Temperature Profile

ProtoDUNE-SP Cryogenics Instrumentation Review

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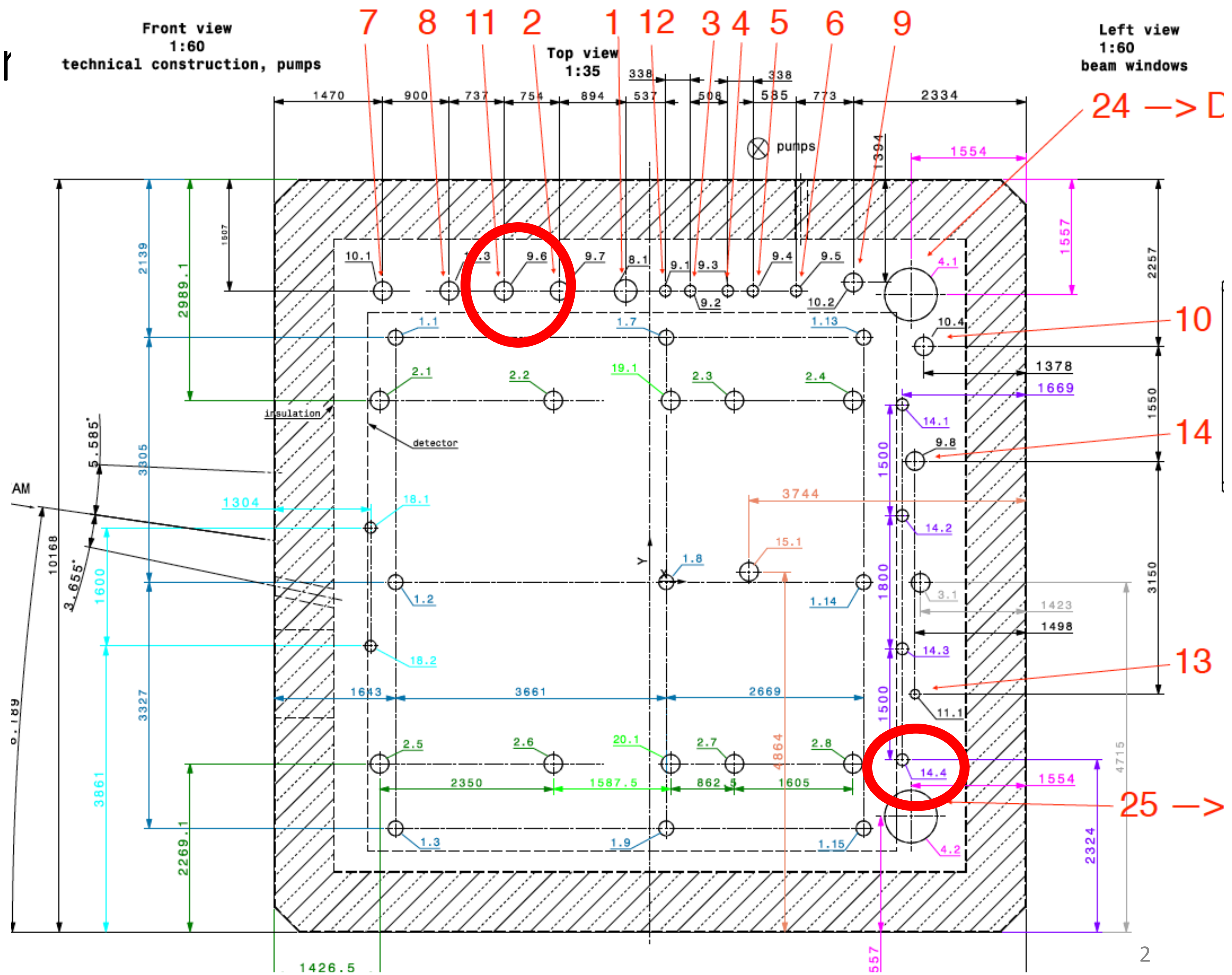
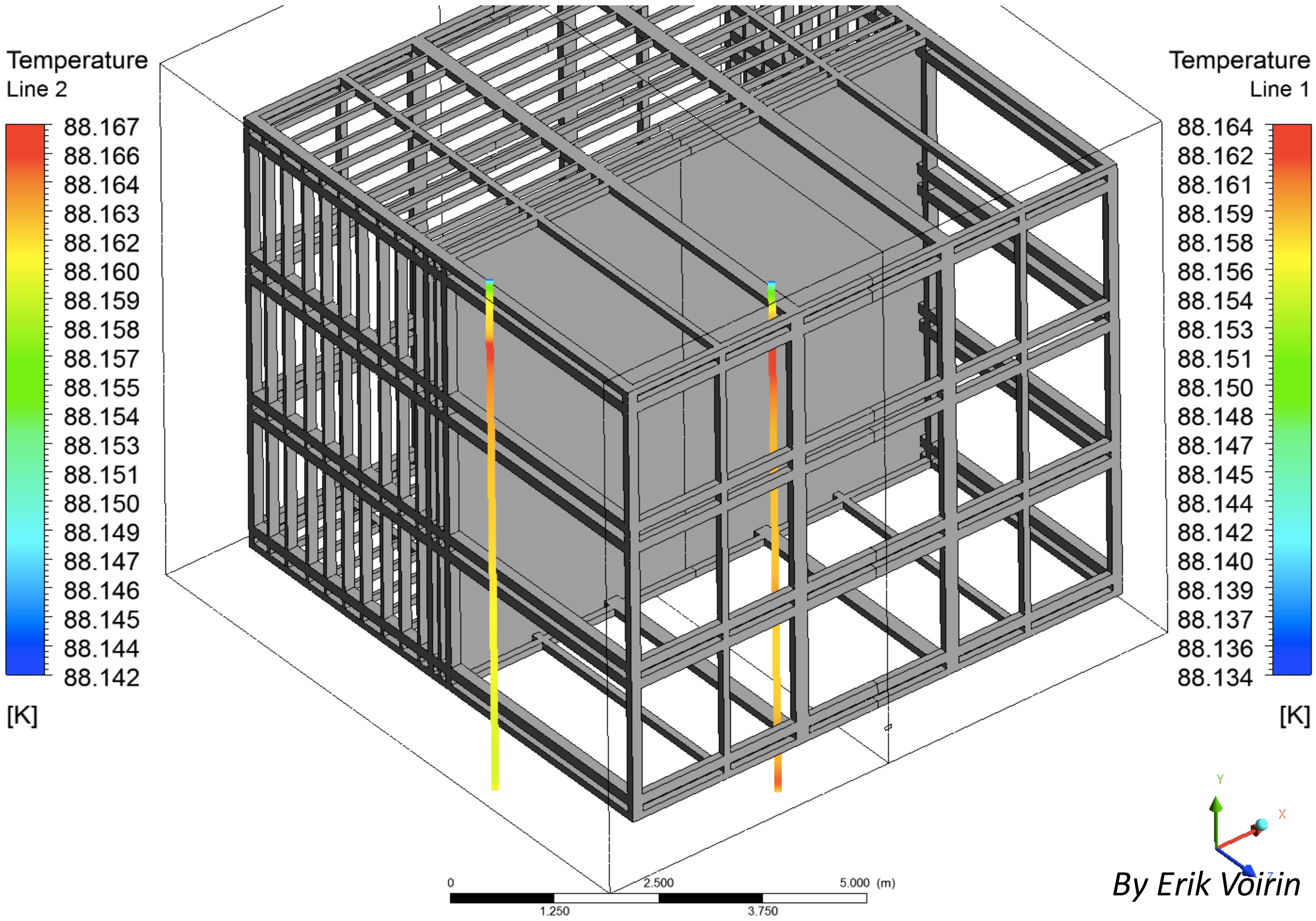
Location of Flanges for Temperatur Profilers

