DUNE
Cold Electronics Cryo Testing
Update on RTS
(Robotic Testing Station)

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Outline

Why RTS? (skip)

Overall design

Robotic ASIC handling

Electrical tests of test sockets

Status and next steps

RTS (Robotic Testing System)

DUNE will use many cryo ASICs

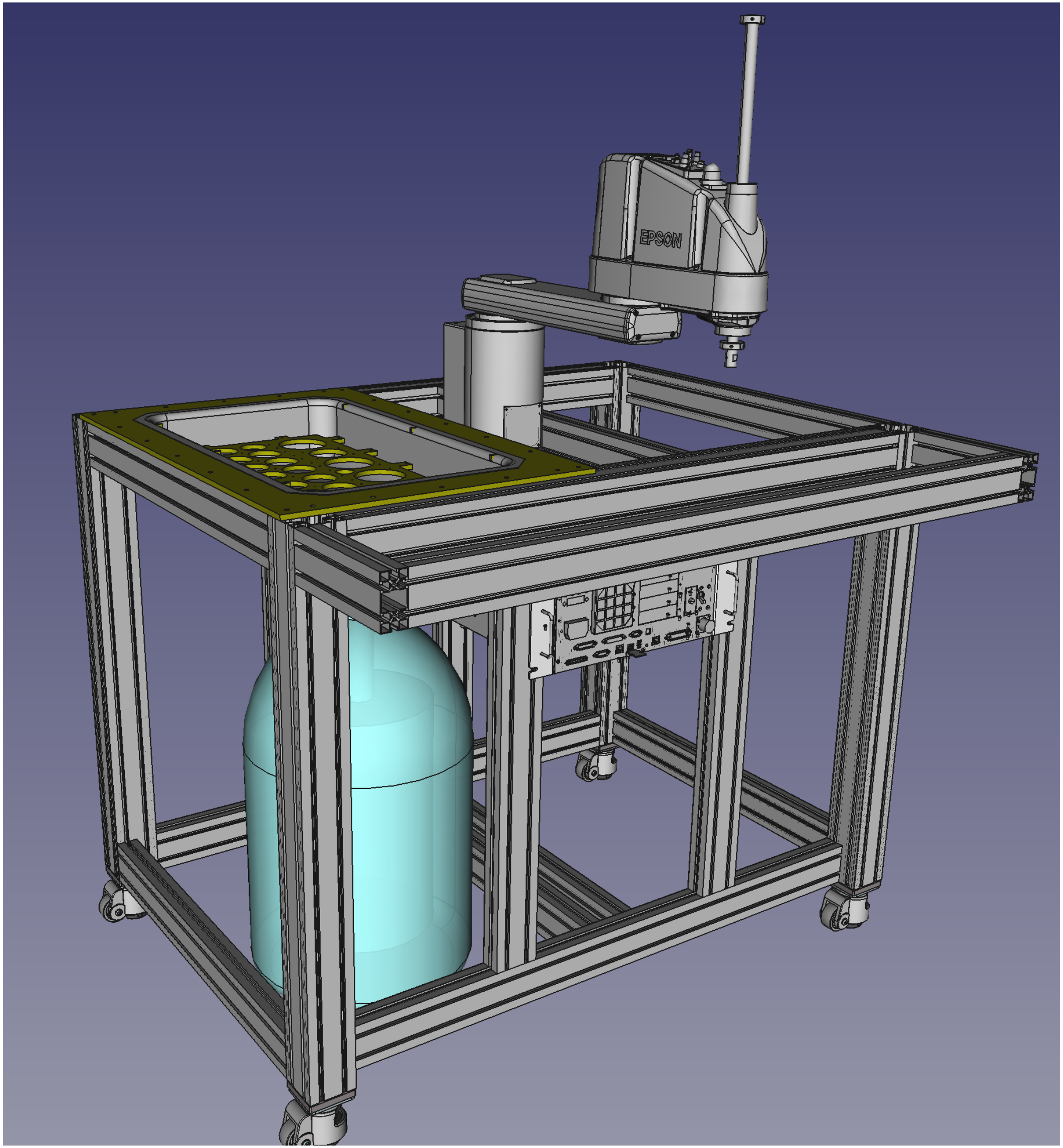
– Enough to make automated handling sensible
– The chips are easily damaged (ESD and mechanical)
– *Thus the Robotic part*

Any cryo testing needs to be done in a controlled environment

– Else water condensation
– *Thus the CTS part*

Workstation operating modes

– ASICs are handled with the robot, but manual handling is also OK
– Workstation provides a Faraday enclosure around the DAT (DUNE ASIC Tester) board
– Cryo cycle of ASICs is optional



The RTS comprises:

A commercial robot to pick and place the ASICs from trays to test sockets

A test chamber that supports the testing hardware.

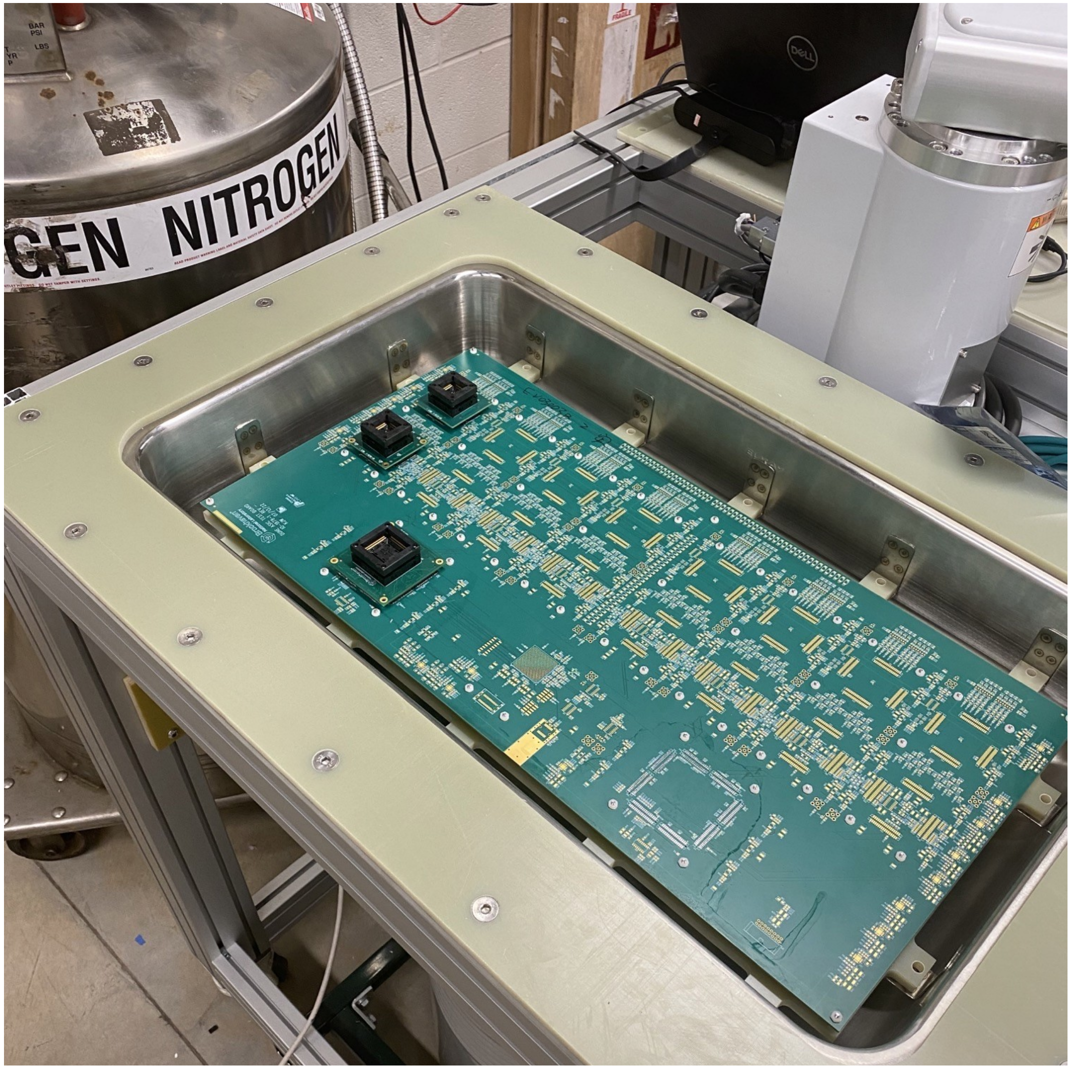
A cryogenics system that can fill and drain the test chamber.

An aluminum strut framework to hold this all together.

An upper level to the strut framework to provide a safety enclosure with access doors (not shown).

RTS prototype recent photo

Cryogenics status: Test run with DAT board



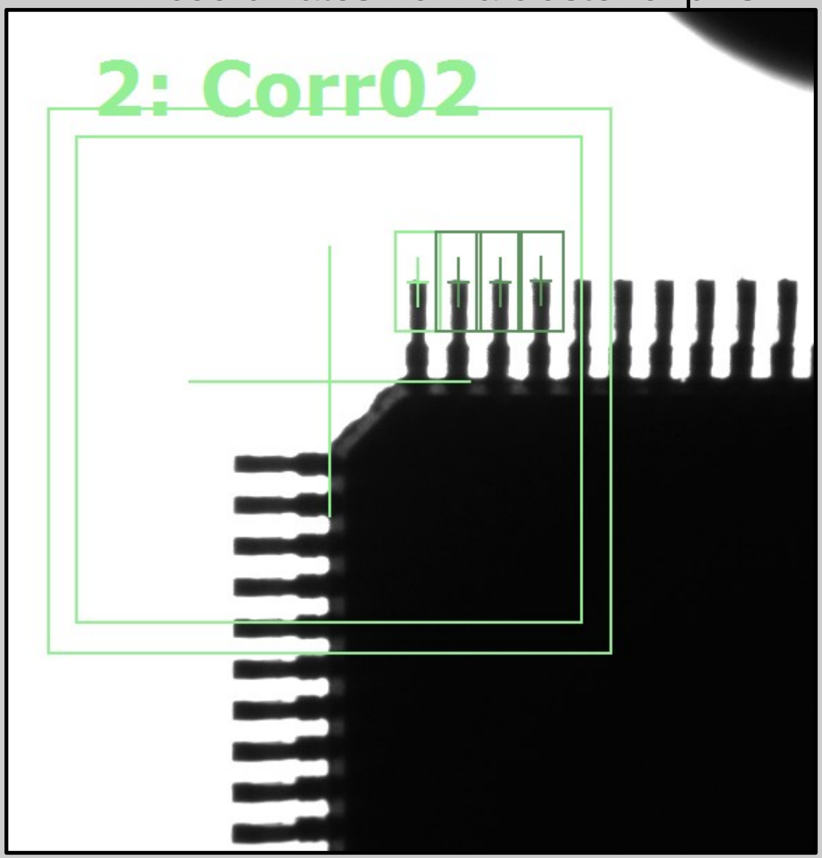
An unpopulated BNL DAT board was cryo cycled in the RTS. We maintained LN2 immersion for 20 minutes without problems. After warm-up the board appeared fine- no noticeable damage.

We then shifted focus to the robotic part of the RTS system.

