# Staying Cool: the Thermoelectic Cooling of SiPMs

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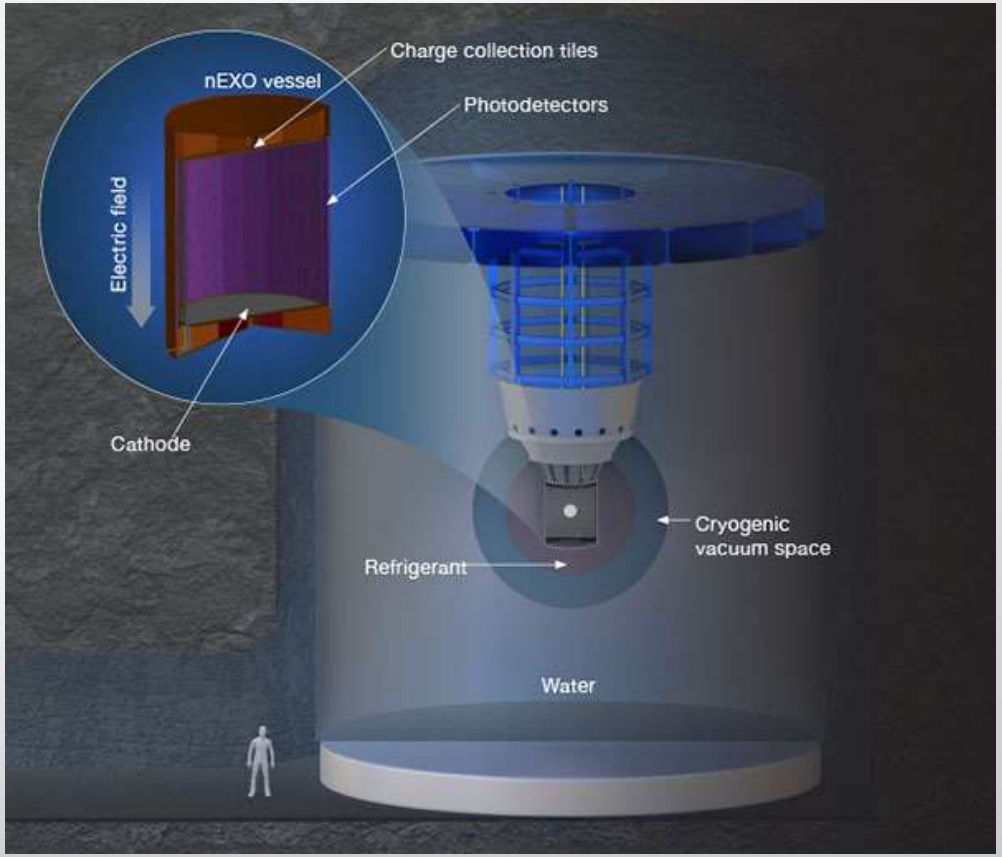
# The nEXO Experiment

- A proposed search for the hypothetical neutrinoless double beta decay ($0\nu\beta\beta$), proposed to be at SNOLAB
  - 5 tonnes LXe enriched to 90% $^{136}$Xe
  - The time projection chamber houses ~$10^4$ silicon photomultipliers (SiPMs) to detect scintillation light from $0\nu\beta\beta$
- Projected half-life sensitivity of 1.35x$10^{28}$ years at 90% C.L.
- Characterize how silicon photomultipliers (SiPMs) act at LXe temperatures




https://nexo.llnl.gov/nexo-overview

Hacot-Slonosky, McGill, Thermoelectric Cooling of SiPMs, CASST 2024

# SiPM Characterization at Low Temperatures

- Silicon photomultipliers (SiPMs) in nEXO will work to detect scintillation light from $\beta\beta$ decay events at LXe temperatures (~ -100°C).
- One part of testing SiPMs is measuring their sensitivity to a single photon at low temperatures, and so we want to suppress the dark count rate.
- -40°C is a low enough temperature where the dark counts can be neglected.
- Can reach -40°C much more easily with thermoelectric coolers (TECs).

# How Do Thermoelectric Coolers Work?

- TEC employ the Peltier effect:
  - When current passes through two dissimilar semiconductors (n-type and p-type), a temperature gradient forms across the junctions, depending on the direction of the current.
- TE coolers pass direct current from N-type to P-type semiconductors.
- Modules are made of many semiconductors arranged thermally in parallel, but electrically in series.

