Progress on lab setup and site qualification at LBNL

Emily Thompson

Instrumentation meeting

July 14, 2023

ITk Pixel module testing at LBNL

We will be testing ITk Pixel modules at LBNL – preparation for testing is ongoing in 50B-6238

Preproduction is starting now and will continue until November 15th

How are modules tested?

1. Warm (room) electrical tests (→ QC tests presented previously + source scan)
2. Cold (-15℃) electrical tests
3. Thermal cycling (→ 10 cycles w/ 15 minute soak @ -45℃, 40℃ + 1 cycle @ -55℃, 60℃)
4. Burn-in (→ TBD)
5. Warm electrical tests
6. Cold electrical tests

Time to perform all tests: 35m / electrical tests + 1h / thermal cycle + $T_{source\ scans}$ + $T_{burn\text{-}in}$ **≥ 15h**

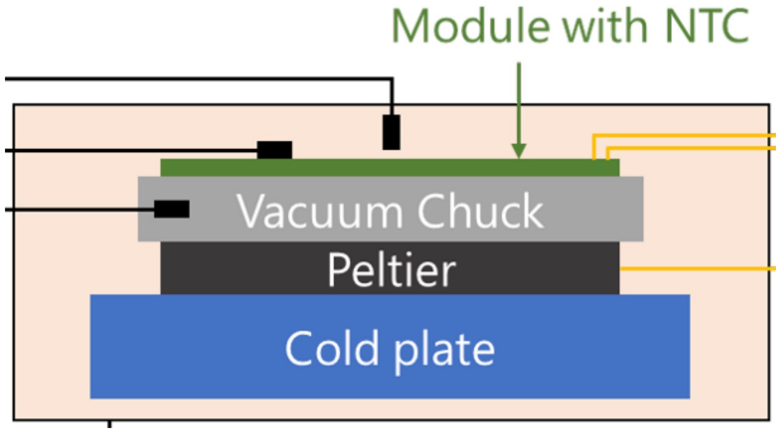
LBNL will need to test **~ 1 module / week** during preproduction and **~ 8 modules / week** during production

→ parallelization is important

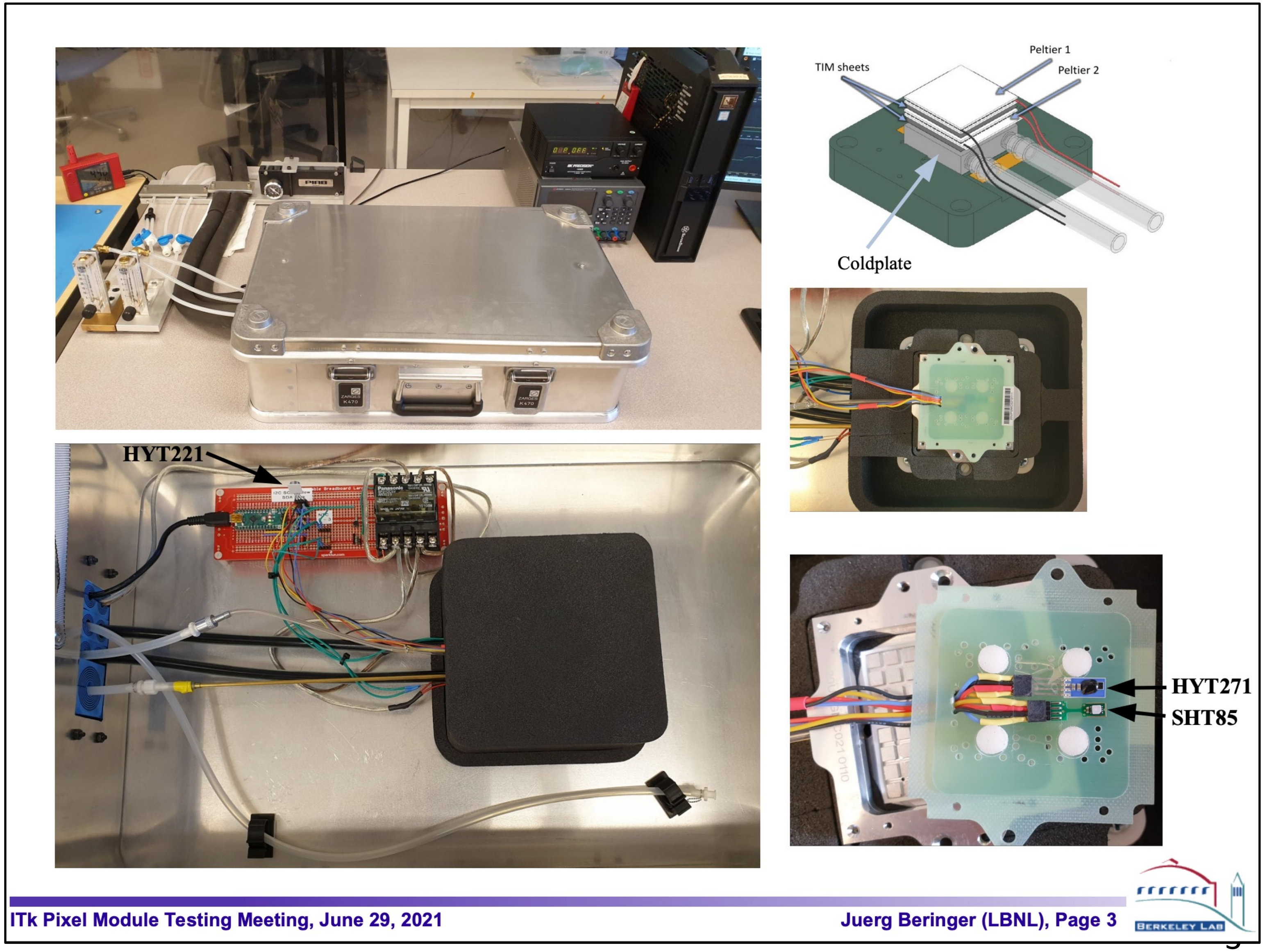
Single module cooling unit

Single module cooling unit is used by most testing sites

Juerg made this setup in 6040, and it was able to meet temperature and humidity requirements



