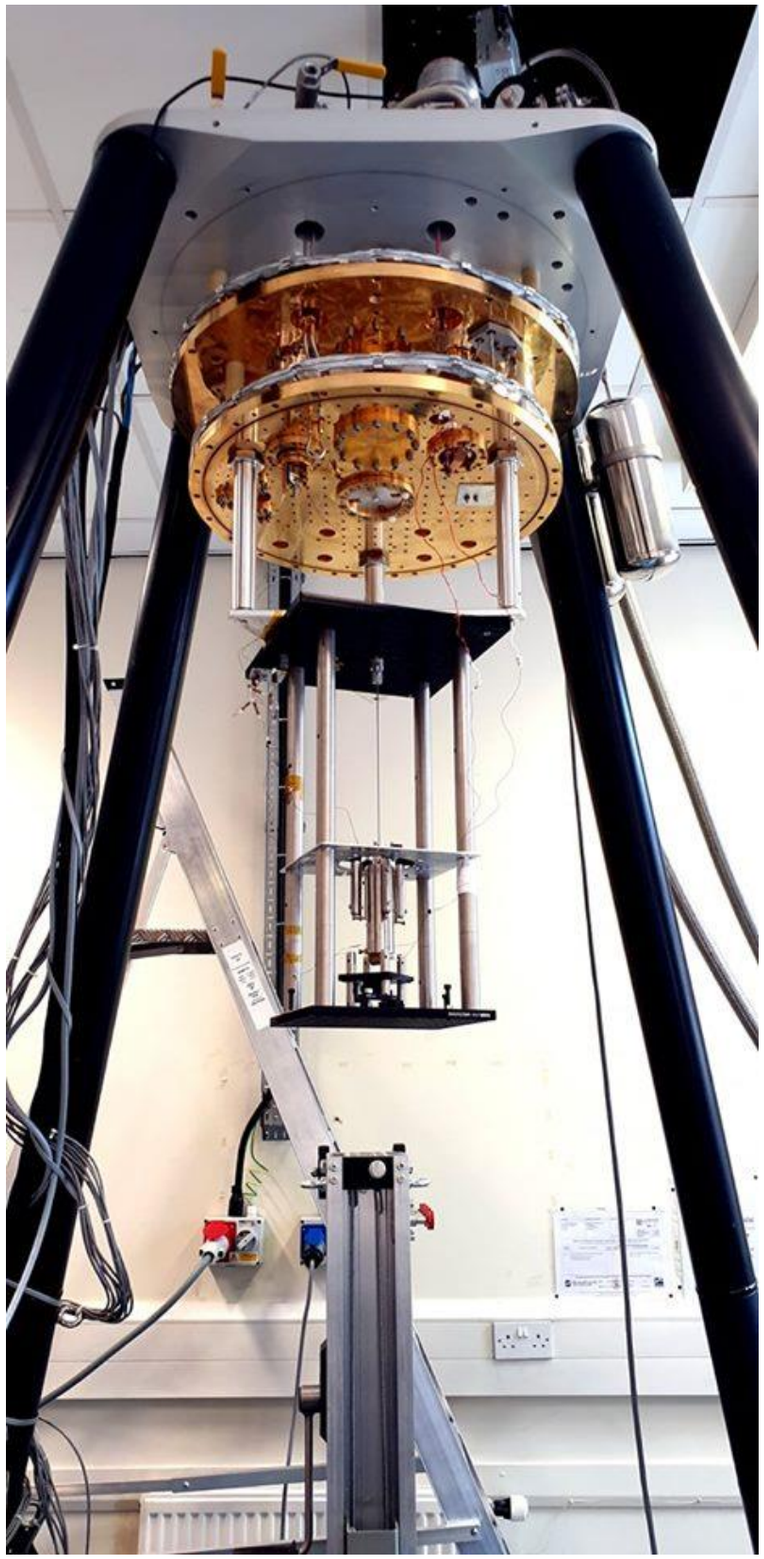
Suspension 8

Ambient load ≈ 4-10 mW



Lessons learned

- This is extremely difficult
- CTE is very important
- Cryogenic wiring needs extreme care
- Procedures
- Handling and tooling
- Timescales
- Luck



Next steps for cryogenic work

- Investigate and fix cryostat compressor
- Re-cool suspension 8 if it survives warm-up
- Successfully HC bond silicon suspension elements in jig
- Develop procedures to successfully hang and cool bonded silicon suspension with metal mass
- Characterise bonds and thermodynamics of bonded system

- Thanks for listening – any questions?