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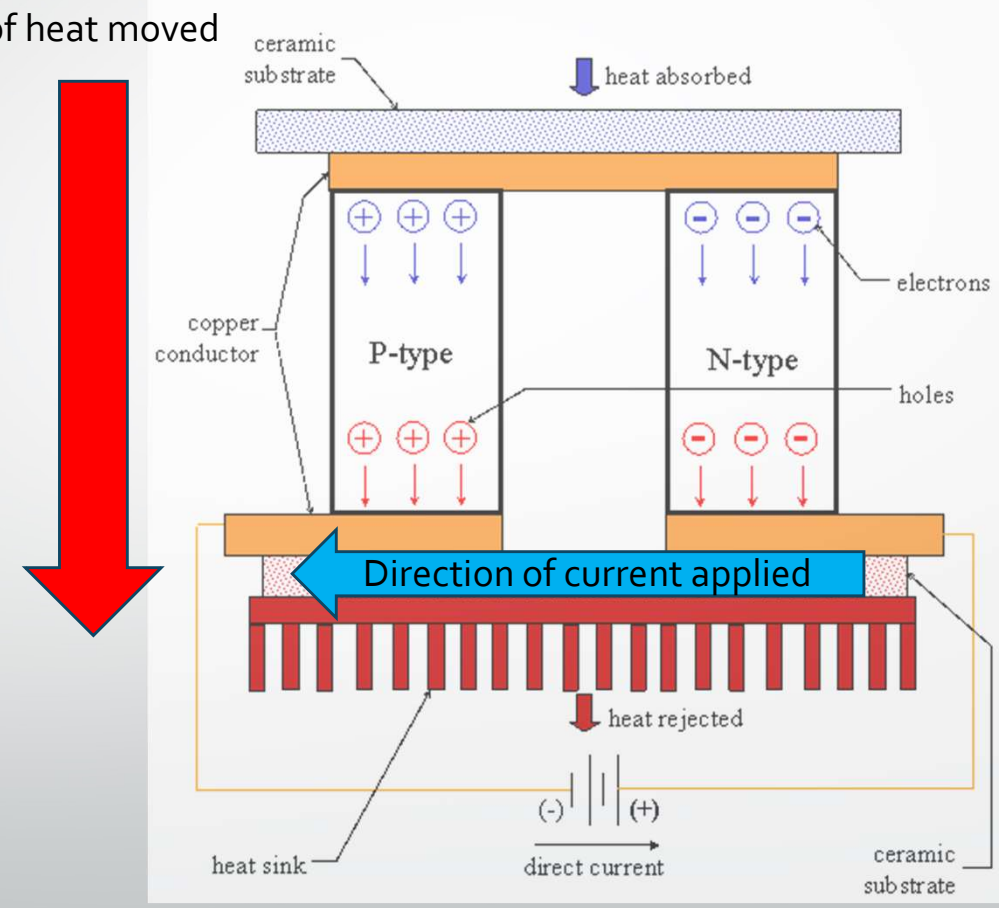
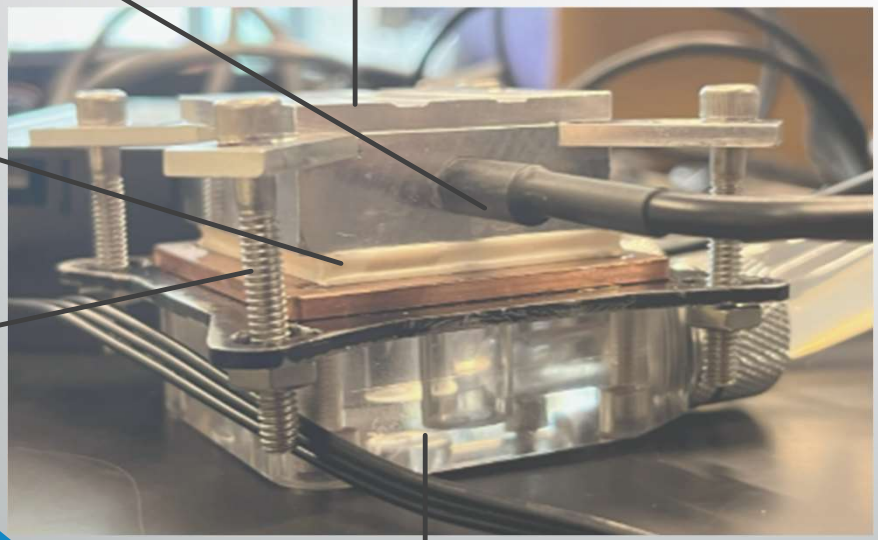