Thermal interface material between cold plate, peltiers, and vacuum chuck



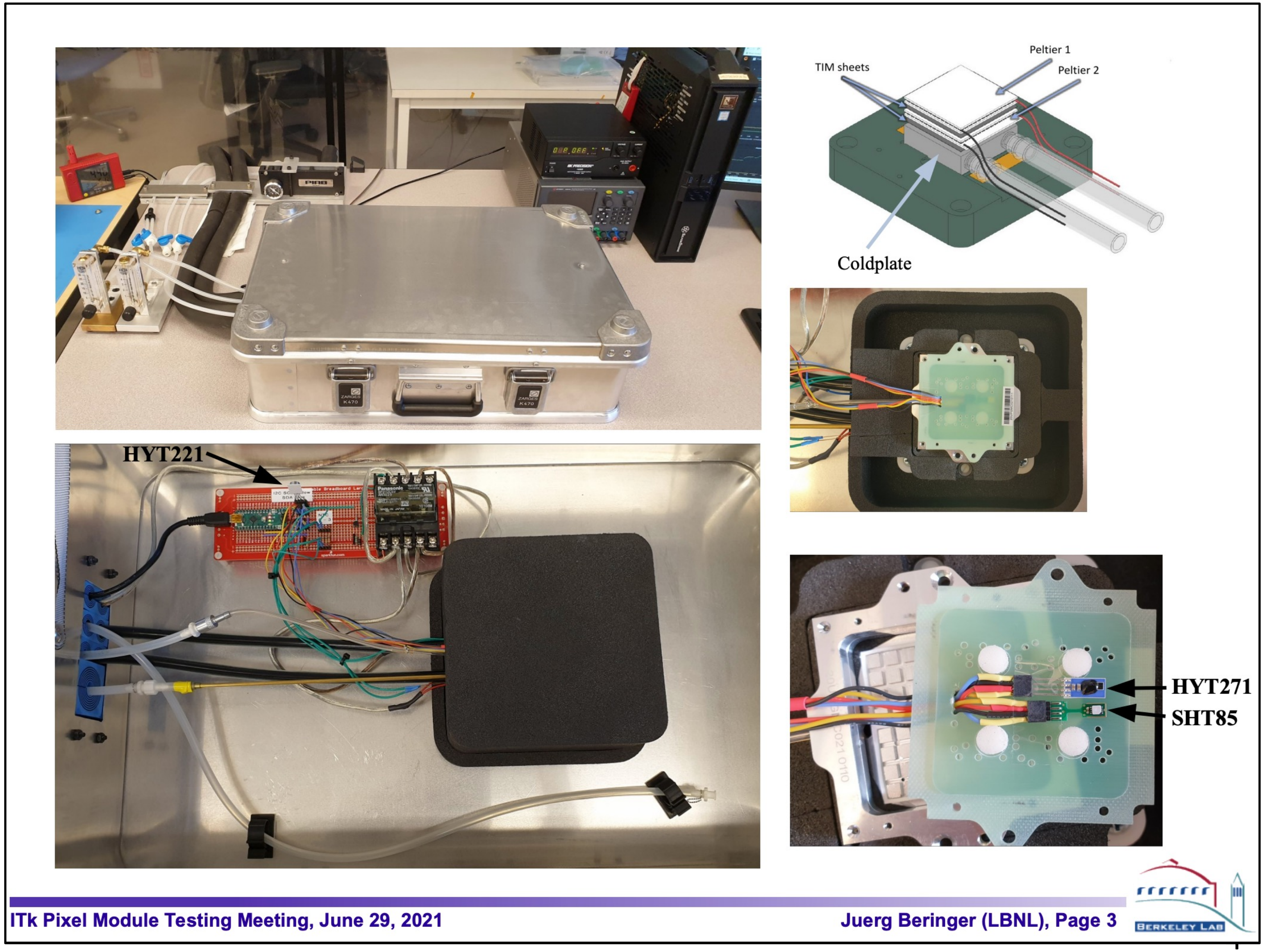
Single module cooling unit

Single module cooling unit is used by most testing sites

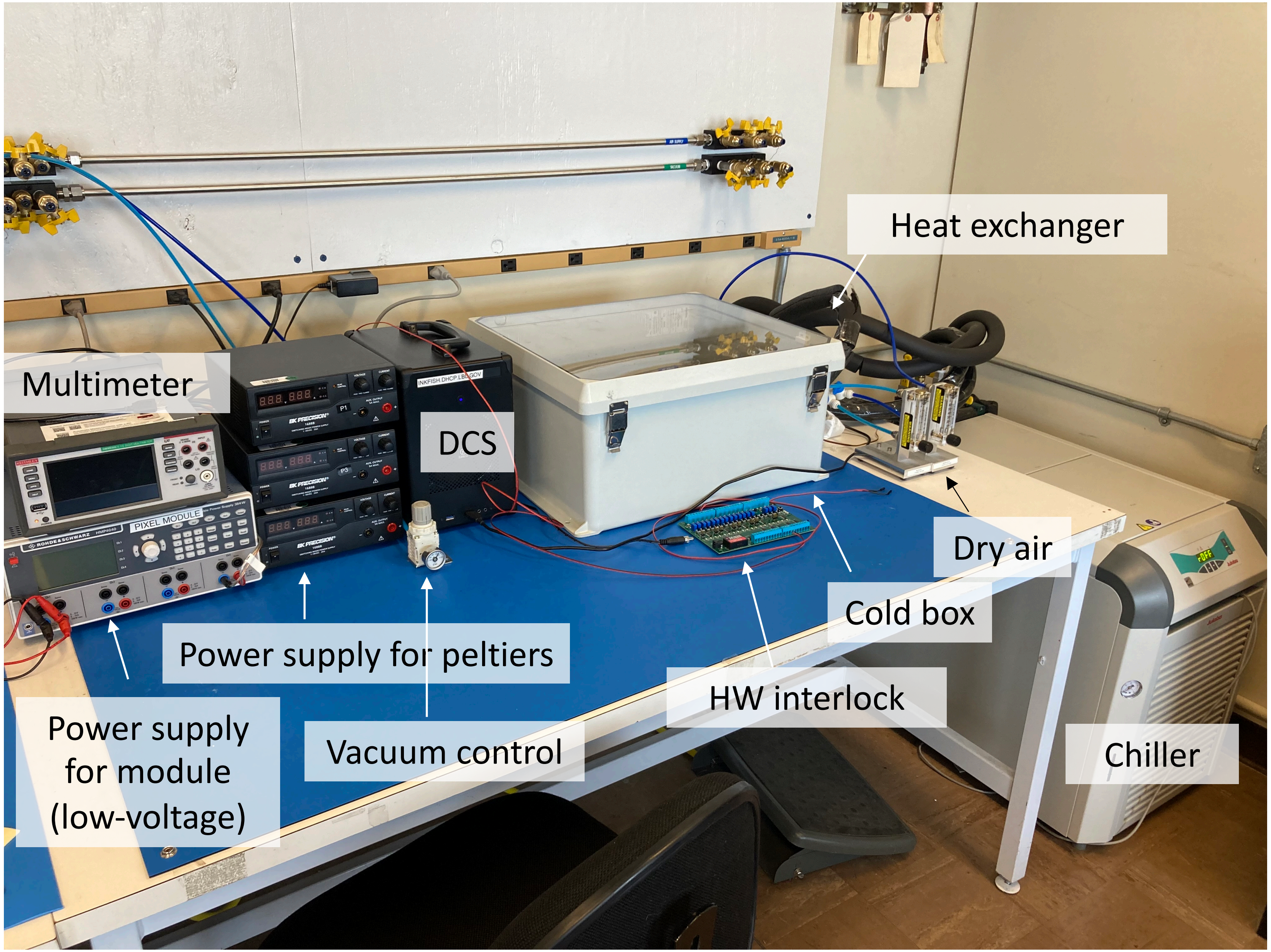
Juerg made this setup in 6040, and it was able to meet temperature and humidity requirements

However there were some challenges:

- Foam acted as sponge – required dry air flushing for several days after closing box
- Not easily scalable to test more modules in parallel