- Two temperature sensor arrays anticipated: use flange 9.6 and 14.4.
- Hawaii plans to use 9.6 flange (250 mm)
- Valencia plans to use 14.4. flange (150 mm)
- *One profile is behind the APA plane, while the other is at near the field cage with rather high electric field →driving the design.*



Expectations for the ProtoDUNE-SP temperature Profile

Simulated temperature profile for protoDUNE



By Erik Voirin

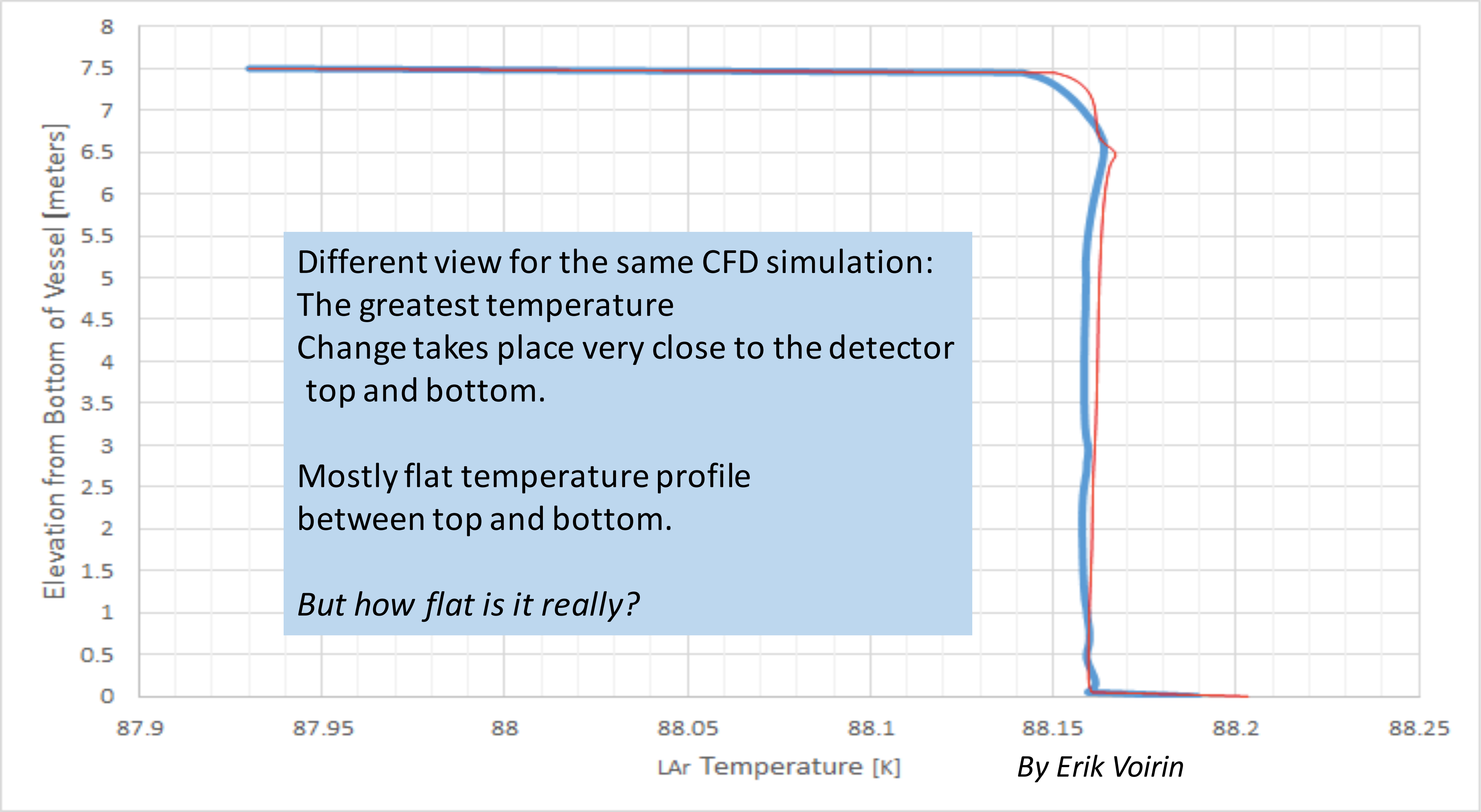
Based on the design of the protoDUNE SP and Computational Fluid Dynamics (CFD) models.

CFD model has been checked against the data in the past increasing its credibility for planning purposes.

Slow variations in temperature. **Small variation ~20 mK over the entire height.**

Input from Erik:
1 m sampling with high precision desired.