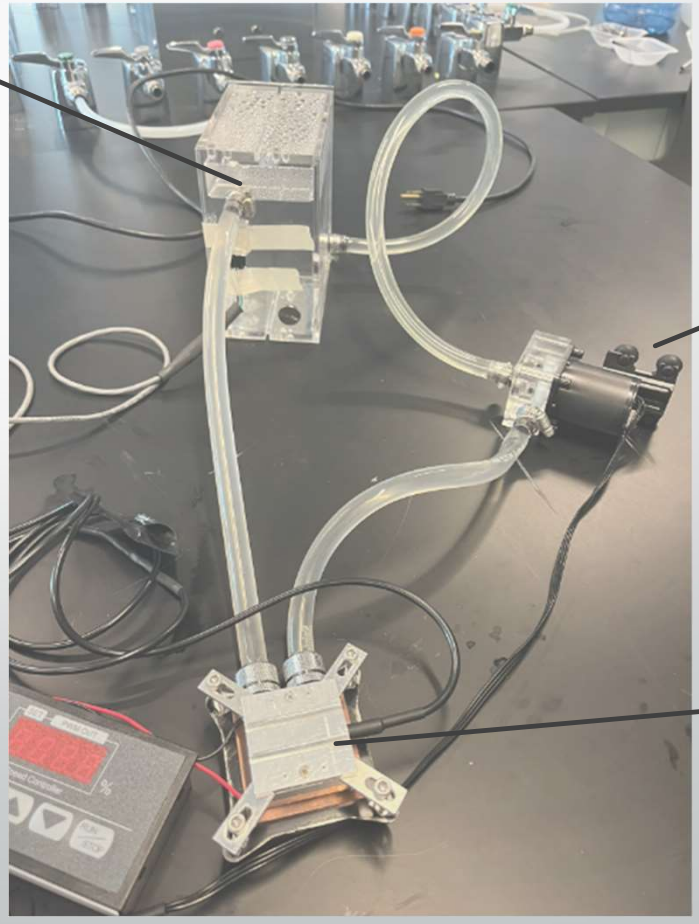



https://tetech.com/faqs/#15

# Initial Tests

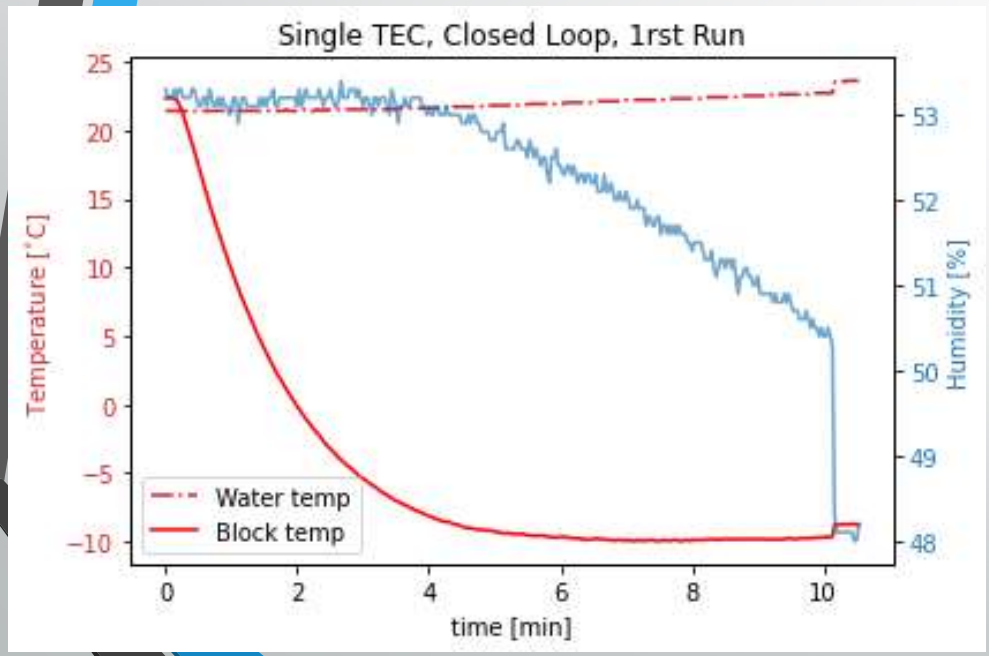
- 1 TEC pressed between a pc chip water cooling block and an aluminum thermal load.
- Closed loop cooling