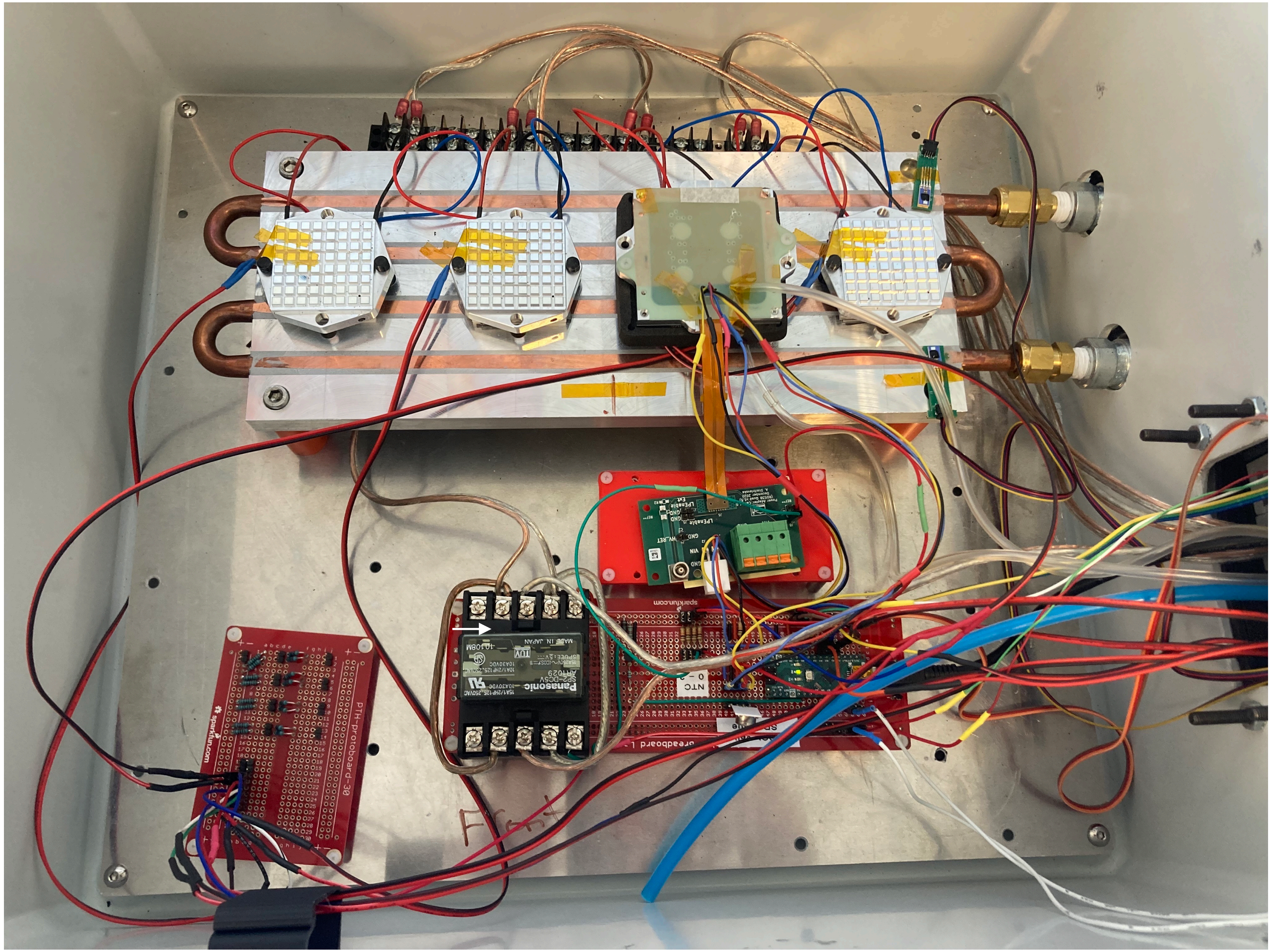


Multi-module cooling unit

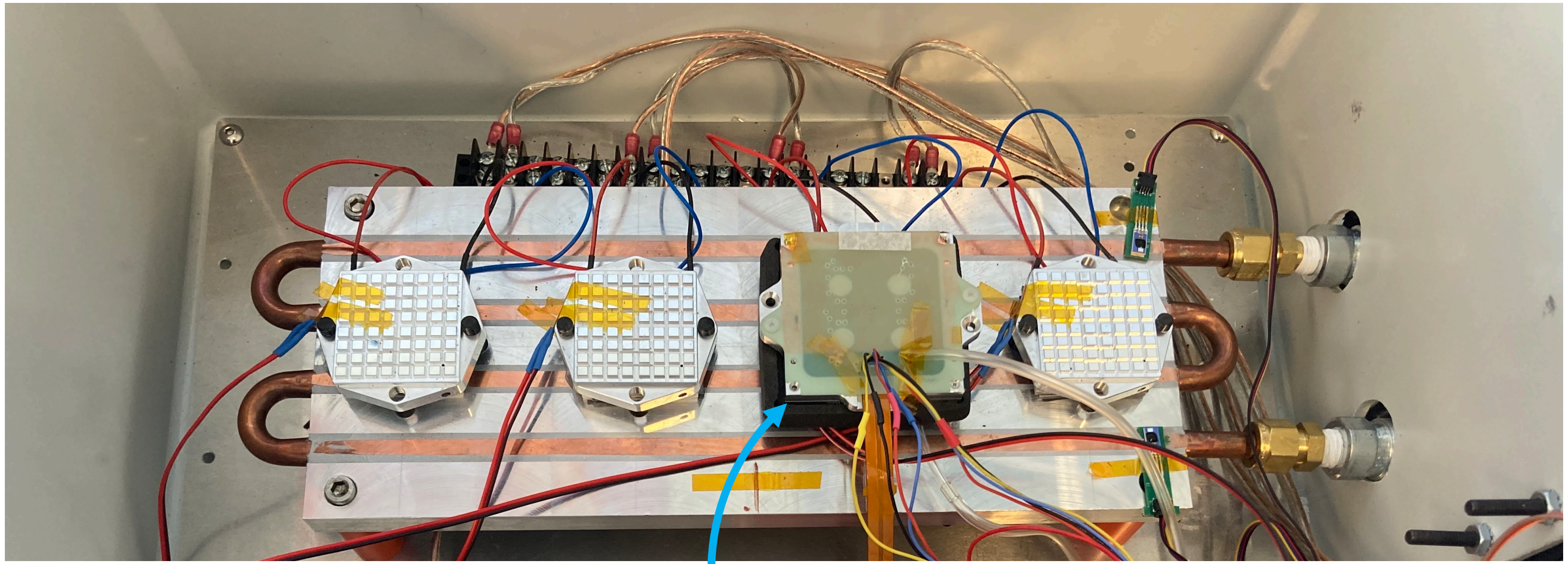


We are now setting up a multi-module cooling unit

Multi-module cooling unit: cold box



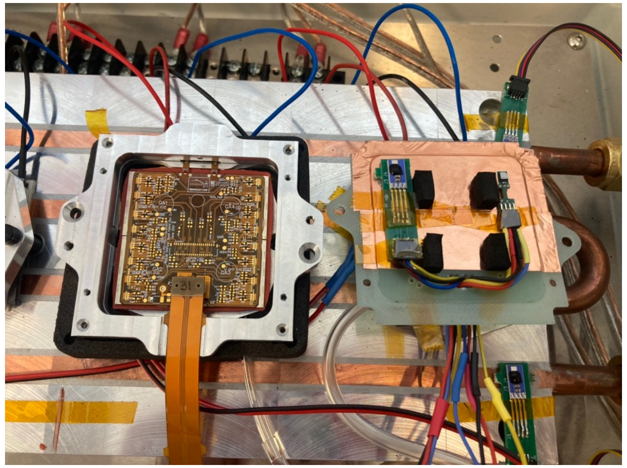
Multi-module cooling unit: cold box



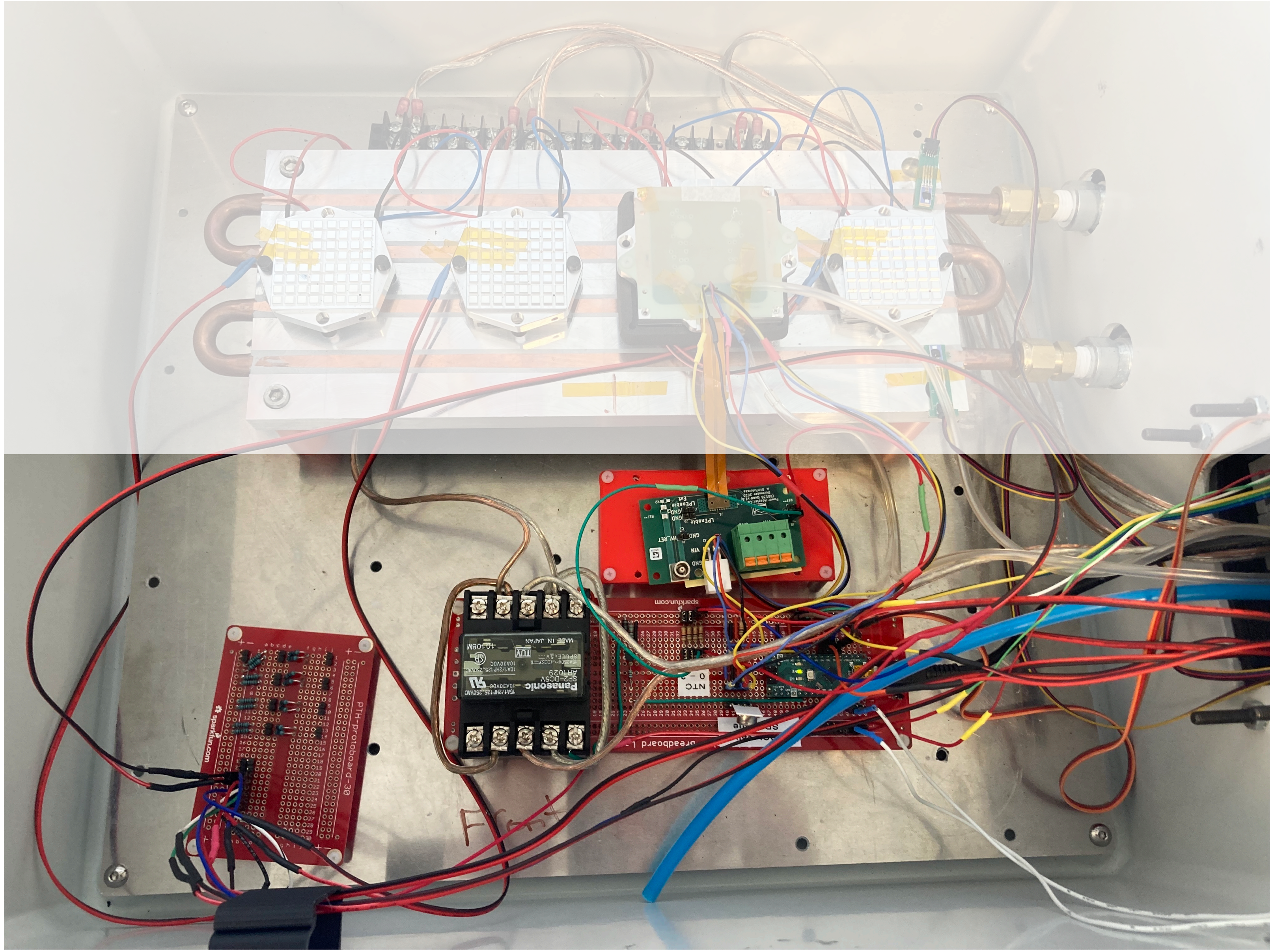
- Cold plate circulating chiller fluid at -15°C
- Four stacks of peltier elements and vacuum chucks, fitted with RENY screws and disc springs
- NTCs glued to side of vacuum chucks
- Single stack fitted with dummy module, carrier with T/RH sensors and cooled dry air flow
- Temperature of cold plate at inlet/outlet is measured