Simulated Temperature Profile – very stable

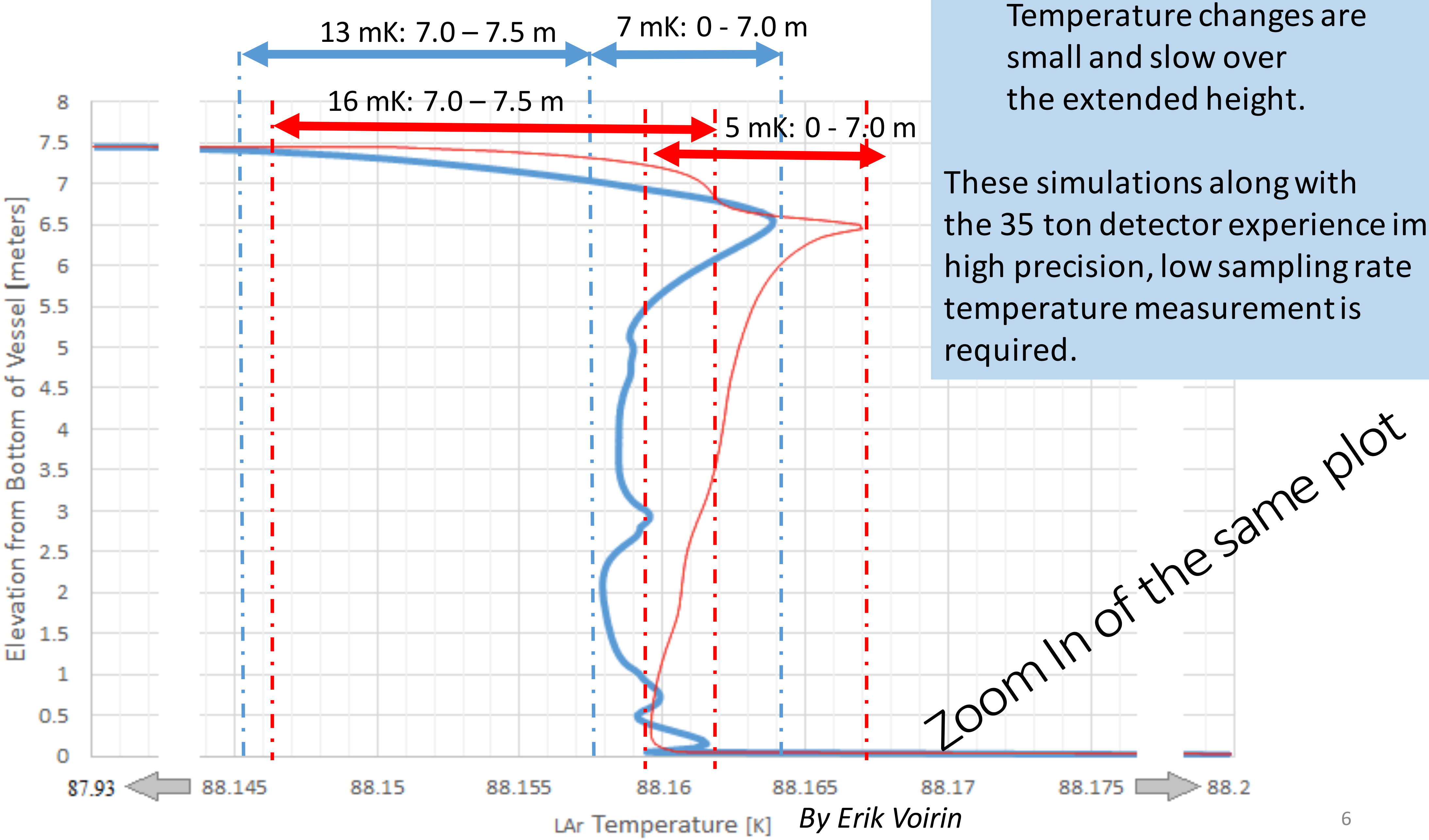


Different view for the same CFD simulation:
The greatest temperature
Change takes place very close to the detector
top and bottom.

Mostly flat temperature profile
between top and bottom.

But how flat is it really?