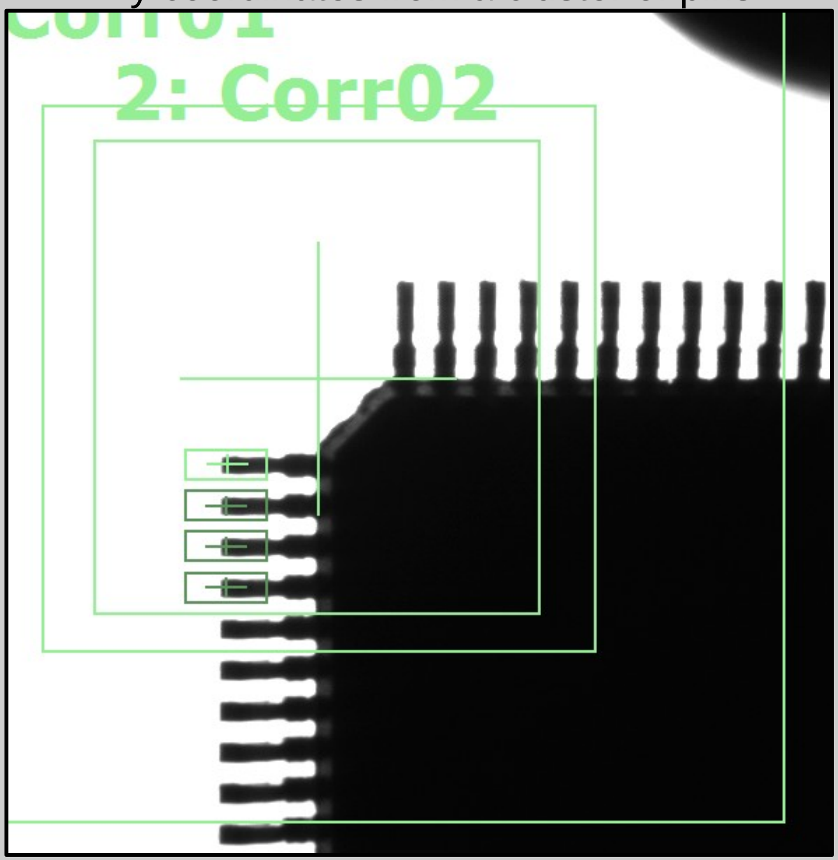
ASIC image recognition and positioning using up-facing camera

– The robot is moved to an initial position centered over the camera (call it “P1”).
– Two sets of pins are used to define an x,y fiducial point at one corner of the ASIC. Repeat for other corner.
– The robot is then moved to place geometric center of the fiducial points at P1.
– Then the ASIC is rotated 180 degrees and the rotational center is determined. *(Robot tooling now folded in)*
– Finally the ASIC’s rotational center is moved to P1. *(This aligns the ASIC with the robot coordinates)*
– Final state: ASIC at P1, and robot at new position “P2”.
– The resulting vector from P1 to P2 is the “Tool Offset” (x,y,u) used to:
  (1) Transform from robot coordinates to ASIC coordinates
  (2) Optionally refine the coordinates of the original pickup point of the ASIC

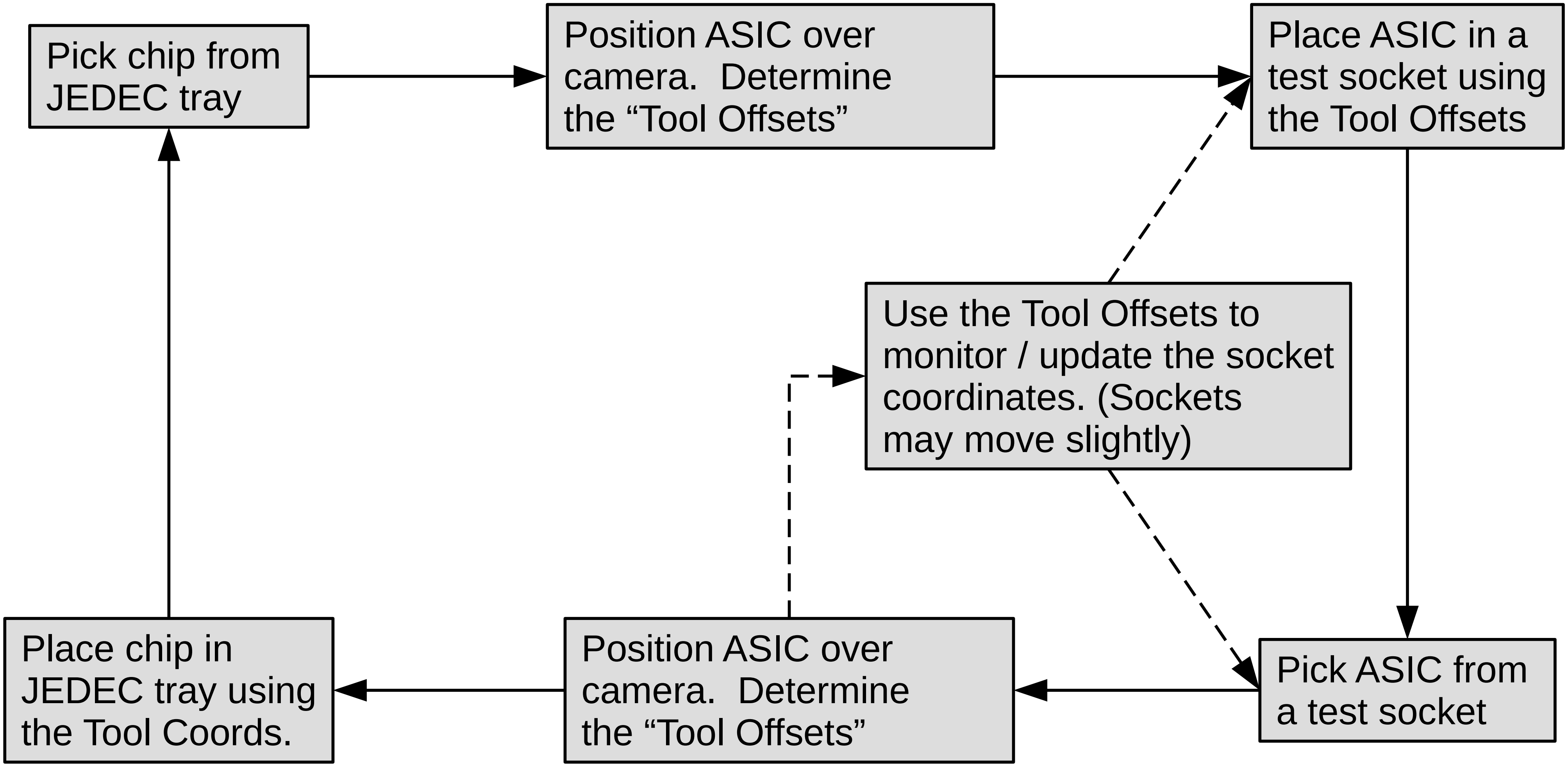
x coordinates from a cluster of pins



y coordinates from a cluster of pins



ASIC Pick-and-Place process



ASIC positioning tests and results

<u>Testing with the robot system up-facing camera</u>

– Pick up an ASIC, determine the Tool Offsets

– Position robot over camera, apply the Tool Offsets, and measure the ASIC fiducial points

– Do this at -90, 0, +90 and +180 degrees

<u>Results</u>

ASIC fiducial position measurements are consistent to < 10 microns (four orientations tested)

Compare to the original goal of ¼ width of an ASIC pin (200 um / 4 = 50 microns): OK

Compare to manufacturer spec for robot reproducibility (+/- 15 microns): OK

<u>–> ASIC positioning working well, move on to functional tests</u>

Electrical testing of ASIC test sockets

We have a few trays of “dummy” ASICs: LQFP-128 chips with pairs of pins internally connected.

We also have some socket cards that complete a daisy chain through the dummy chips.

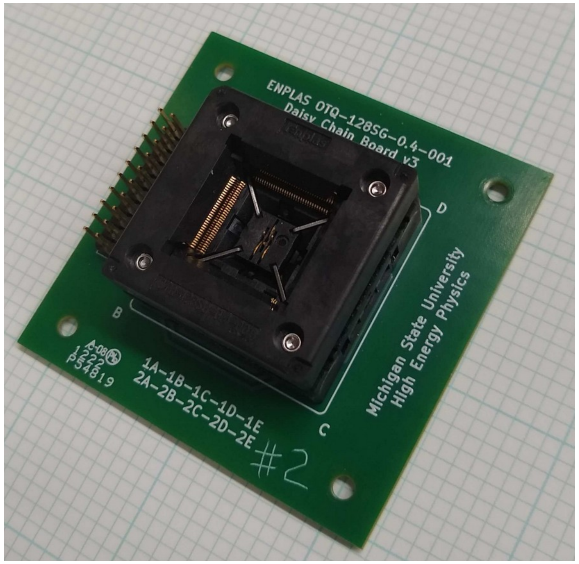
– We use the dummy chips to complete a daisy-chain through the socket:chip interface

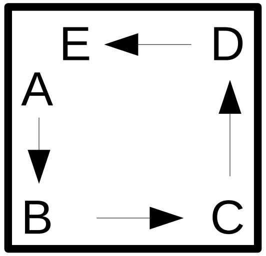
– Two interleaved daisy chains allow for:
  – Measuring contact resistance (ENPLAS spec is 50 to 100 milliohms initial value)
  – Detecting shorts between neighboring pins (indicated by Chain-1 and Chain-2 conduction)

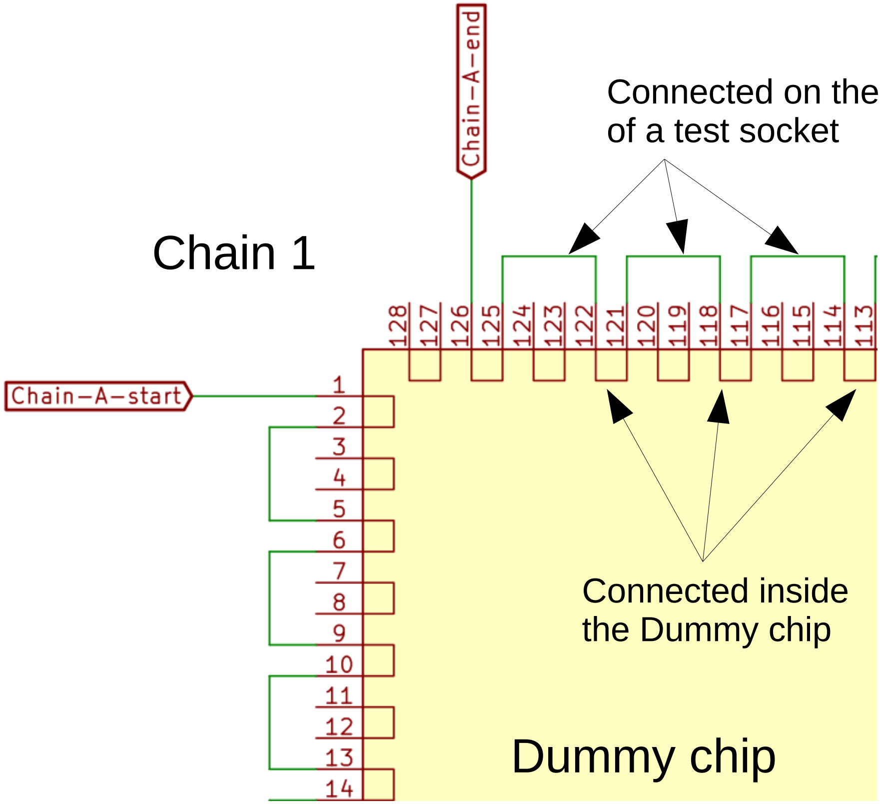
– The Daisy chains have taps in each corner for finer granularity measurements (8 segments of 16 pins)