Module secured with vacuum to chuck

Carrier case fitted with copper tape, T/RH sensors

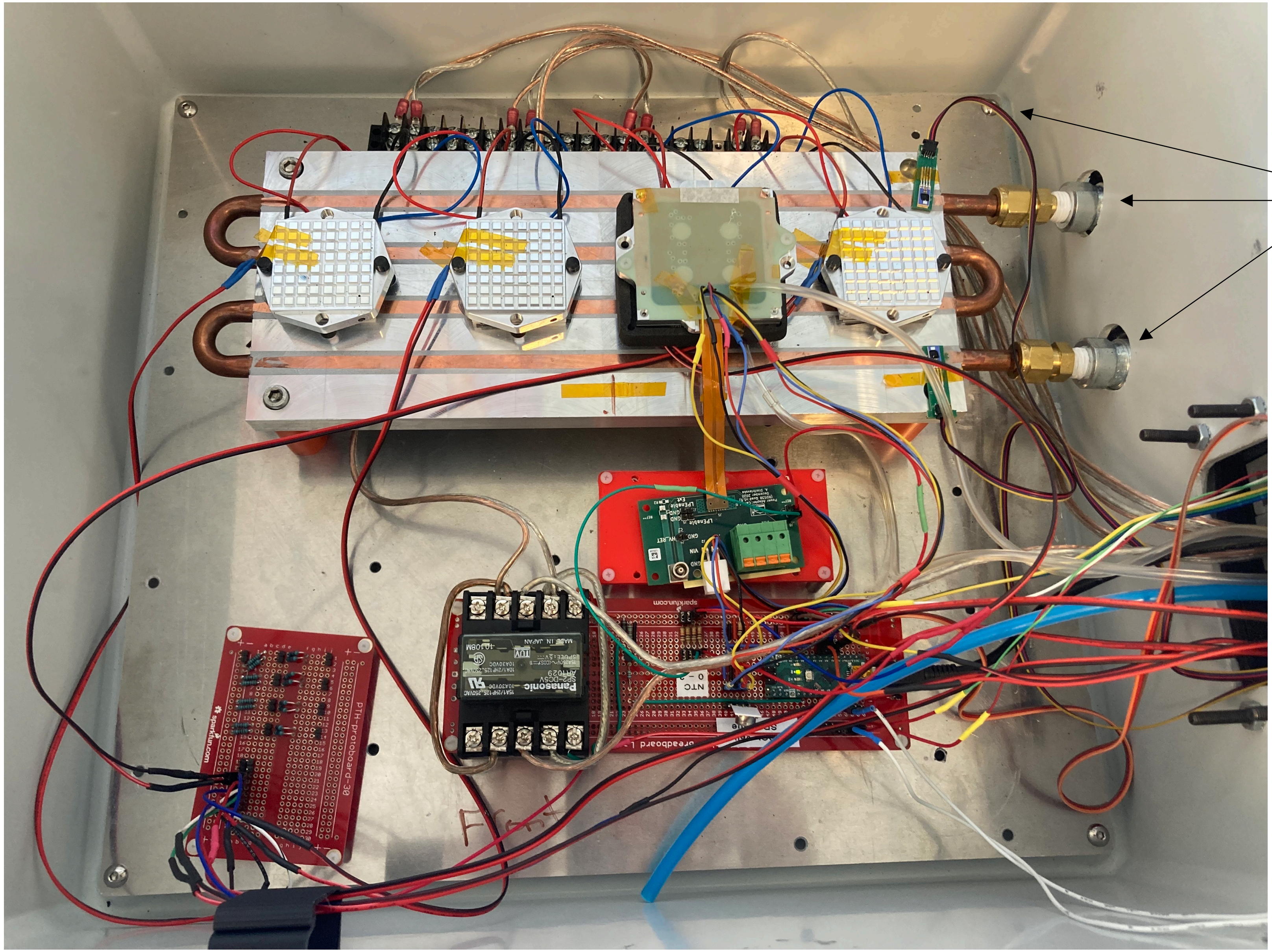


Multi-module cooling unit: cold box



- NTC of module read out through power adapter card
- Peltier relay to control heating/cooling
- Monitoring and peltier relay control handled by Arduino nano
- Some sensor signals also sent to HW interlock
- NTCs on other vacuum chucks read out with multimeter
- Warm dry air circulated through box

Multi-module cooling unit: cold box



Multi-module cooling unit inside box (not thermally insulated)

Chiller quick connects and mounting on removable plate allow for moving of entire setup to another box (i.e. with a source)

Pixel testing DCS software is developed as a labRemote app, written by Juerg Beringer

1. **Monitoring** – read all sensors through Arduino nano, monitor status of devices.
2. **Control** – user defines desired module temperature or thermal cycle, program uses PID loop to adjust peltier power until desired temperature is reached. Cannot be run without watchdog active.
3. **Watchdog** – ensures that monitoring is running before control can be used. Automatically restarts monitoring if interrupted.
4. **Software interlock** – Sends alerts and performs actions if conditions are dangerous to module (Taurean)

Processes track each other using files in /tmp directory:

```
(qcenv) /home/eathompson/pixelmoduleqc$ ls /tmp/
coolman-setup1-control.json
coolman-setup1-control.lock
coolman-setup1-control.pid
coolman-setup1-monitoring.lock
coolman-setup1-monitoring.pid
coolman-setup1-watchdog.json
coolman-setup1-watchdog.lock
coolman-setup1-watchdog.pid
```

Hardware interlock

The hardware interlock turns off the system if any of the following conditions are met:

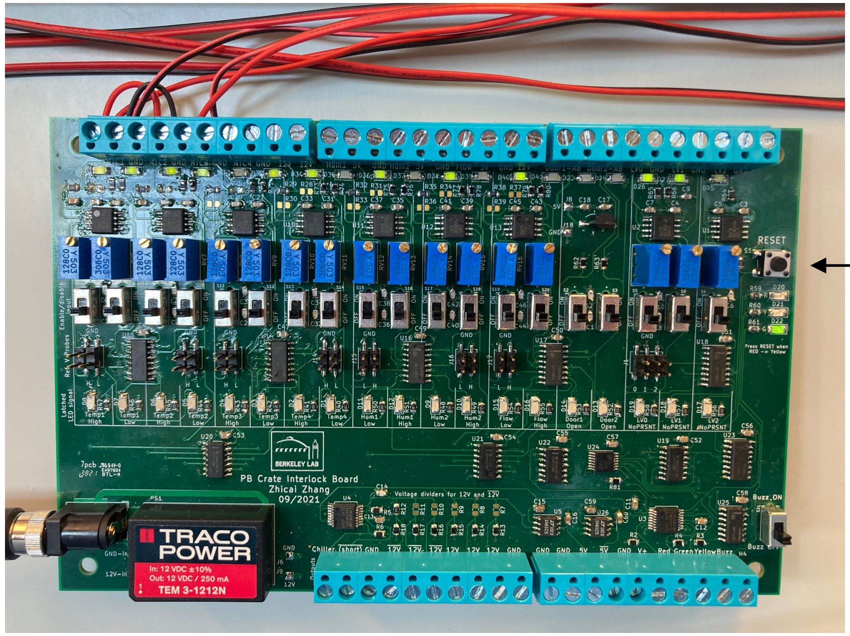
Setup	*Interlock trigger condition*	*Interlock action*
Cold test	$T_{NTC} > 45°C$ $T_{NTC} < -60°C$ $T_{dew} \geq T_{chuck}$ Lid/door switch	Module HV, Module LV, Peltier LV

Hardware interlock takes only analog signals – instead of monitoring T_{dew}, it will monitor dry air flow and humidity

Still to-do:

- Monitor door switch and analog humidity
- Route HW interlock to PS relays and DCS

Mounted on outside of cold box:



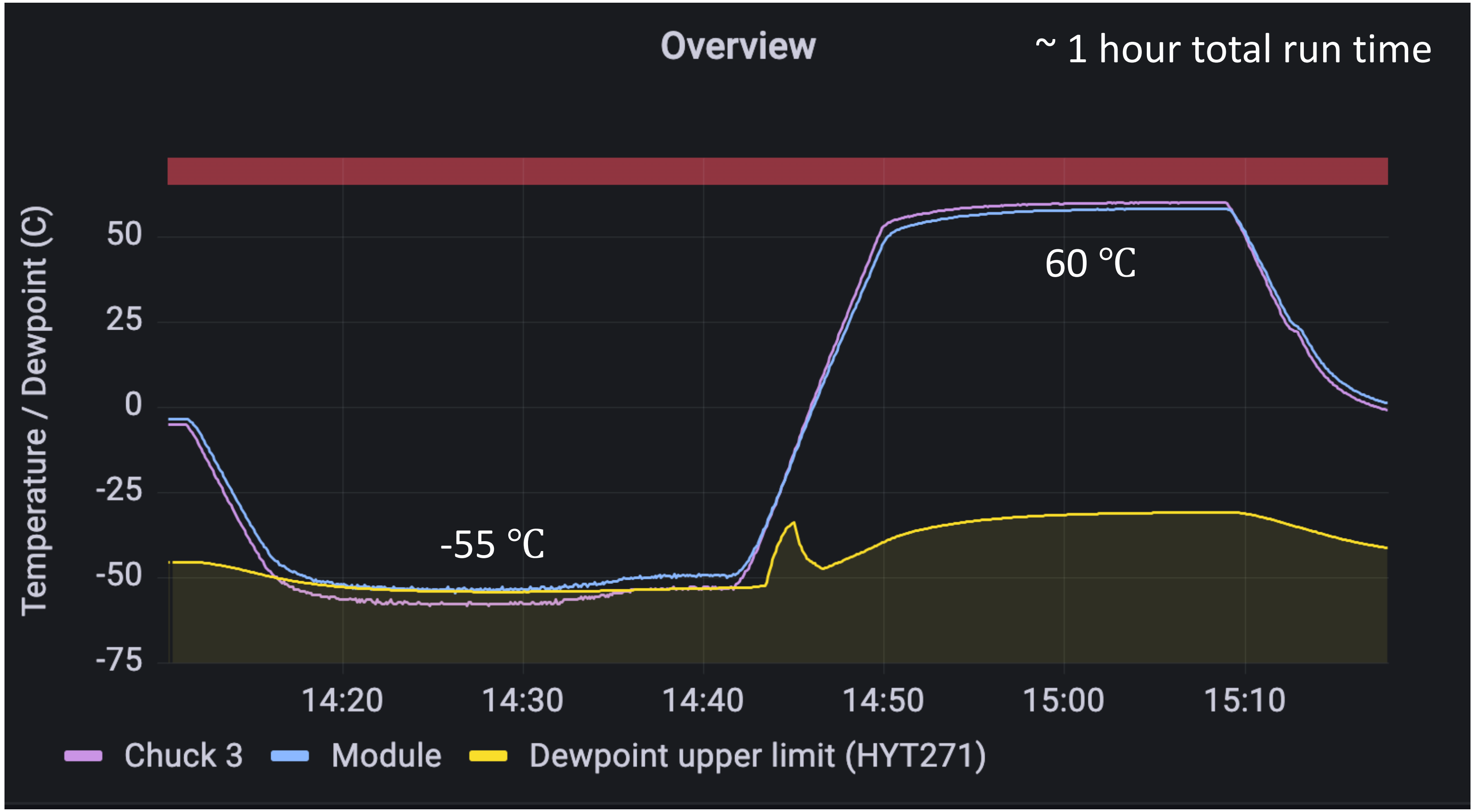
Can only be reset manually

Designed by Zhicai

Demonstration of extreme cycle

We are able to thermal cycle module from -55℃ to 60℃ (most extreme cycle)

Box flushed with warm dry air continuously during test. Cold dry air only flushed into carrier before cycling.



T (air in box) = 16 °C

T (air in carrier) = -6 °C (cold), 32 °C (hot)

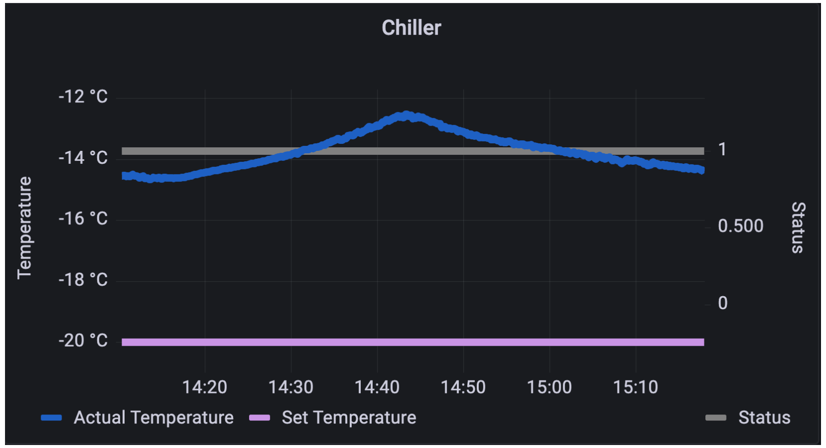
ΔT(chuck, module) ≈ 5°C

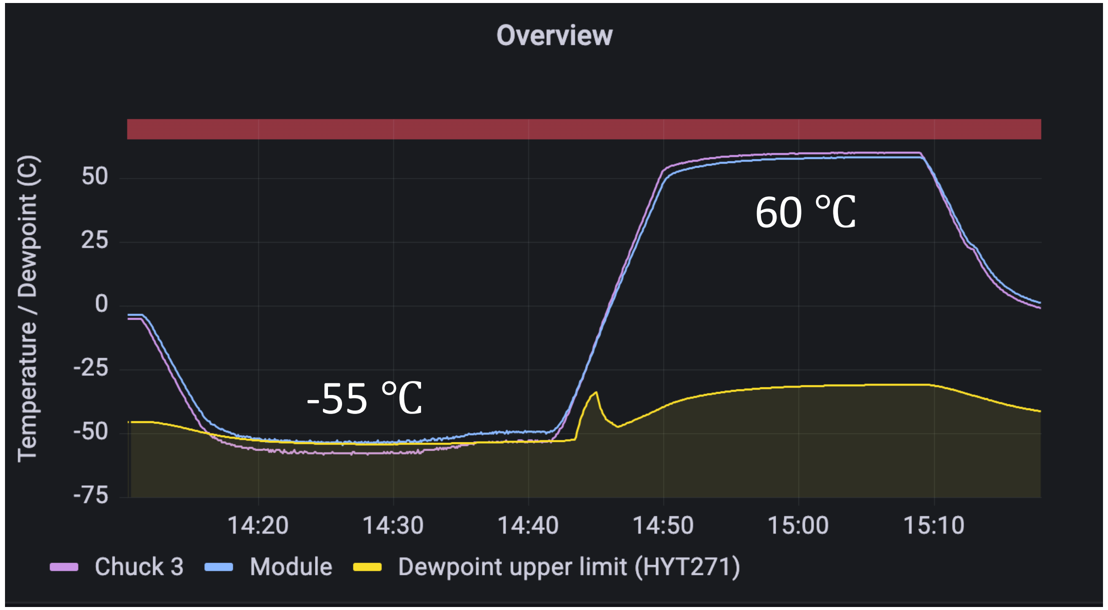
Demonstration of extreme cycle

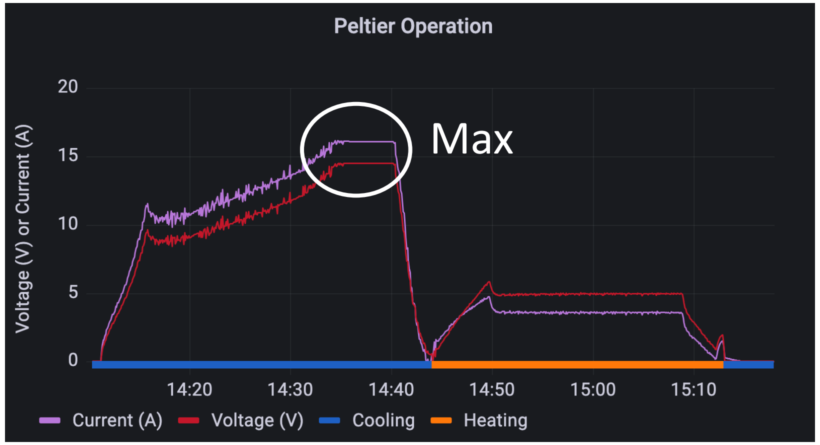
We are able to thermal cycle module from -55℃ to 60℃ (most extreme cycle)

However we have a few problems still to solve:

1. No margin at lowest temperature (peltiers were pushed to limit) → improve chuck contact with cooling plate, cool air inside carrier further







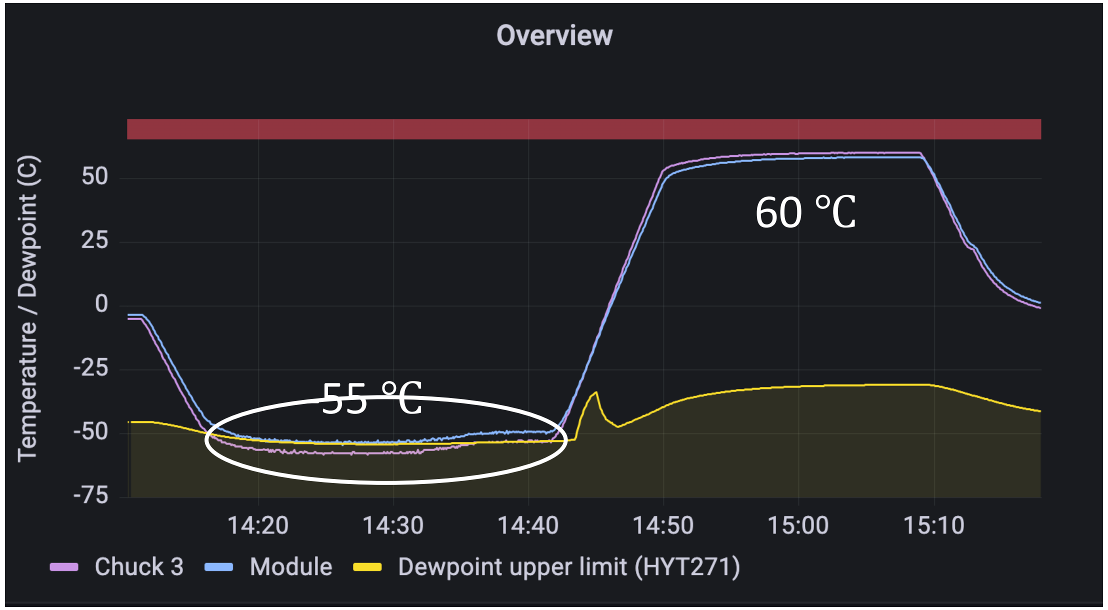
Demonstration of extreme cycle

We are able to thermal cycle module from -55℃ to 60℃ (most extreme cycle)

However we have a few problems still to solve:

1. No margin at lowest temperature (peltiers were pushed to limit)

2. Dewpoint too high



T_{chuck} = -58 ℃ $T_{dewpoint}$ = -54 ℃

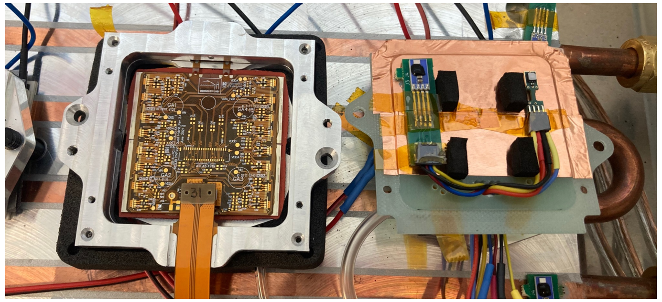
→ According to these measurements, we would have had condensation (ice) on vacuum chuck during this test.