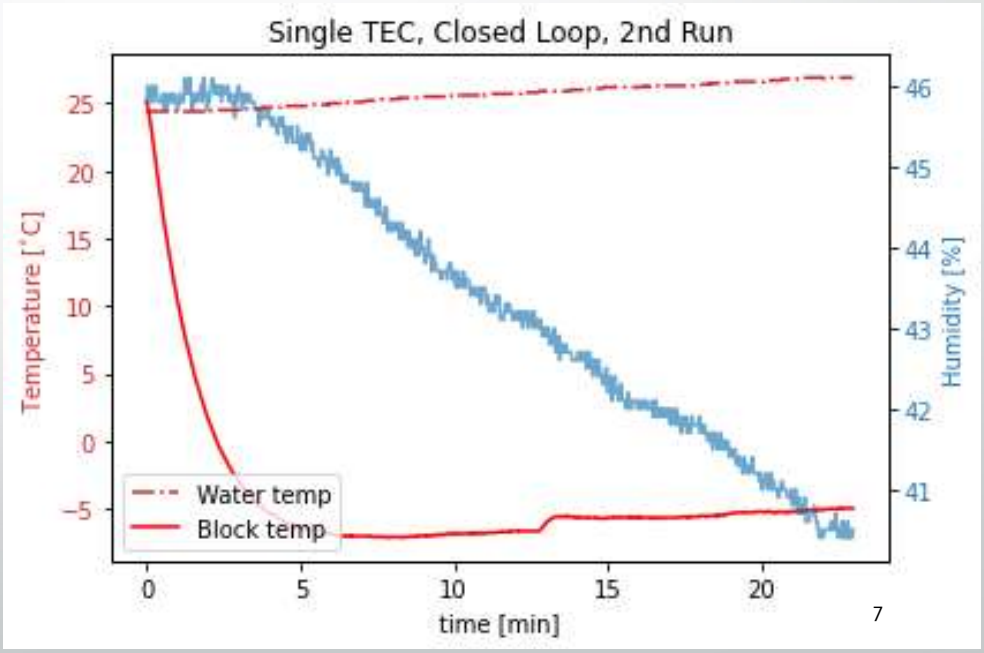


# Initial Tests

- The original setup works:
  - As the water temperature increased, so did the temperature of the aluminum block.
  - Recycled water from closed loop decreases the amount of heat able to be pulled away.
  - Single unit gave a constant $\Delta T \sim 30°C$.



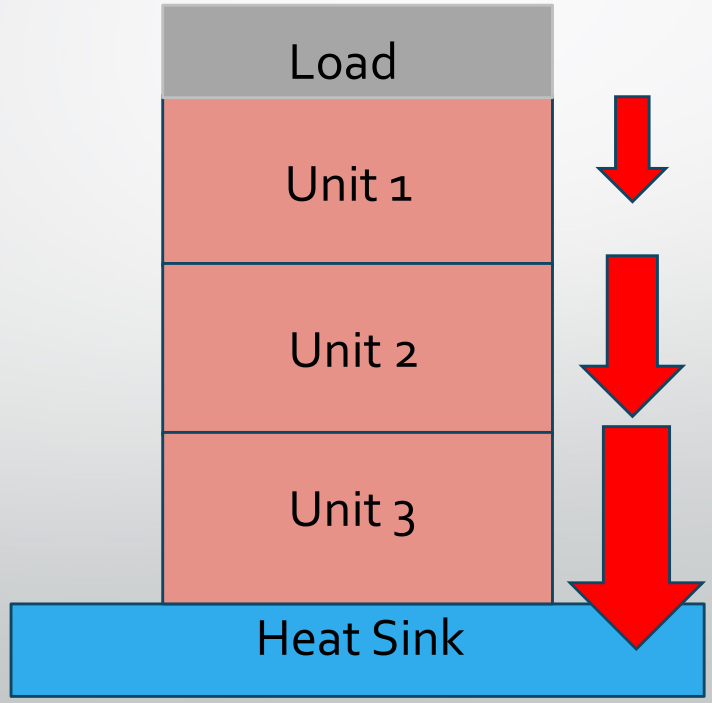
# Upgrading the System

- Two avenues for improvement:
  1. Better heat sink
  2. More heat moved

1. Better heat sink:
   - Closed loop recycles warm water with limited heat dissipation
   - Open loop from the building chilled water supply allows for cooler water at constant temperature
2. More heat moved
   - Using more units allows for greater $\Delta T$
   - Stacking units loses efficiency quickly

# The Trouble With Stacking TECs

- The thermal load on an individual TEC increases the further down the stack it is until it cannot cool the load any further.



# The Trouble With Stacking TECs

$\Delta T = 37°C$ 8 V x 3 A = 24 W used

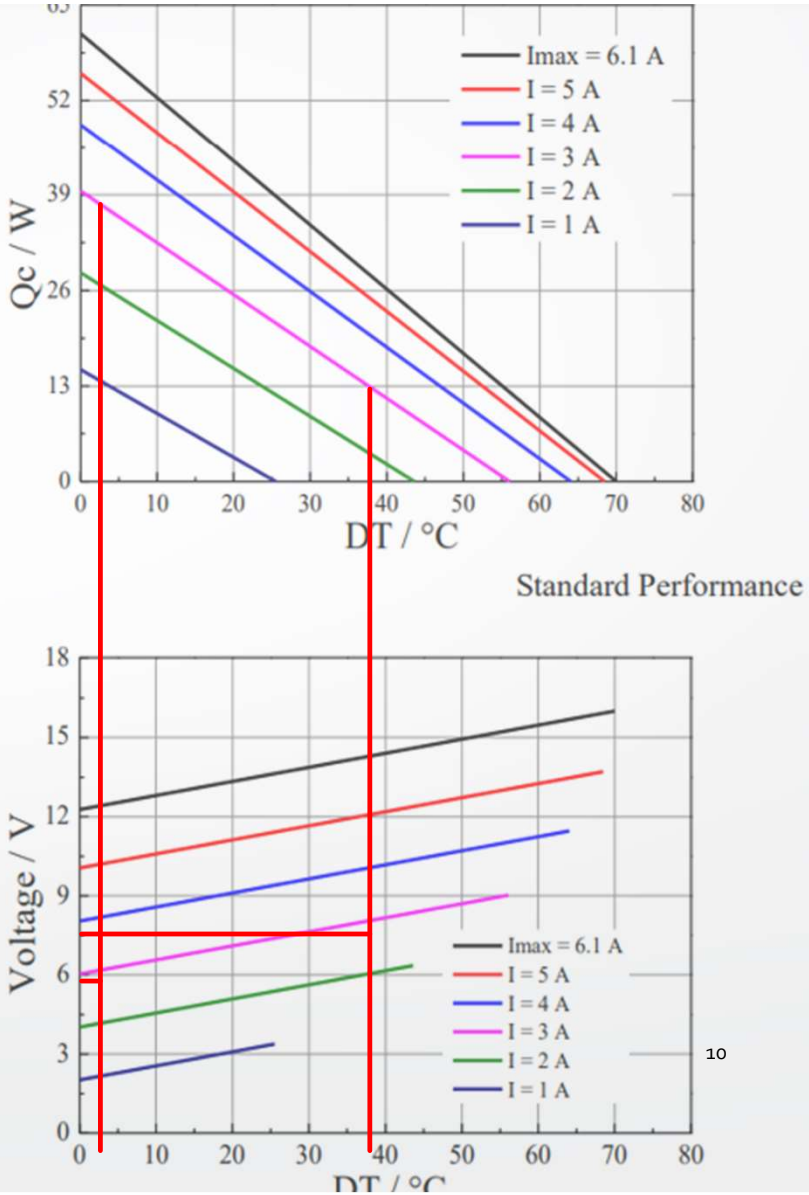
For first unit 24 W used + 13 W pumped = 37 W total