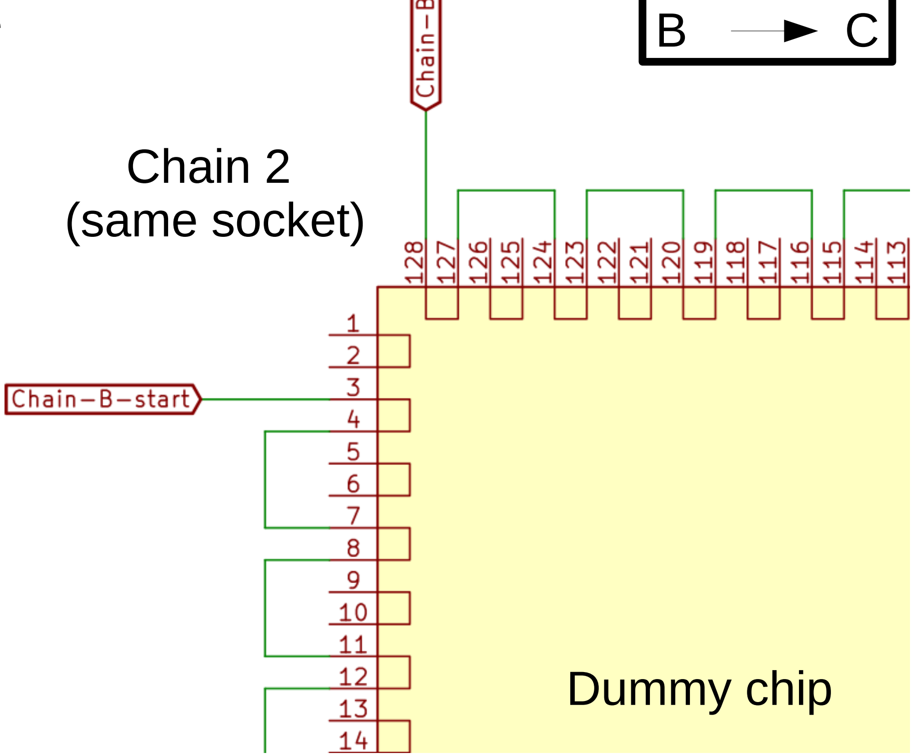
– We will measure how the contact resistance evolves over workstation cycles
  -- Obtain a measure of the practical socket lifetime in the workstation

Milestone: Processing a full JEDEC tray of dummy ASICs with electrical readout of socket performance

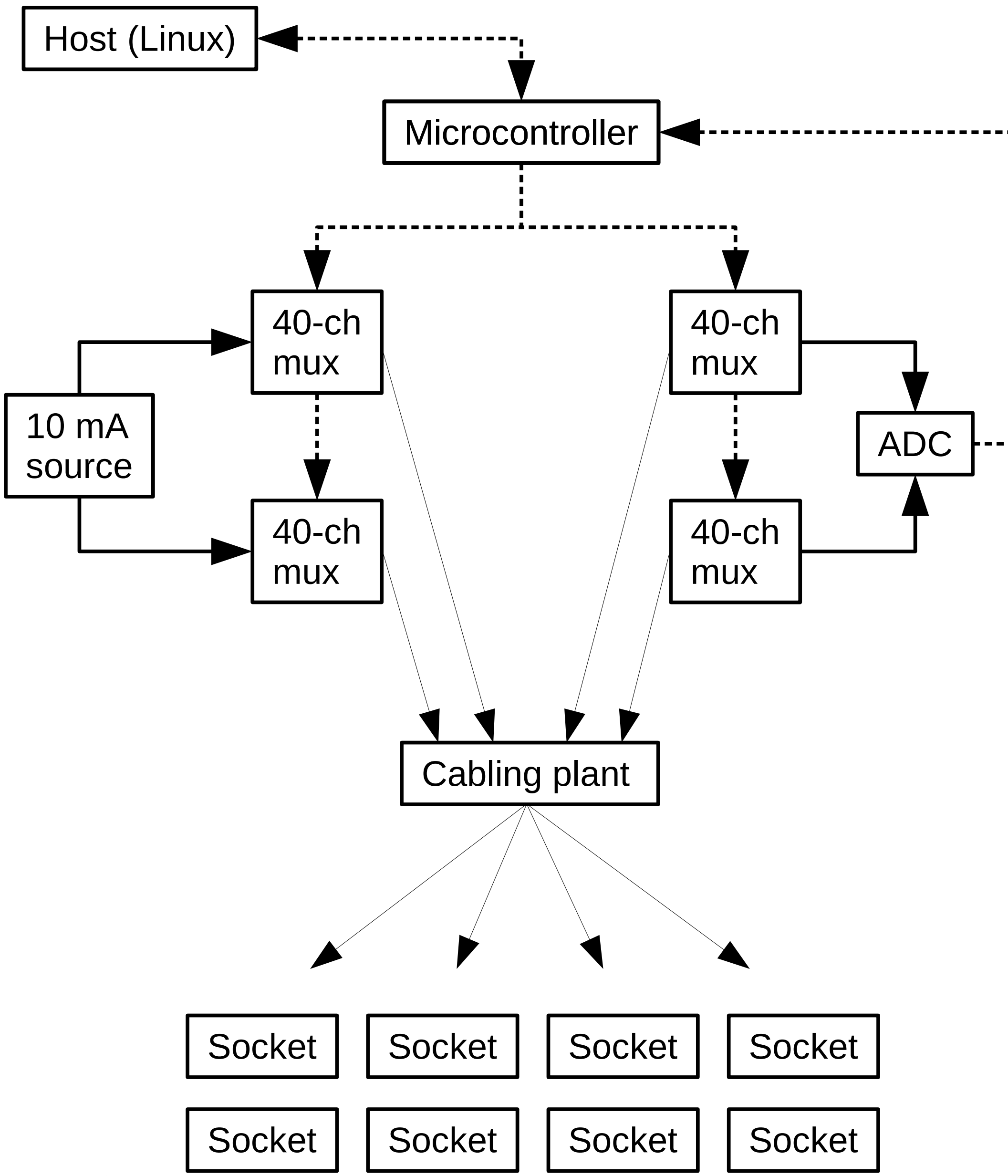


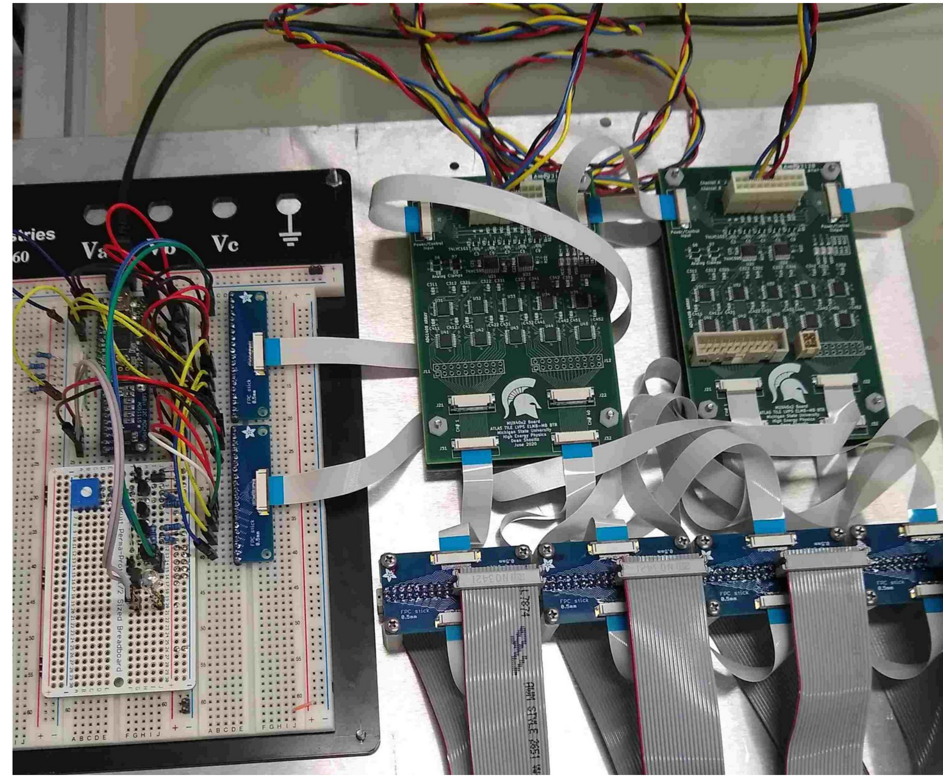


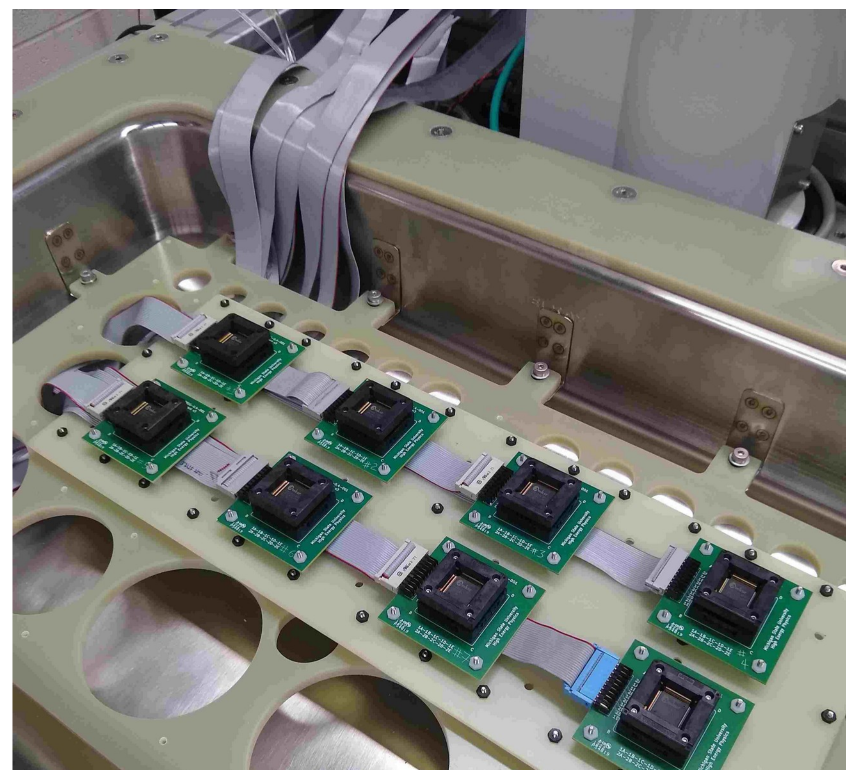




Socket resistance measurements are made with a 4-wire (Kelvin) connection all the way to the socket test boards. (uses 20 lines per socket)