Dewpoint calculation

$$\Gamma = \frac{(\log(RH/100) + b \times T)/(c+T))}{b}$$

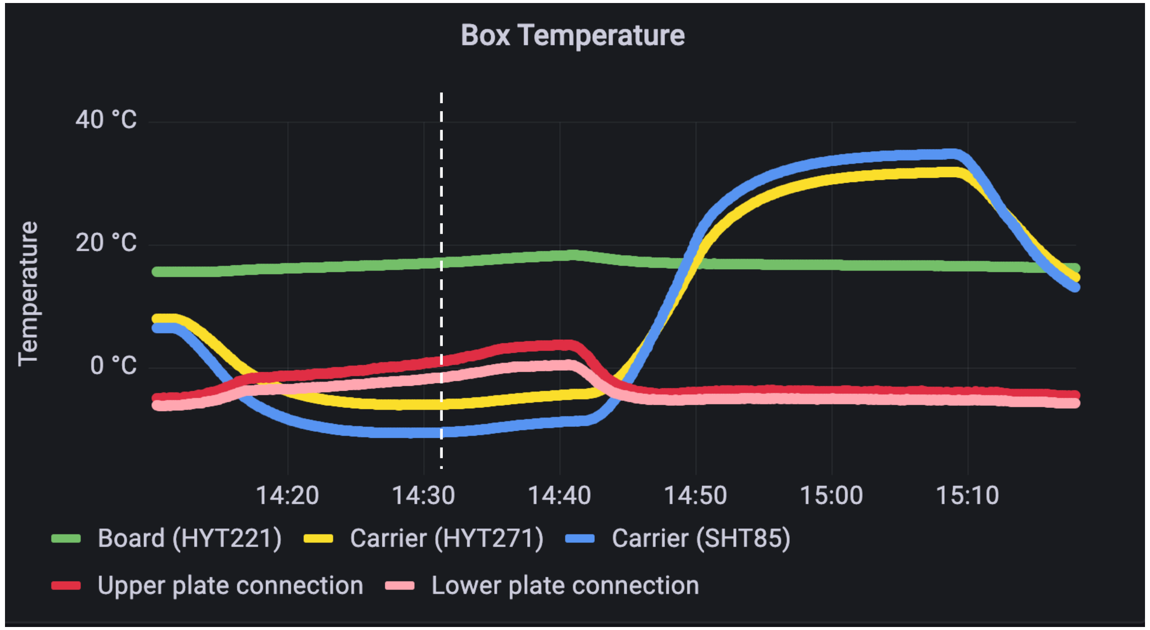
$$T_{\mathrm{d}} = c \times \Gamma/(1-\Gamma)$$

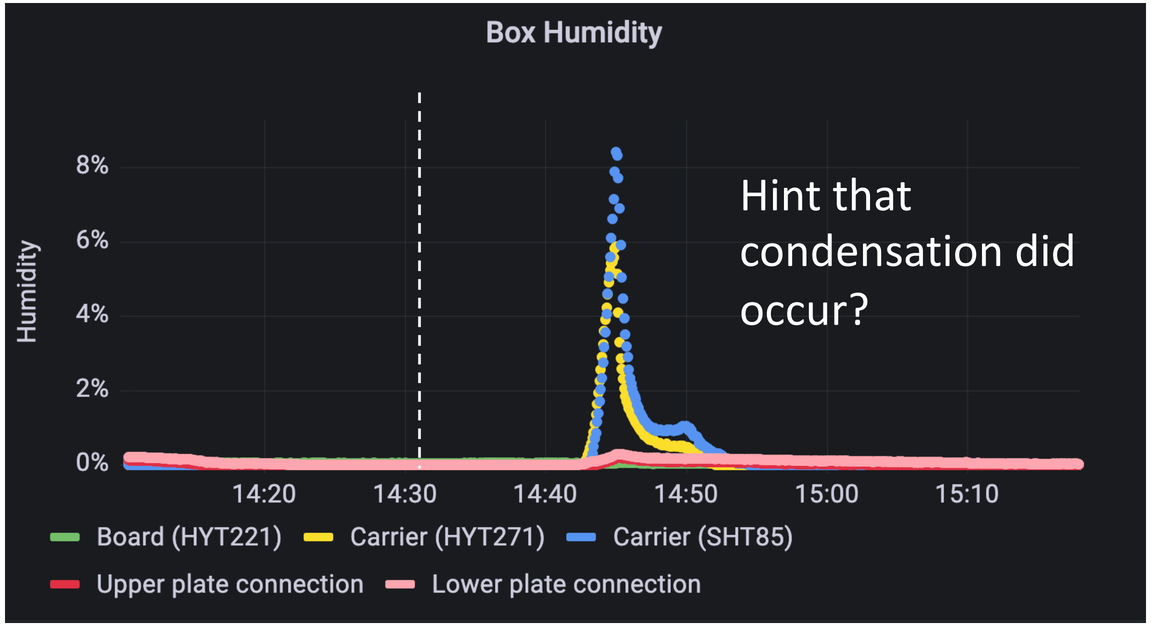
Dewpoint is measured using relative humidity (RH), T from HYT271 sensor inside carrier



We should measure RH/T closer to coldest part of system:

1) We cap RH at 1% in dewpoint calculation → Need T < -20°C to reach T_d < -60°C
2) Will give us more precise measurement of dewpoint temperature





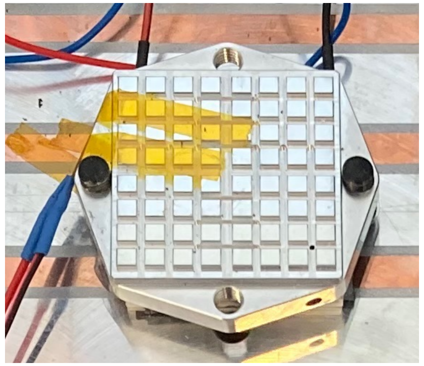
Future work

Our #1 priority right now is to pass site qualification:

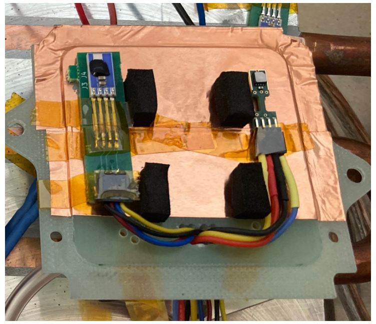
- Fix dewpoint issue
- Finish implementing HW interlock and relays
- Integrate SW interlock
- Install module data/power adapter cards into box
- Document system for site qualification

Then we will make further improvements to setup:

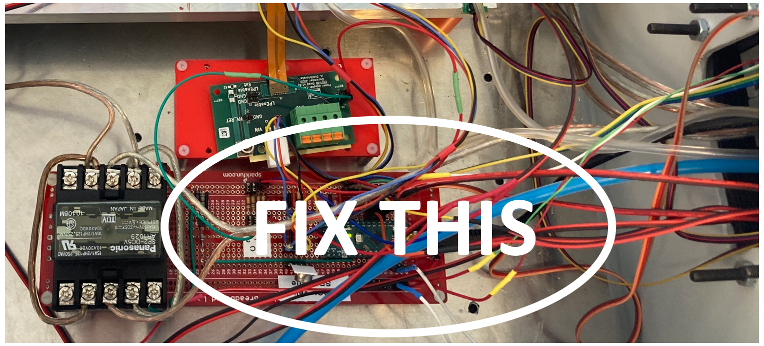
- Redesign vacuum chuck
- Design special module carrier case
- Design PCBs where useful, reduce mess of wires
- Adjust setup to allow for testing 4 modules at once