$\Delta T = 3°C$ 6 V x 3 A = 18 W used

For second unit 18 W used + 13 W pumped = 31 W total

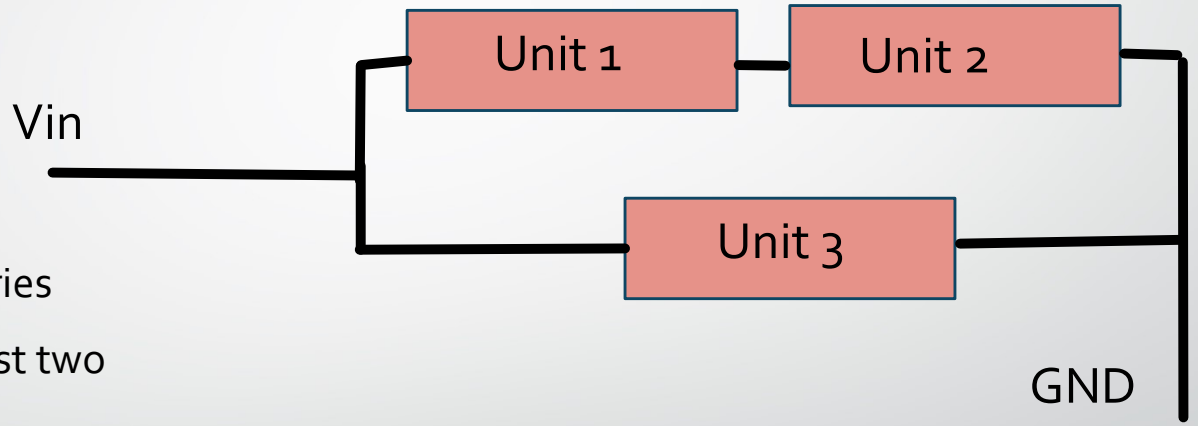
In total, 18 W used + 21 W used = 39W total for a $\Delta T = 40°C$