Validating the daisy-chain testing setup

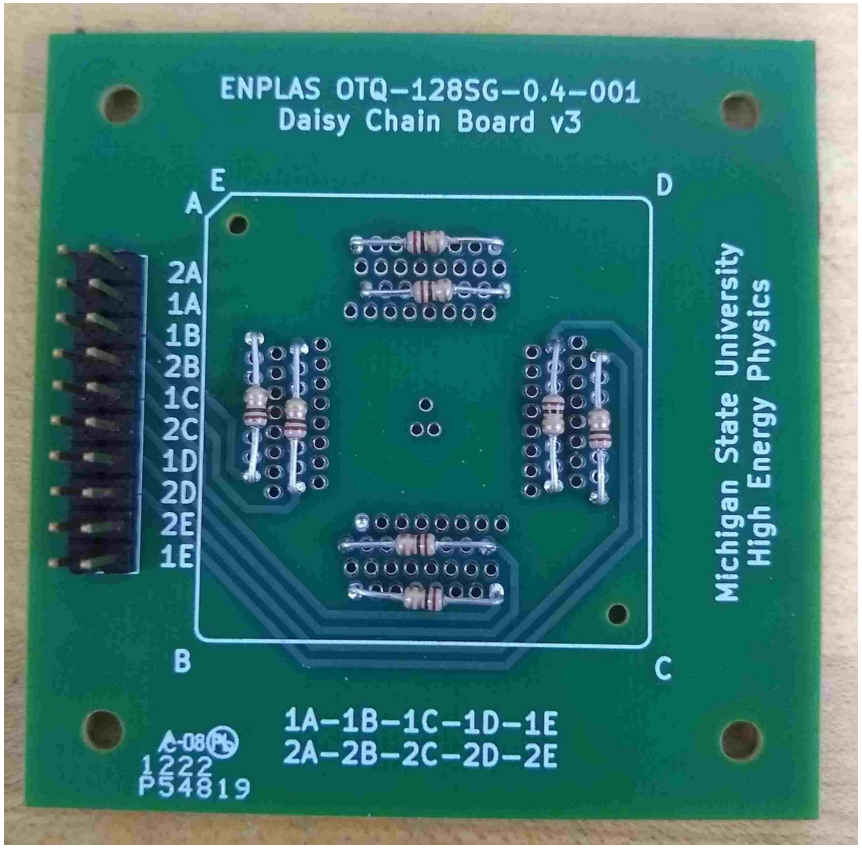
– Enplas sockets have an initial contact resistance spec. of 50 - 100 milliohms at 10 mA.

– Each of the eight daisy chain segment passes current through 16 pins, expect ~ 0.8 to 1.6 ohms on each chain.

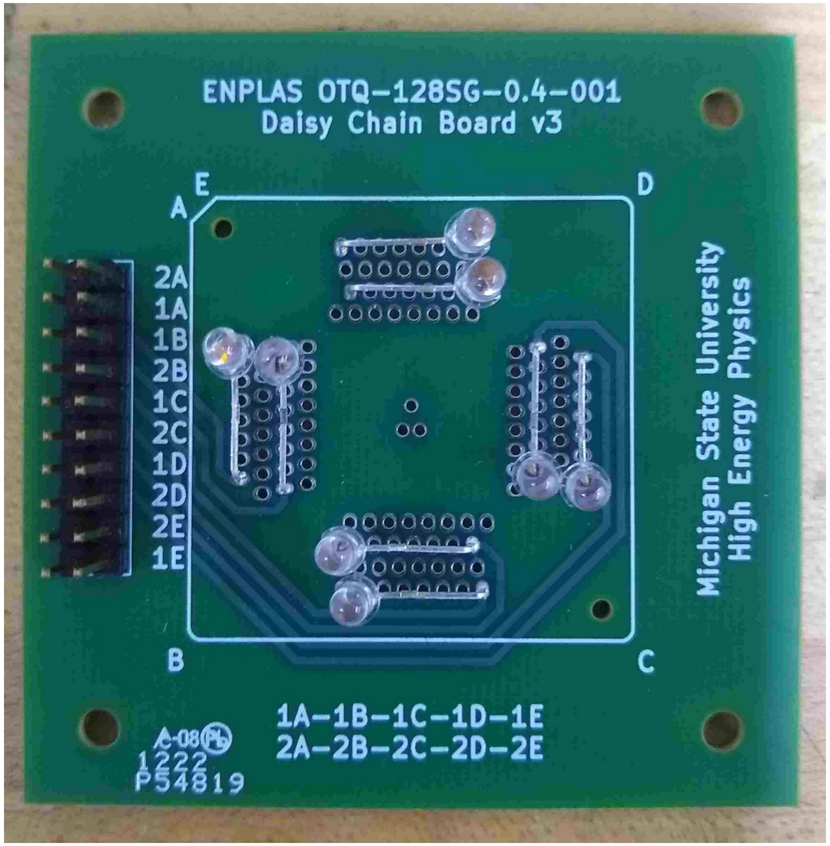
– A test card with 1 ohm resistors reads correctly: we see a 10 mV drop on each resistor with the 10 mA source.

– A test card with LEDs is used to indicate proper programming of the MUX cards.

Test board: 1 ohm resistors



Test board: LEDs



ASIC sockets: Electrical testing results

Results are stored in a log file with:
– Date, Time, Socket number, Measurement identifier, MUX channels,
– ADC count, ADC_Gain, mV, (for the daisy chain segment addressed by the MUXes)
– ADC count, ADC_Gain, mV (for the current source monitor (10 ohm resistor))
– Time-stamped inline comments