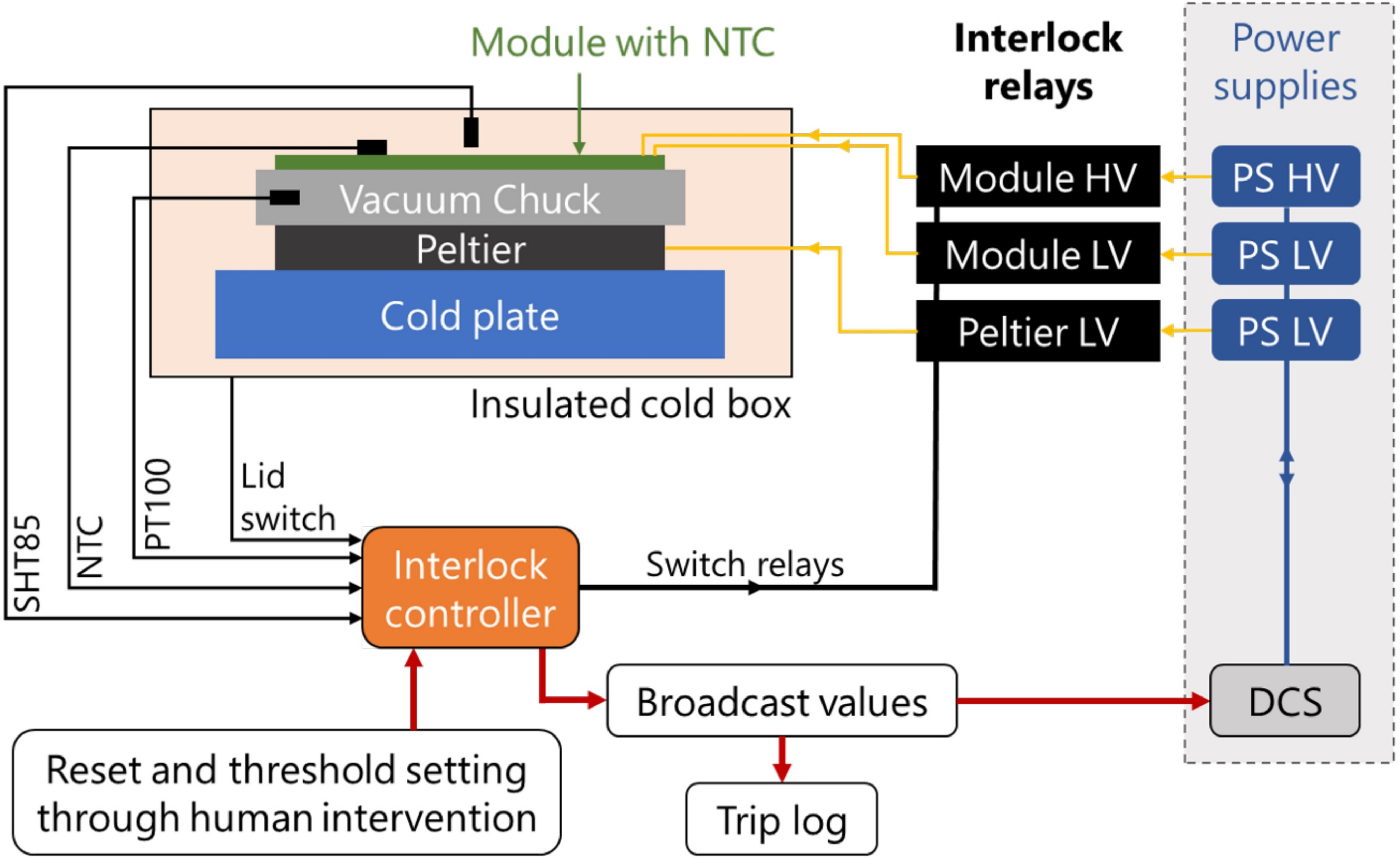
Make chuck larger so we can use all screws



Make carrier a PCB that is in thermal contact with chuck

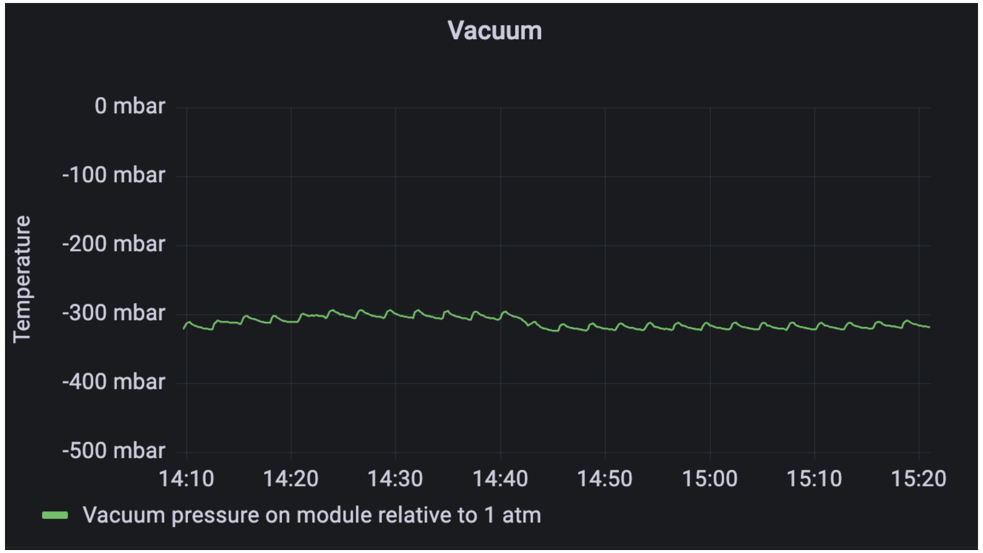


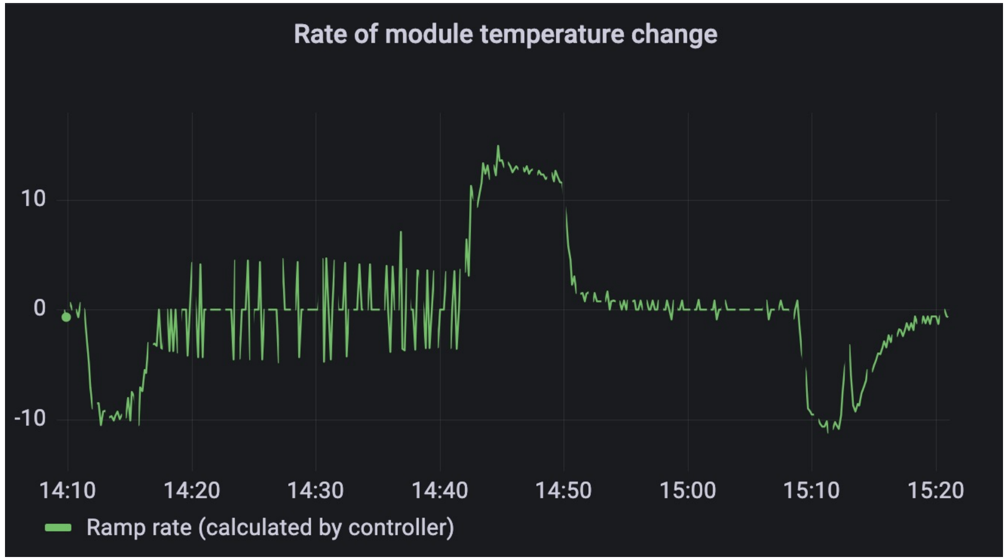
Backup

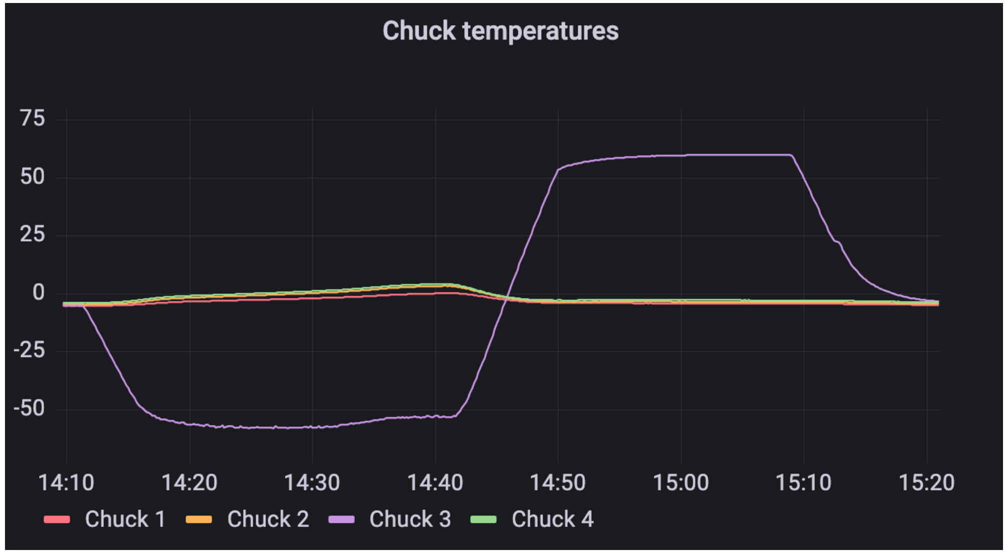


Module with NTC
Interlock relays
Power supplies
Vacuum Chuck
Peltier
Cold plate
Insulated cold box
Module HV
Module LV
Peltier LV
PS HV
PS LV
PS LV
SHT85
NTC
PT100
Lid switch
Interlock controller
Switch relays
Broadcast values
DCS
Trip log
Reset and threshold setting through human intervention