Quickly diminishing returns



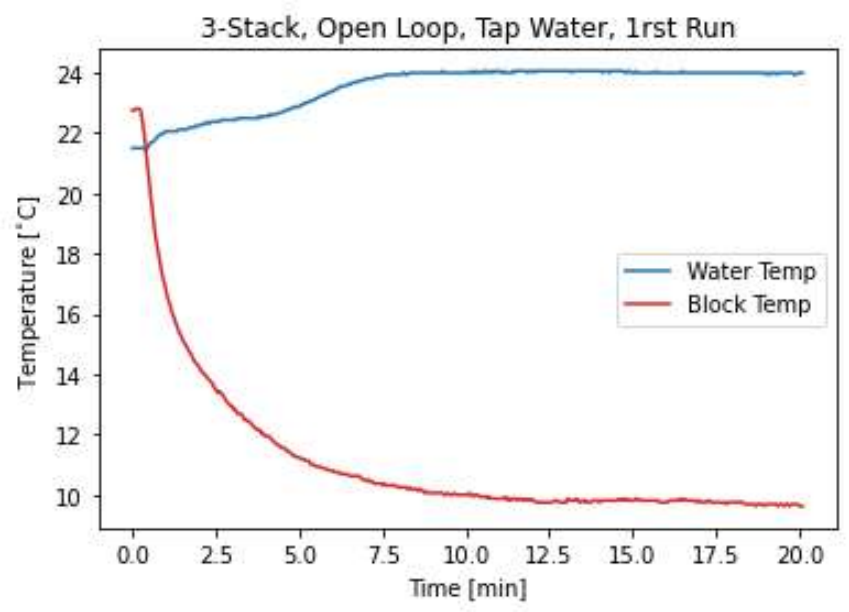
# How to Stack TECs

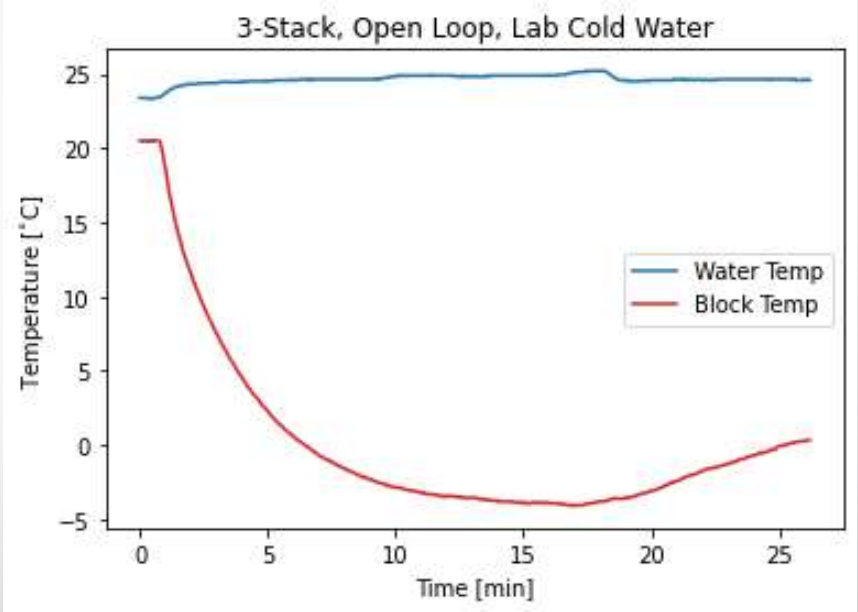
- 3-stack
  - All thermally in series
  - First two electrically in series
  - Bottom in parallel with first two
- Bottom receives twice the current to deal with the extra heat load



# First Trials

- Tested a 3-stack with open loop cooling with water from the tap

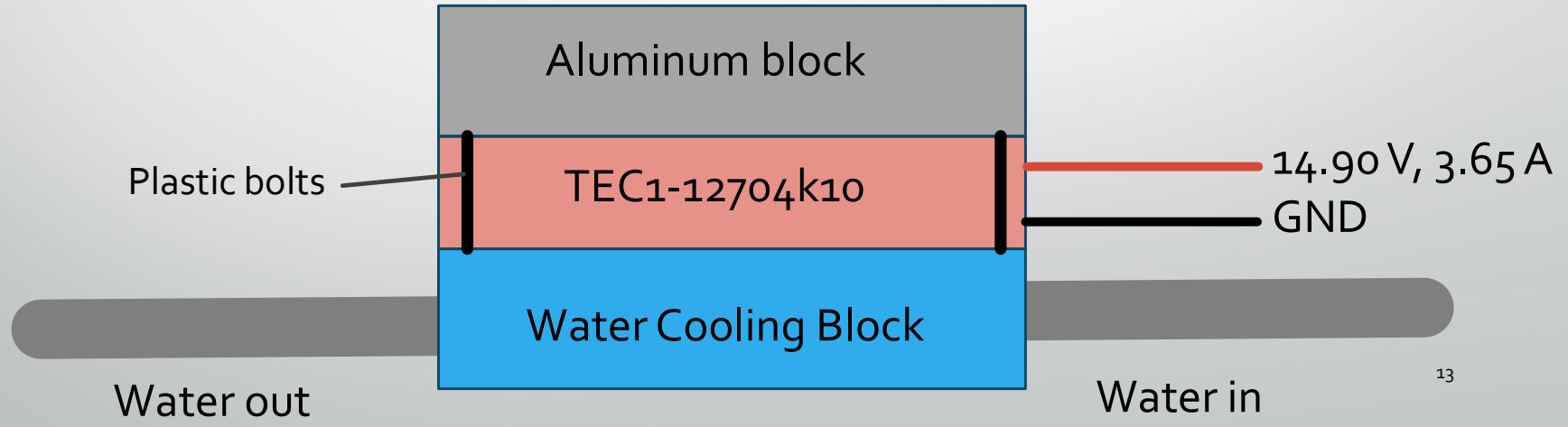



Clearly something is not working as intended…

# Back to Basics

- The 3-stack method only works if all the units are the same, these were not…
- Replaced the 3-stack with one TEC1-12704k10 unit
- Replaced the stainless steel bolts with plastic bolts
- Used open loop water cooling