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2023-04-03 , 16:24:01.074404 , S7,2A-2E,60,68,2366,G16,18.48,6430,G8,100.47
2023-04-03 , 16:24:01.264550 , S8,1A-2A,71,70,24247,G0,4546.31,0,G8,0.00
2023-04-03 , 16:24:01.454593 , S8,1B-2B,72,73,24248,G0,4546.50,0,G8,0.00
2023-04-03 , 16:24:01.645422 , S8,1C-2C,74,75,24248,G0,4546.50,0,G8,0.00
2023-04-03 , 16:24:01.836946 , S8,1D-2D,76,77,24248,G0,4546.50,0,G8,0.00
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2023-04-03 , 16:24:02.358818 , S8,1A-1B,71,72,617,G16,4.82,6429,G8,100.45
2023-04-03 , 16:24:02.689764 , S8,1B-1C,72,74,627,G16,4.90,6429,G8,100.45
2023-04-03 , 16:24:03.020791 , S8,1C-1D,74,76,639,G16,4.99,6430,G8,100.47
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2023-04-03 , 16:24:04.675201 , S8,2C-2D,75,77,629,G16,4.91,6430,G8,100.47
2023-04-03 , 16:24:05.004812 , S8,2D-2E,77,78,643,G16,5.02,6430,G8,100.47
2023-04-03 , 16:24:05.336421 , S8,2A-2E,70,78,2335,G16,18.24,6430,G8,100.47
2023-04-03 , 16:34:23.333447 , Sockets Reloaded
2023-04-03 , 16:34:26.820137 , Scanning Sockets
```

No current flow between the interleaved daisy chains

Results so far:
– 32 batches of 8 sockets reloaded. 256 total RTS socket load cycles measured.
– Contact resistance is ~ 30 milliohms (spec is 50 milliohm) (new sockets).
– All chains daisy chains conduct
– Zero short circuits found between the interleaved daisy chains.
– 256/256 successful socket loads.
– Hands-off operation: we only pushed a button to start each cycle.

RTS Status

Robotic ASIC handling is performing well

- Robust detection of ASIC positions; able to align with robot coordinates
- 256/256 successful robotic socket loads with electrical validation (very easy to do more)
- No chips damaged, no operator interventions were required

RTS next steps