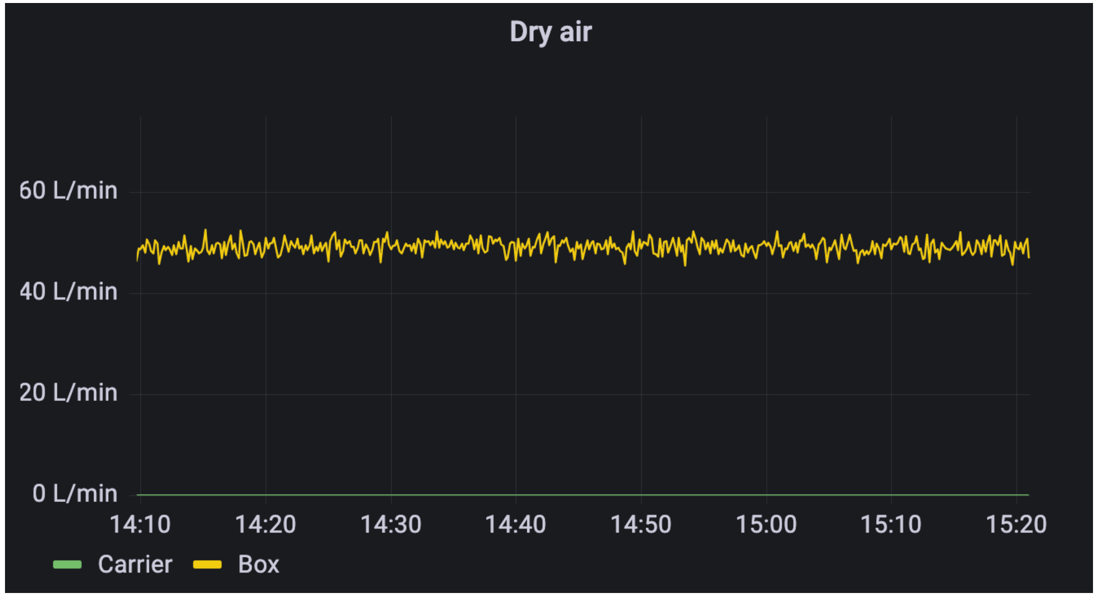
Backup

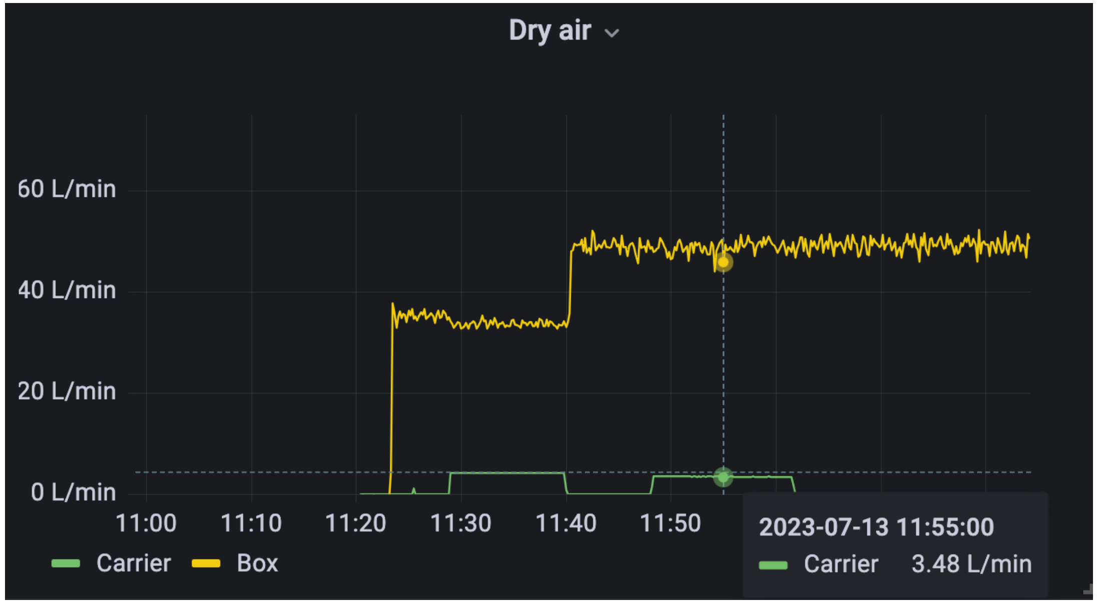

Vacuum
0 mbar
-100 mbar
-200 mbar
-300 mbar
-400 mbar
-500 mbar
Temperature
14:10
14:20
14:30
14:40
14:50
15:00
15:10
15:20
Vacuum pressure on module relative to 1 atm

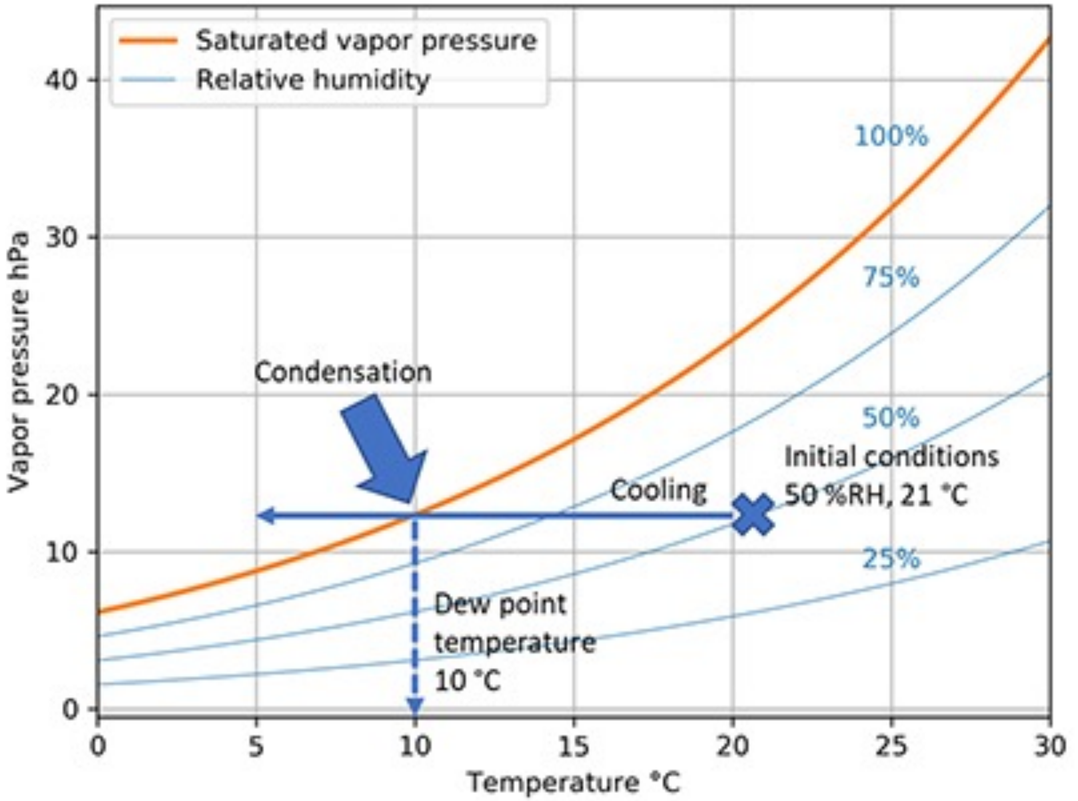

Rate of module temperature change
10
0
-10
14:10
14:20
14:30
14:40
14:50
15:00
15:10
15:20
Ramp rate (calculated by controller)


Chuck temperatures
75
50
25
0
-25
-50
14:10
14:20
14:30
14:40
14:50
15:00
15:10
15:20
Chuck 1
Chuck 2
Chuck 3
Chuck 4

Backup


Dry air
60 L/min
40 L/min
20 L/min
0 L/min
14:10
14:20
14:30
14:40
14:50
15:00
15:10
15:20
Carrier
Box


Dry air
60 L/min
40 L/min
20 L/min
0 L/min
11:00
11:10
11:20
11:30
11:40
11:50
Carrier
Box
2023-07-13 11:55:00
Carrier 3.48 L/min


Saturated vapor pressure
Relative humidity
100%
75%
50%
25%
Condensation
Cooling
Initial conditions
50 %RH, 21 °C
Dew point
temperature
10 °C
Vapor pressure hPa
Temperature °C
0
10
20
30
40
0
5
10
15
20
25
30