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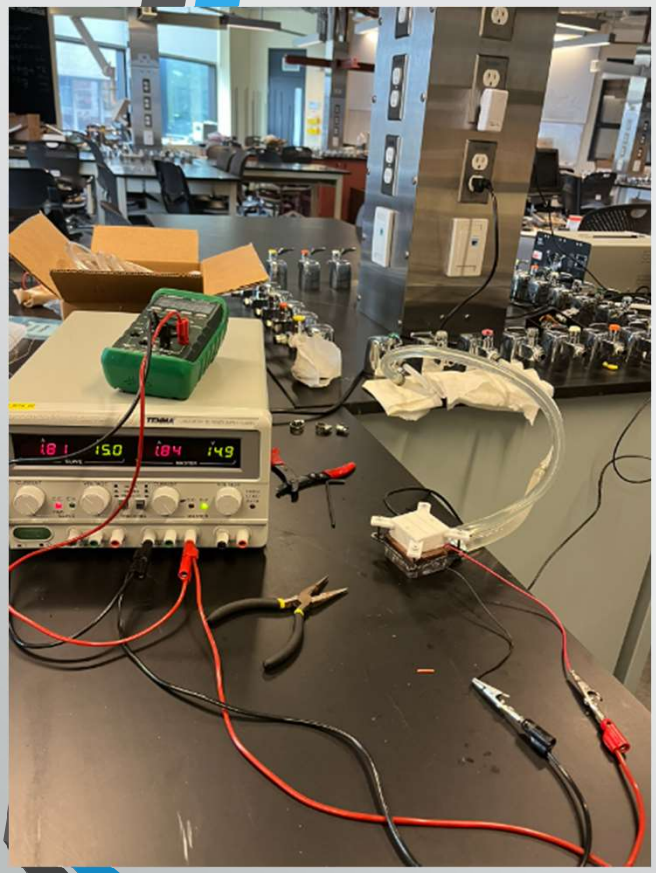
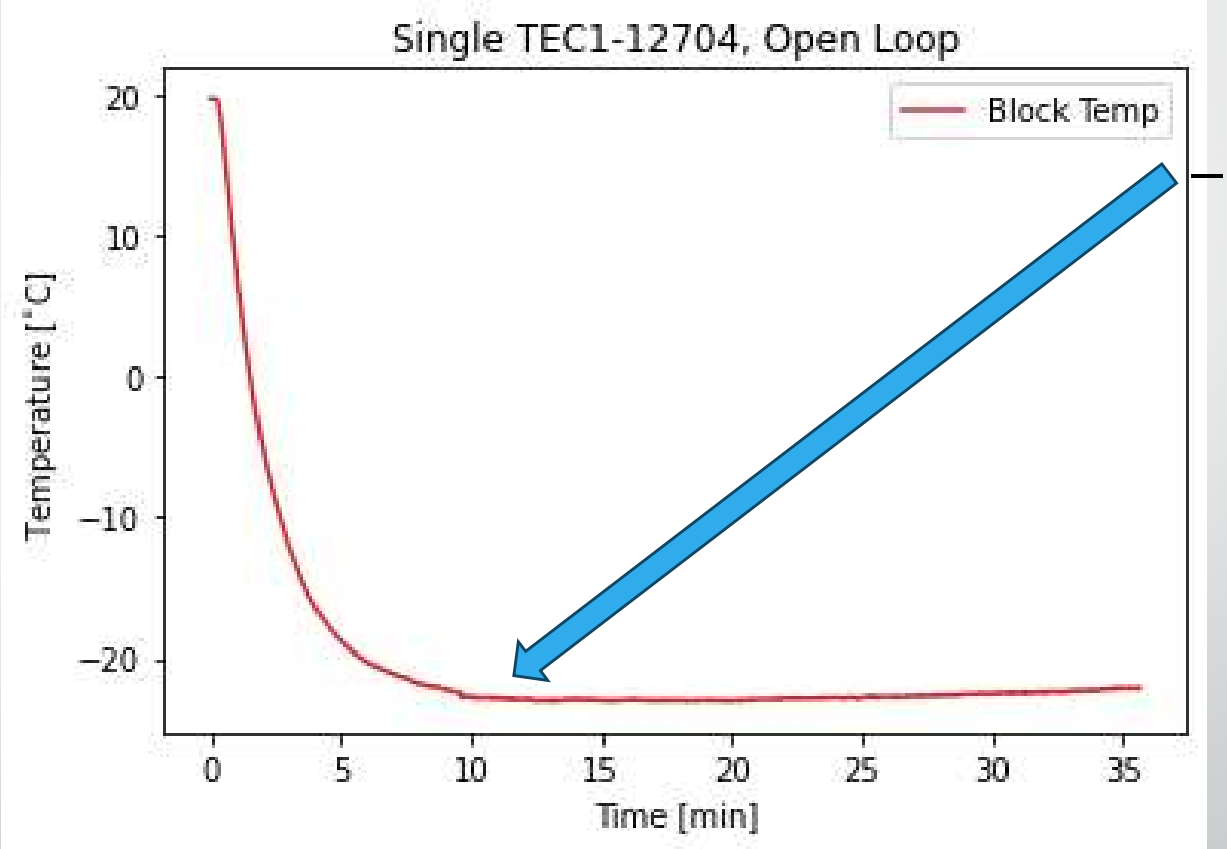