(1) Repair the test chamber: initial welding of sump tube caused minor warping of the bottom of the commercial sink. This causes a couple of LN2 puddles that don't drain, which significantly affects the chamber warm-up time.

(2) Implement an improved chamber lid design (initial tests went well).

(3) Work up an adaptable approach for cabling feed-through (see slide 11 lower image)

(4) Continue the robotic socket loading tests with cryo cycles ASAP.

(5) Work on mitigation of ice formation in the sump tube (also a problem with CTS).
Current thinking: install a small line to supply N2 purging gas into the sump tube.
Alternate idea: install a heater inside or outside the sump tube.

Extra Slides

Cryogenic system description and pictures

DAT support plate description

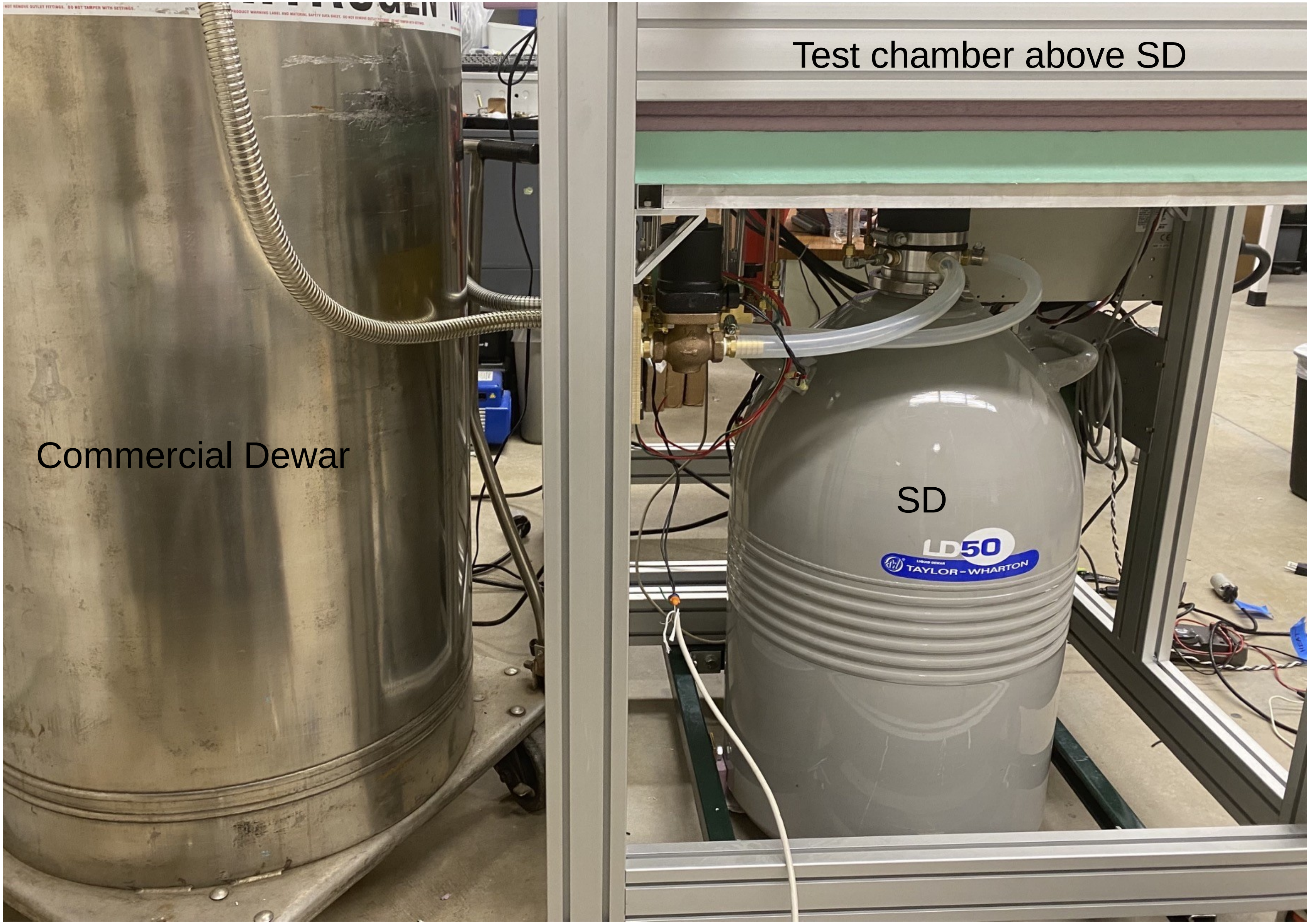
Initial list of RTS robot fault conditions

Other RTS descriptive material (for people unfamiliar with RTS)

The RTS is supplied from a commercial LN2 Dewar, and uses a smaller Storage Dewar (SD) to fill and drain the test chamber. A sump tube extends from the test chamber down into the SD.

-- Slight pressure in the SD is used to fill the test chamber

-- Relieving the SD pressure lets the LN2 drain back down into the SD



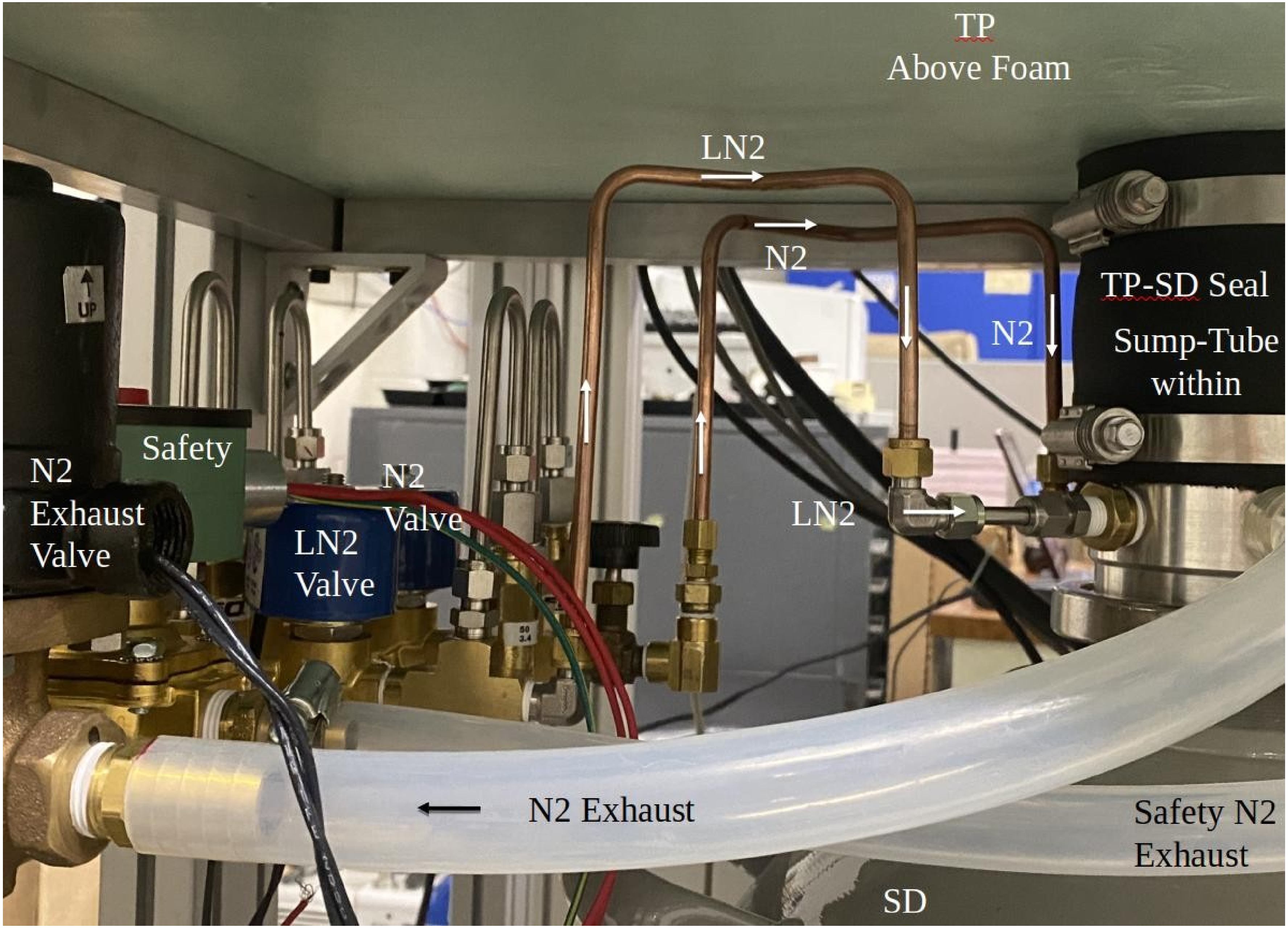
The prototype RTS cryogenic plumbing is assembled and tested.
The design follows advice from cryogenic safety experts.

View from behind RTS frame

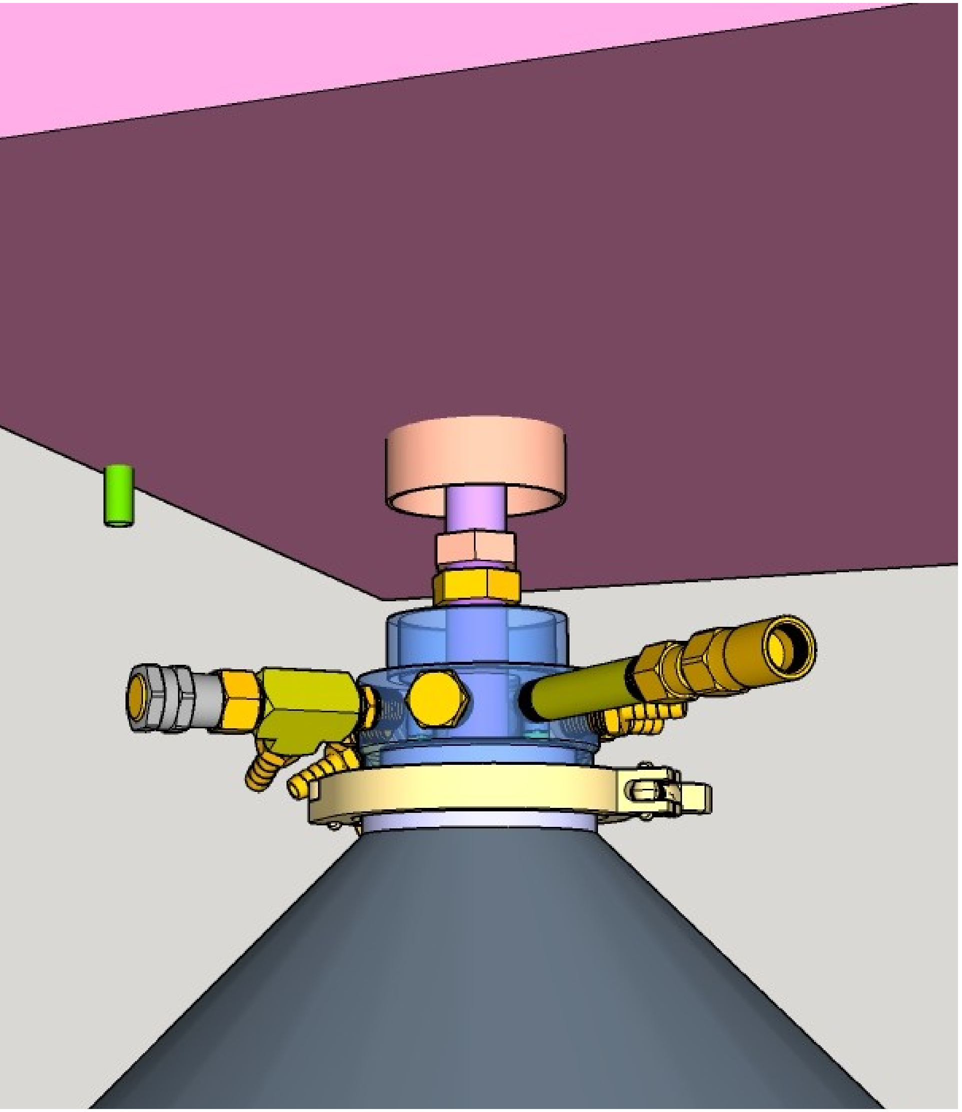
View from inside framework

<u>Annotated view of the RTS cryogenic plumbing.</u>

The RTS cryogenic controls are very similar to the existing CTS, with the addition of automatic refill of the SD from the LN2 supply.



Current Design Walk-through

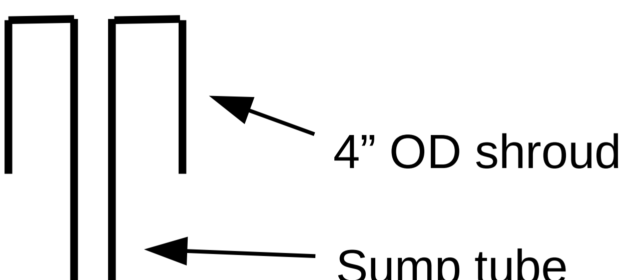


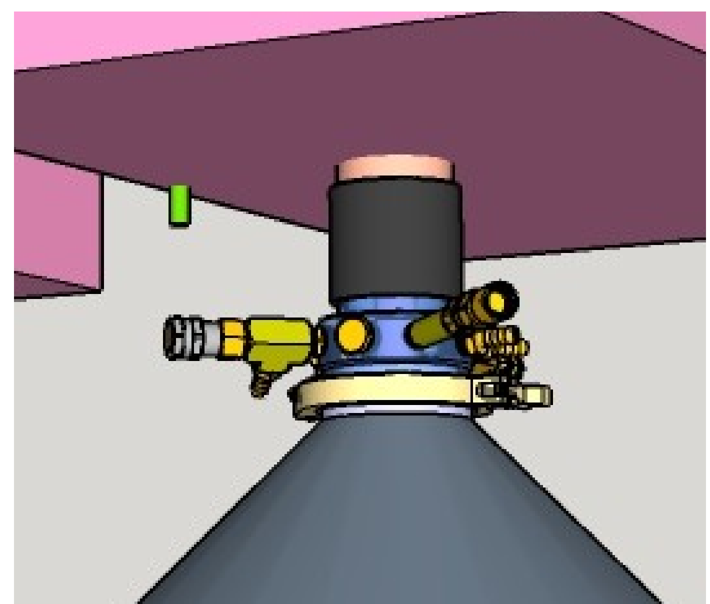
The connection between the 50 liter Dewar and the test chamber uses a new design.

The robotic chip handling requires a rigid connection between the robot arm and the test chamber. This in turn basically requires a non-rigid connection between the test chamber and the large/heavy LN2 Dewar.

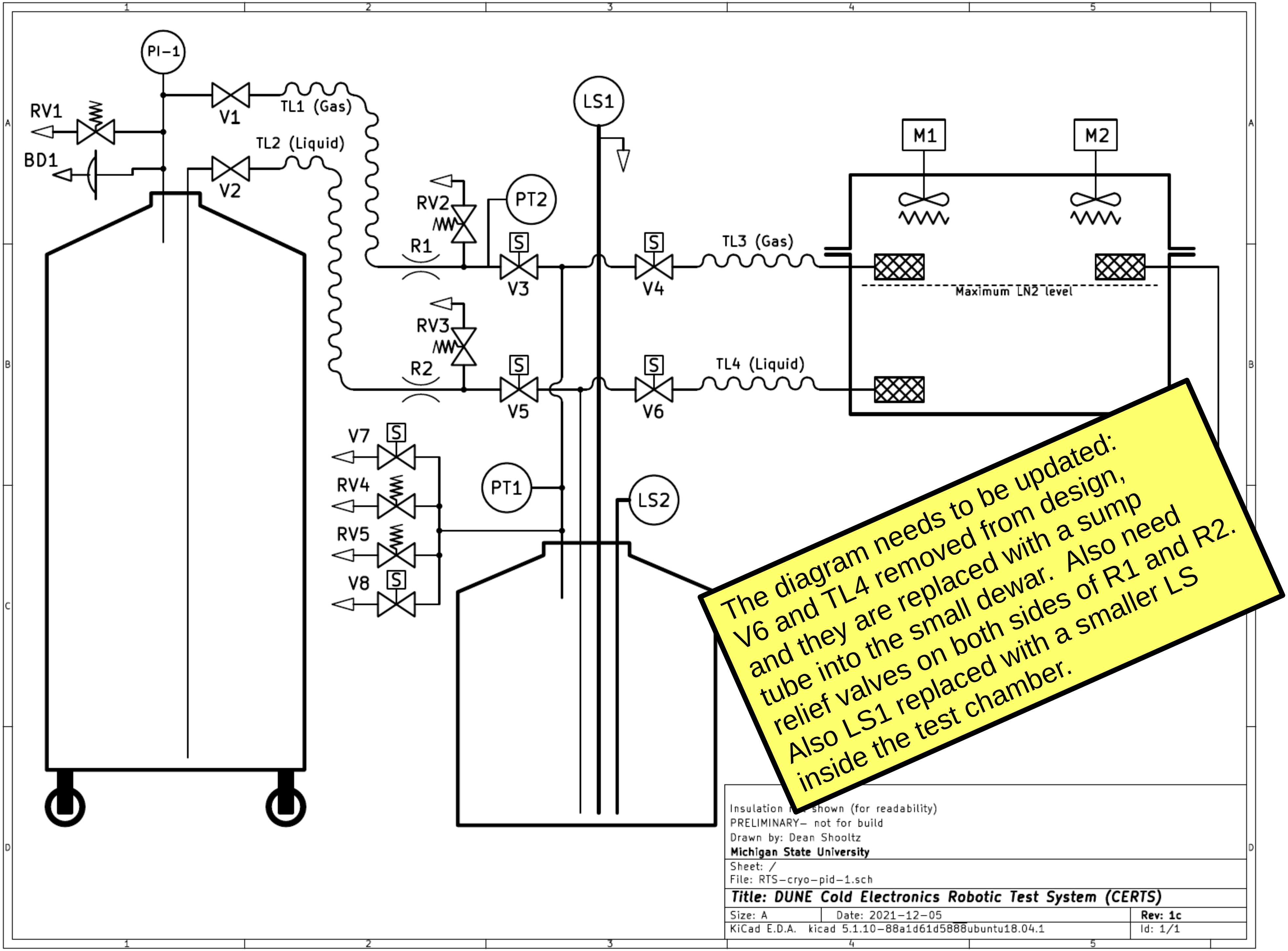
In the new design the sump tube passes through a clearance hole in the adapter at the top of the Dewar. The Dewar head-space continues past this connection and up to a welded connection at the bottom of the sink.

A short section of 4” diameter tubing connects the Dewar adapter to the sink adapter





Full Piping Diagram (no annotation)

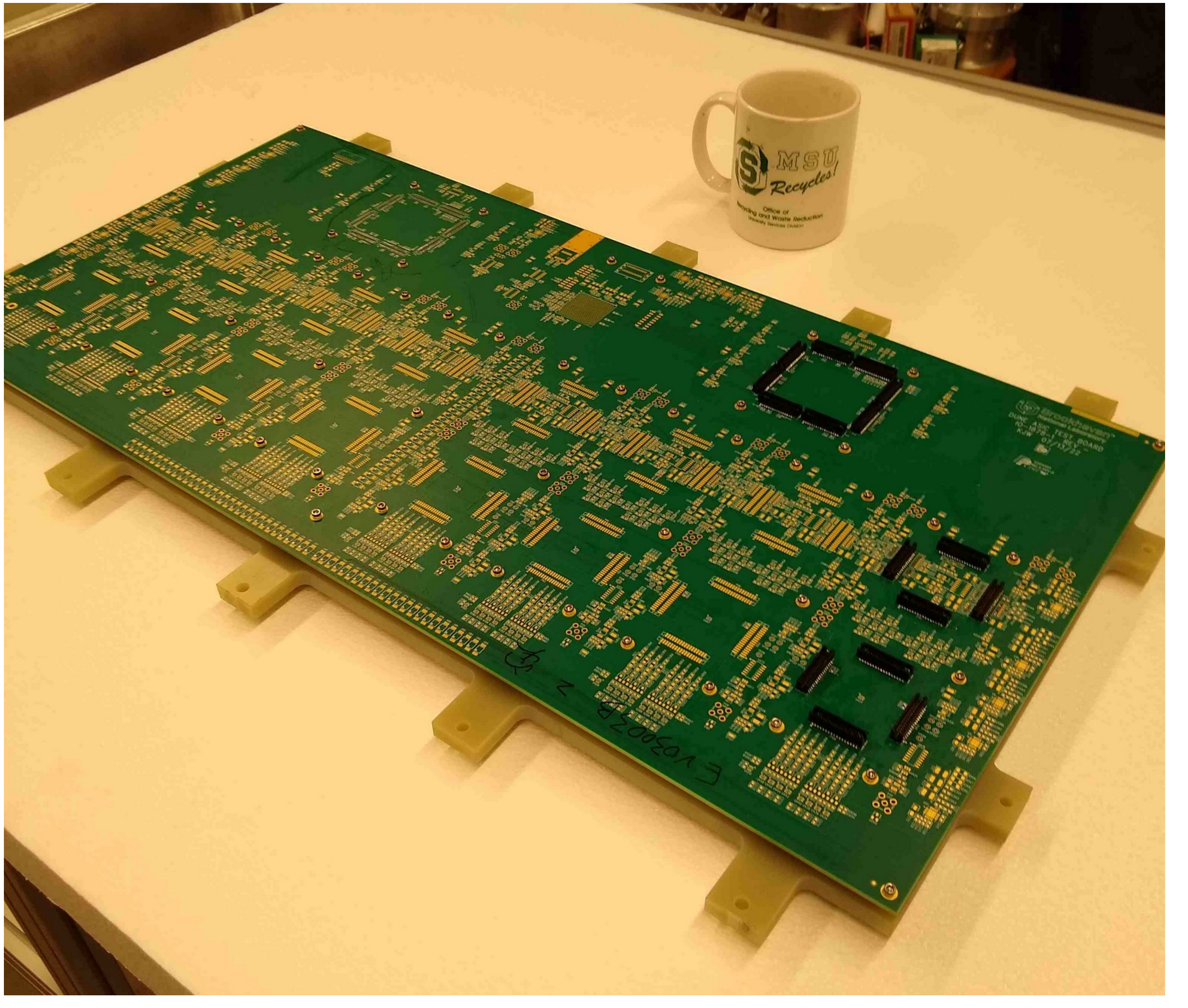


DAT and support plate

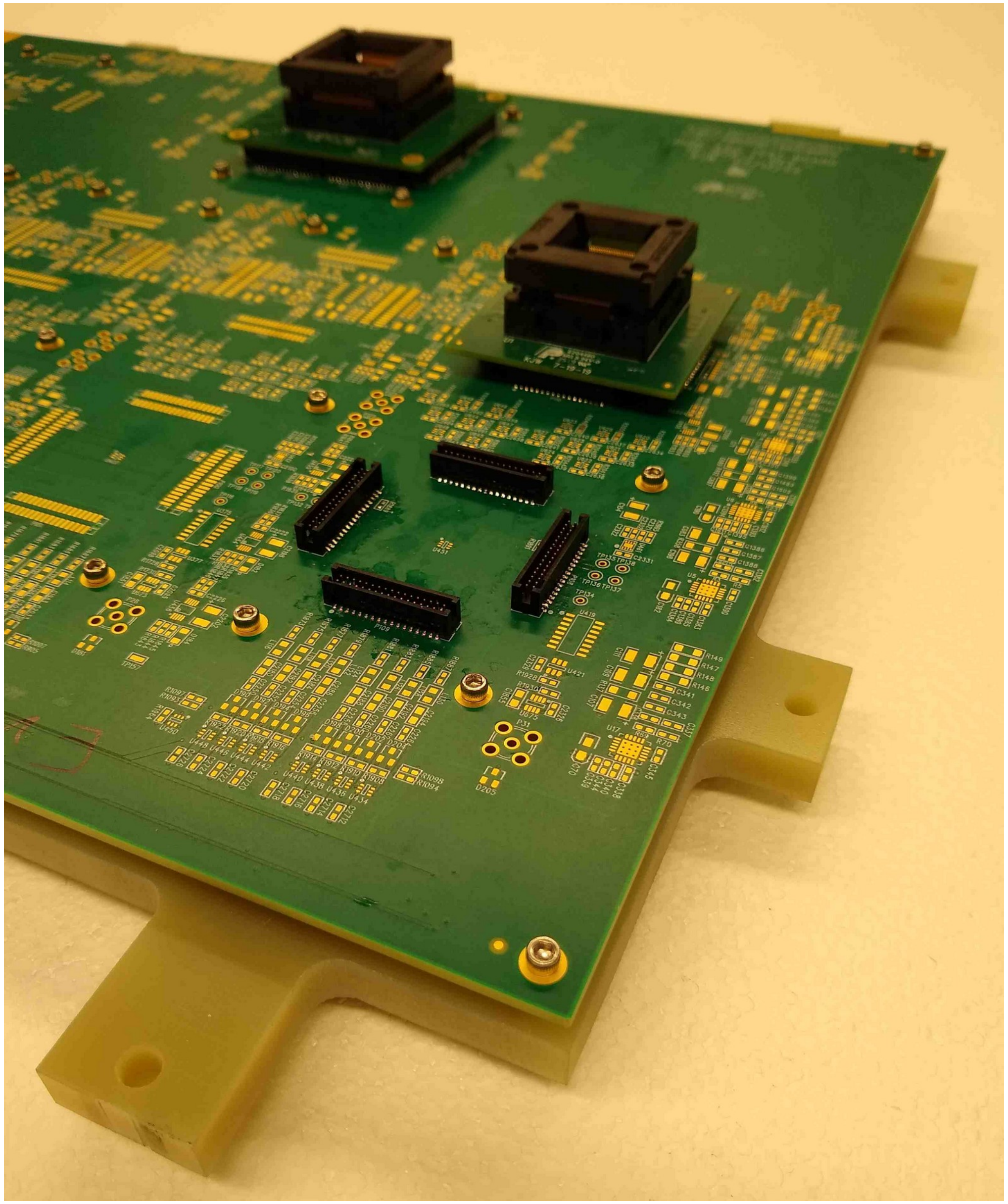
The testing hardware inside the RTS test chamber is the DAT (DUNE ASIC Tester) from BNL.

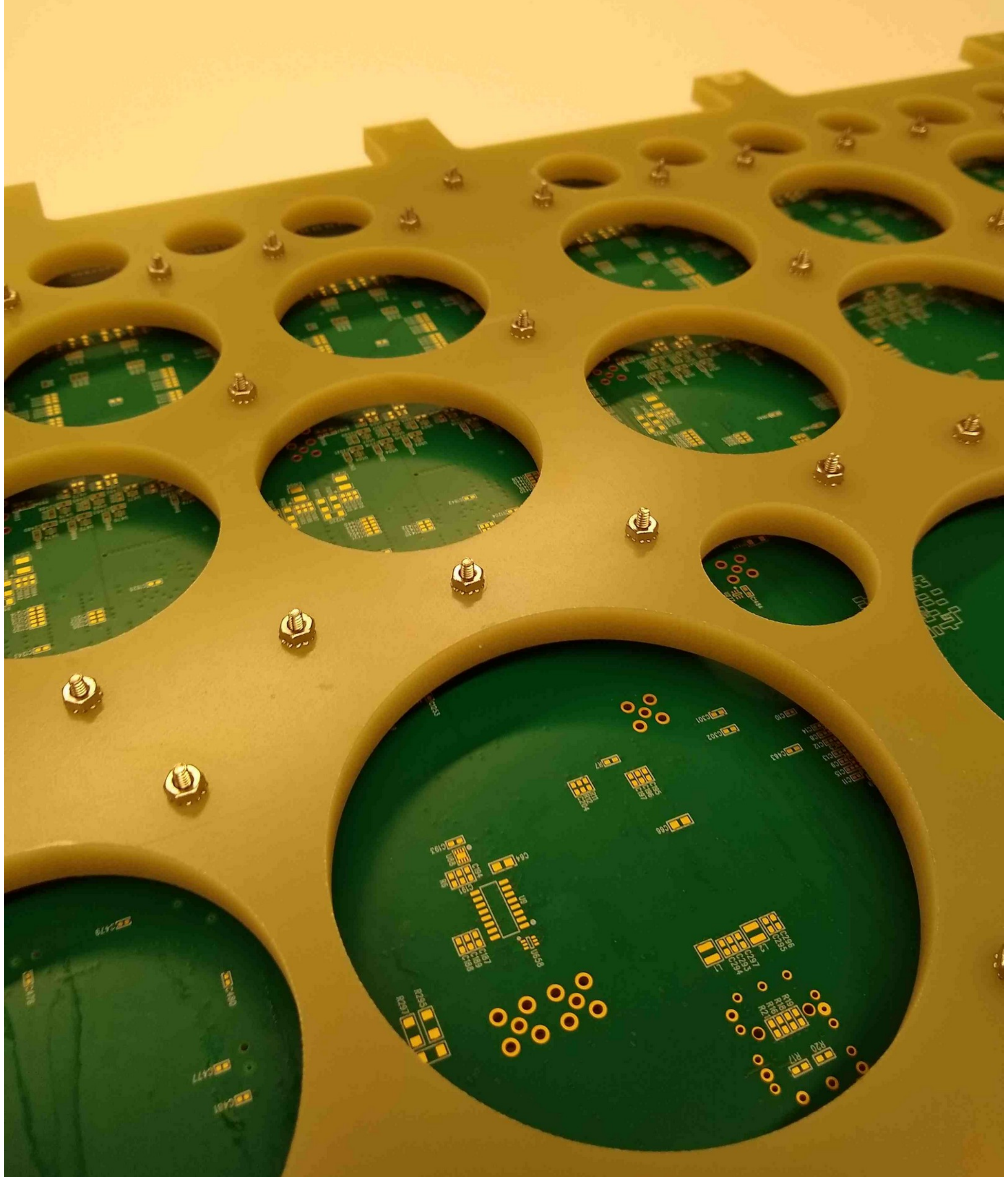
The DAT is mounted to a G-10 support plate that mounts to the RTS test chamber.

A partially populated DAT is shown here



Top and bottom views of the assembly of the DAT board and support plate.

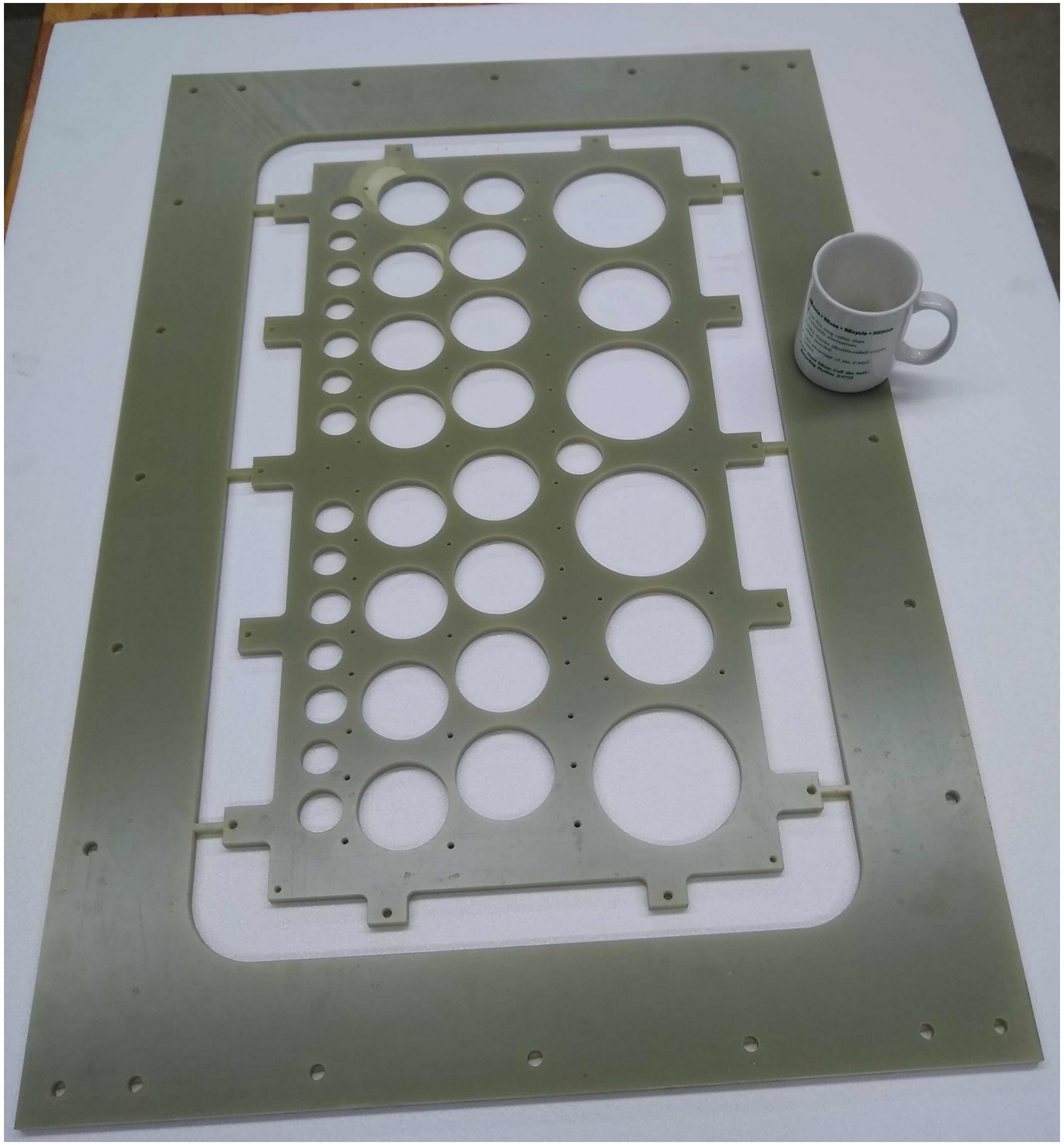




The DAT board support plate and the test chamber support plate are machined from a single sheet of 3/8” thick G-10. (Material cost ~$200 per sheet)

The machining is done entirely with Abrasive waterjet cutting. This method has a fast turnaround and is reasonably priced. (~$200 per sheet machining cost)

The DAT support plate is ported out to remove material the lower the mass of the items in the cryo-cycling chamber, and also allow better gas circulation around the DAT board.



The current model DAT support plate was measured for deflection under load.

The goal is to minimize the flexing of the DAT board during load/unload cycles (within reason).

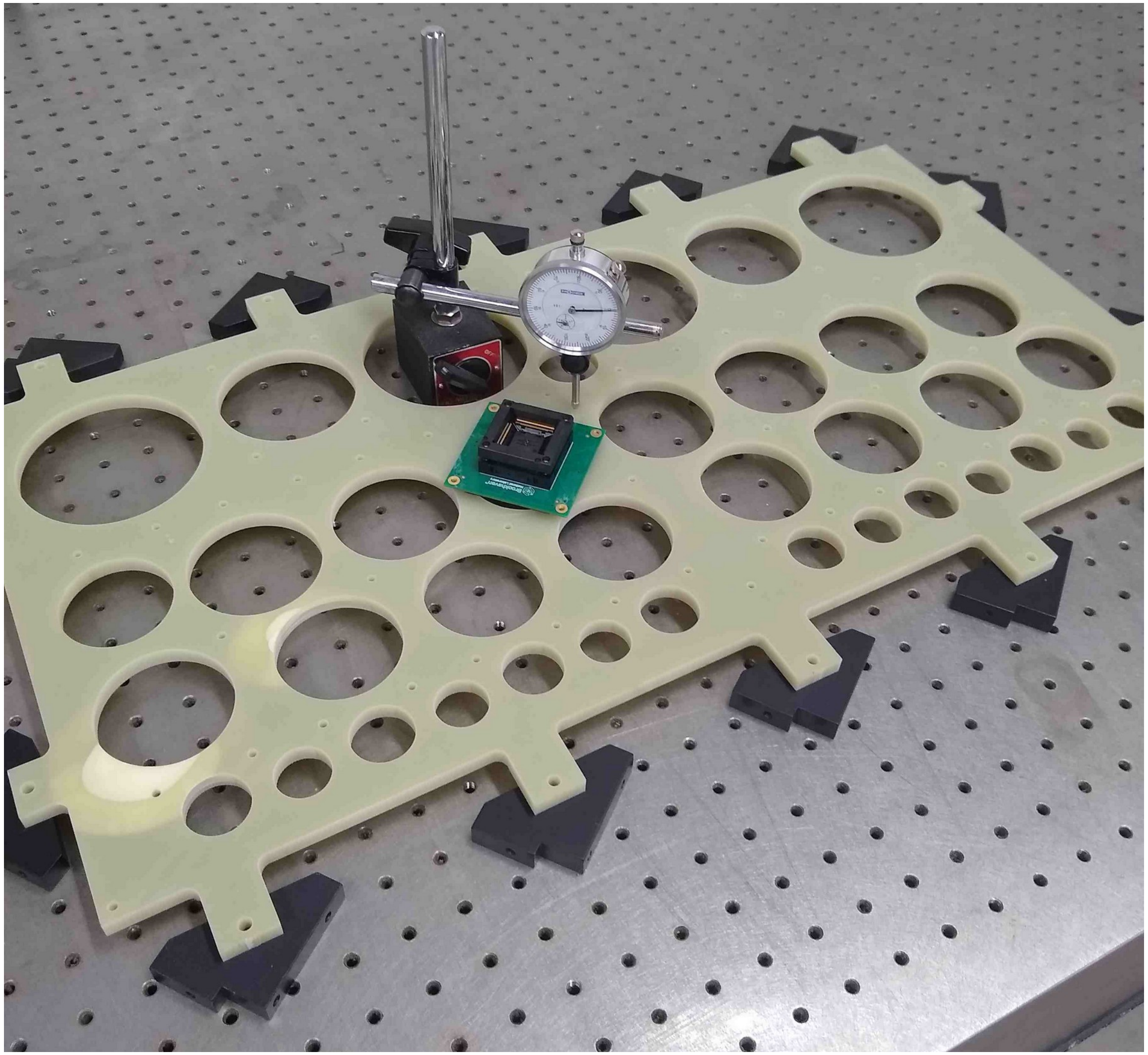
Measurements were made in the worst-case position in the center of the plate.

Deflection was measured while manually actuating the ASIC test socket.