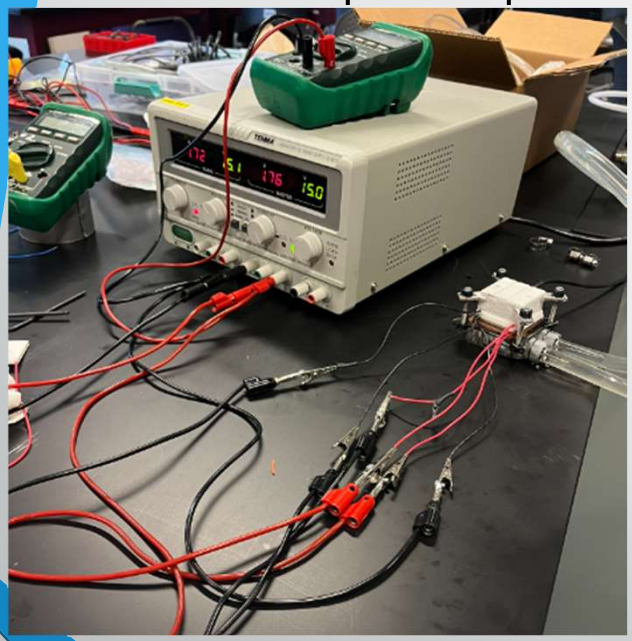


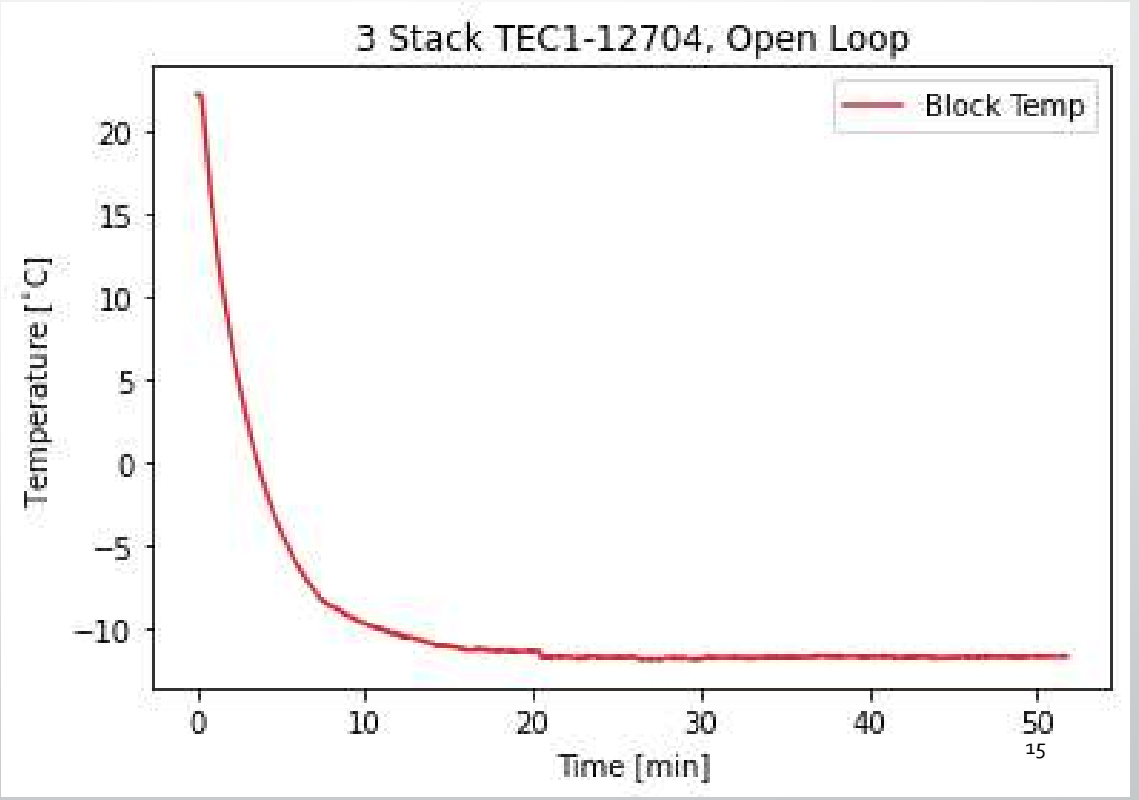

−23°C !

- The open loop cooling is much better than the closed loop cooling
- Using a thermally insulating layer between the hot and cold side also improves performance

# Latest Attempt With 3-Stack

- Stacked 3 TEC1-12704k10
- Used 3D printed spacers between the bolts
- Used open loop cooling






Still only -11°C with the 3-stack

# Moving Forwards

- Find better ways to thermally isolate the load from the environment, hot side
- Prevent the buildup of ice crystals that will envelop the SiPM
- Incorporate the open loop cooling with the building chilled water supply

# Acknowledgements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And all the McGill Physics department technical staff

# Extra Slides

# The Trouble With Stacking TECs

Laird Thermal Systems, Multistage series electric cooler https://www.lairdthermal.com/datasheets/datasheet-MS2-049-14-14-15-15-11-W8.pdfr