For the ColdDATA test socket, plate deflection is approximately 0.012”

For the smaller LArASIC and ColdADC socket, plate deflection was approx. 0.008”

We can possibly improve the plate, but it seems OK for the current RTS prototype.



Robot system fault conditions

There are many fault conditions to consider.

The cameras can help in many cases, but some problems might not be visible to the cameras.

-- Chip already in socket or in tray

-- Chip in wrong orientation in socket or tray

-- Chip mis-loaded in socket or in tray

– Two stacked JEDEC trays in tray holder

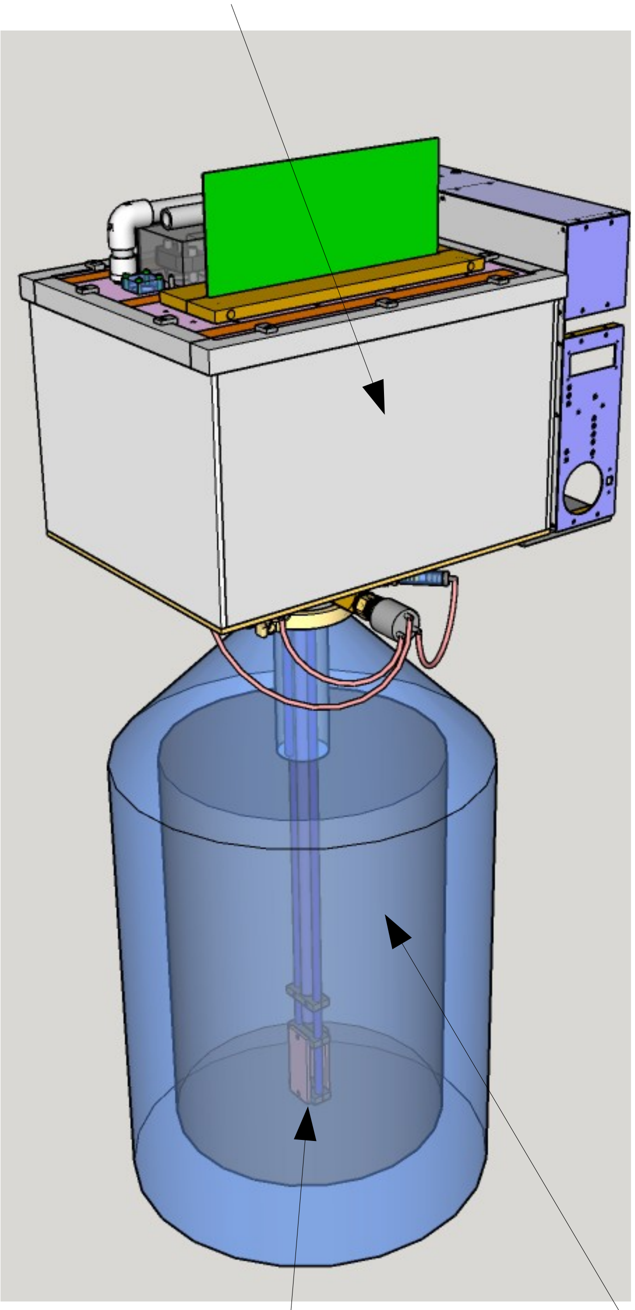
-- Socket on DAT board in wrong position, partially installed, or missing

-- Dropped chip

-- Damaged chip- leads bent or missing

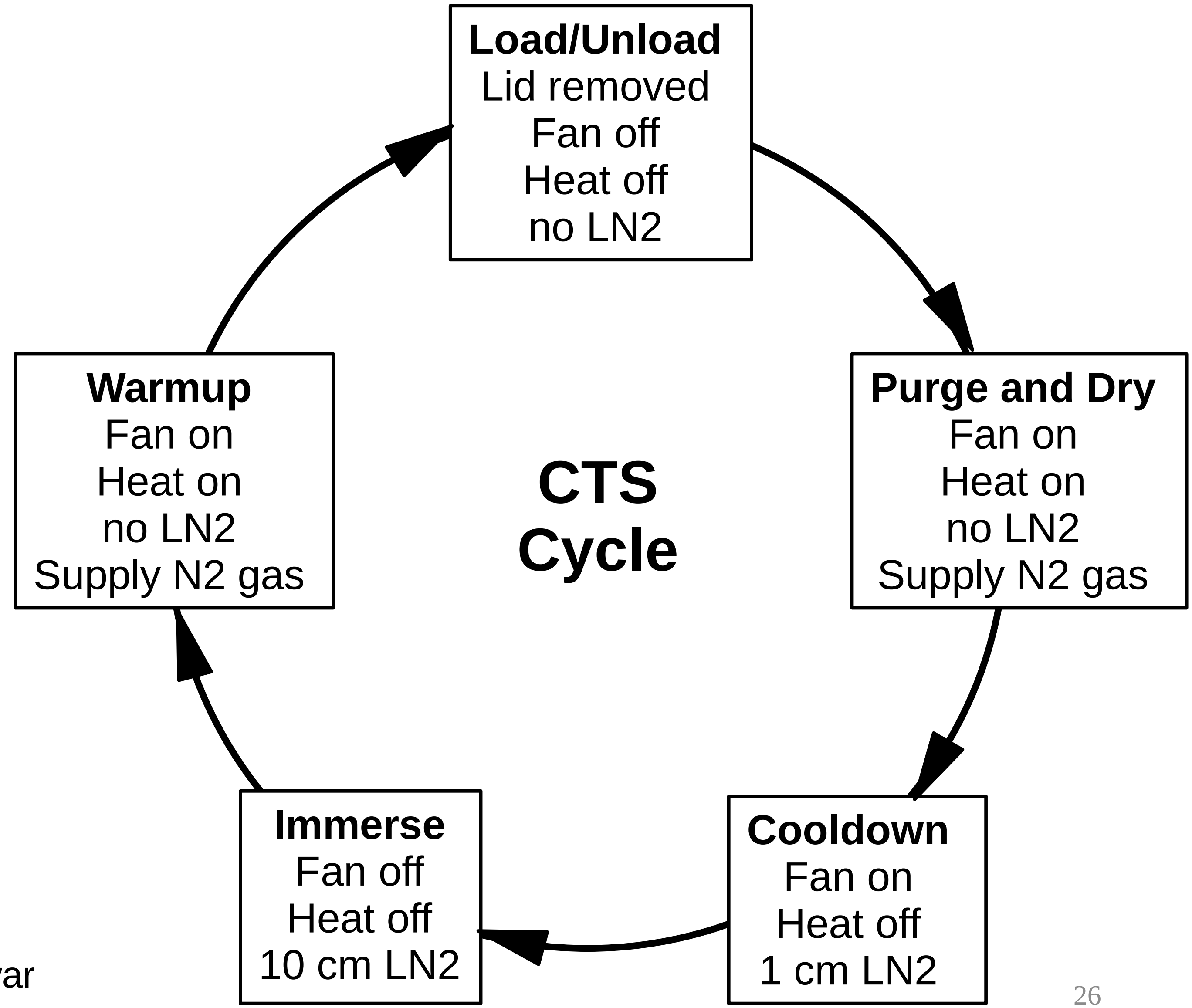
-- Robot collision (unexpected object in robot path)

-- (still building list)



Cryo Testing Station

– Cycle time is roughly one hour (plus electronics testing time)
– Fans and heaters are located inside test chamber
– Slight pressure in Dewar used to raise LN2 into test chamber
– Relieve pressure and LN drains back into Dewar
– CTS cycle keeps DUT dry throughout the cycle



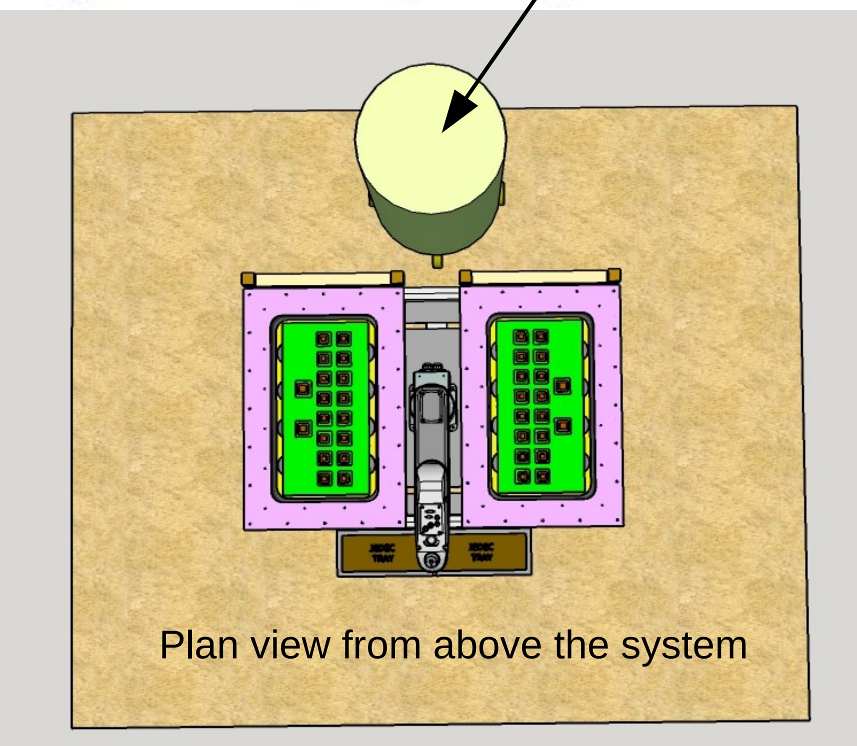
Current Design Walk-through

The RTS is connected to a larger portable supply Dewar.

The portable supply Dewar:
(1) Is used to refill the 50 liter Dewars prior to each cycle
(2) Provides a gas N2 supply to run the cryogenic cycle

Estimated LN2 usage is roughly 10 liters per chamber per cycle.

Thus a full 160 liter portable Dewar should be able to supply the RTS for 16 chamber loads, which is about a full shift of testing.



Plan view from above the system

The overall RTS with the associated supply Dewar will require a open floor space of 11 feet by 9 feet to provide operator access to all four sides of the system.