By Erik Voirin



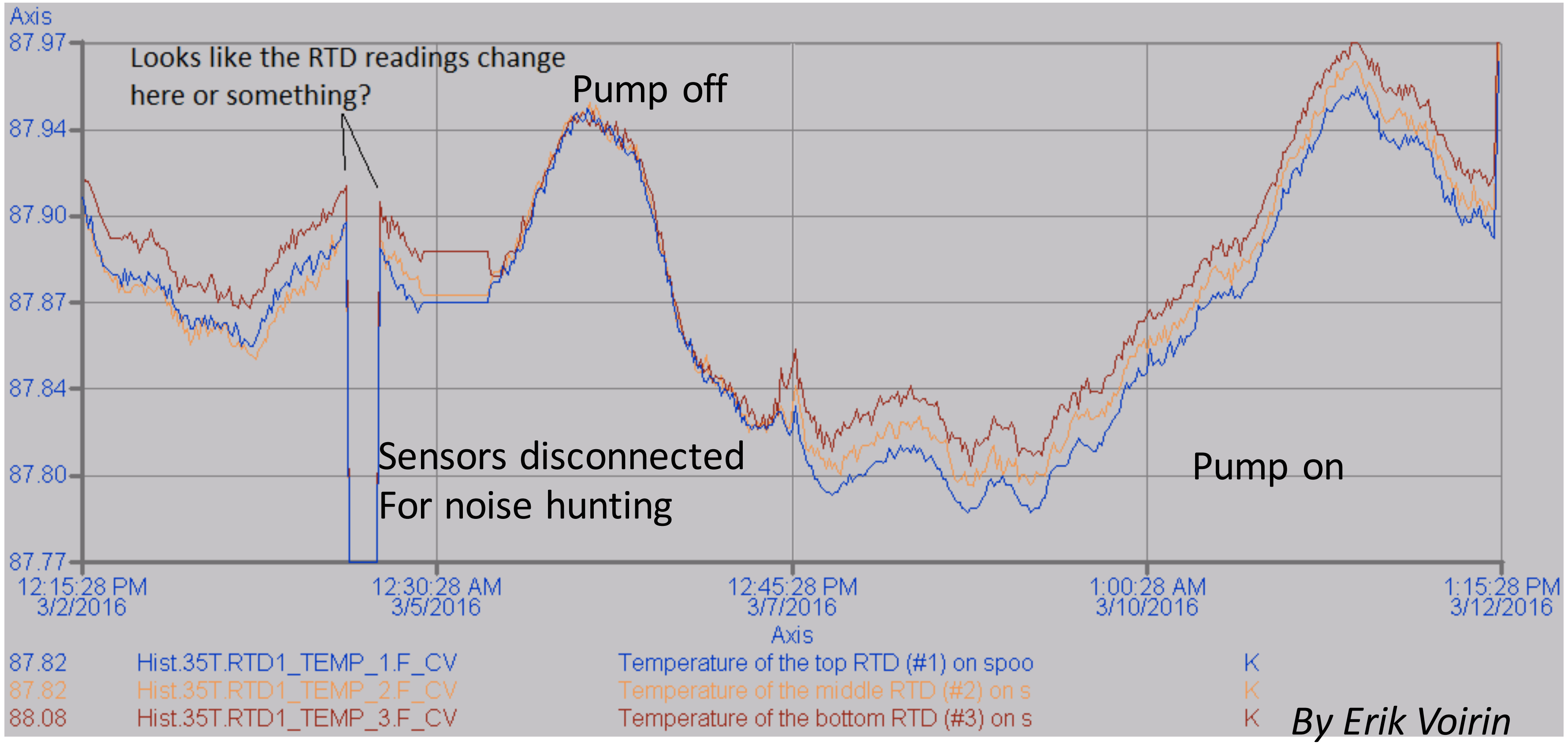
Different lines are for two locations.
Temperature changes are small and slow over the extended height.

These simulations along with the 35 ton detector experience imply high precision, low sampling rate temperature measurement is required.

By Erik Voirin

Experience from 35 ton detector - reminder

- **Clear stratification observed when pumps turned on – based on just 24 mK difference.**
- Numerous connections serve as source of noise and perturb the sensor readings.
- Unplugging and replugging the cables to the flange, flipped signals from RTD 1 and RTD 2 ?!?



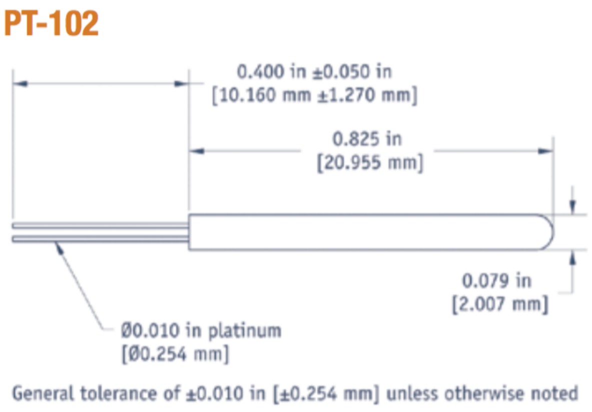
*Overall absolute pressure trend dependent on atmospheric pressure.

Requirements for the Vertical Gradient Measurement

- Measure the LAr vertical temperature gradient in protoDUNE over 7.5 m height with high precision (**at 5 mK level**) using a temperature sensor array
  - 5 mK is the reproducibility uncertainty for the selected sensors
- No requirement stated on the accuracy of the measurement → relative measurement only
- **Frequency of sampling – low** - based on CFD → plans range between 10 cm to 50 cm
  - CFD model suggests greater temperature variations at the top and bottom than in the central region – area of increased sensor density
- Precision measurements require 4 wires per sensor to cancel out any parasitic resistances → still expect additional noise from the feedthroughs and connectors → *currently undergoing testing in LAPD*

Sensors

- Lakeshore Cryotronics produces high precision platinum RTD sensors (used in 35 ton)
  - Temperature range: 14 K to 873 K (model dependent)
  - High reproducibility: ±5 mK at 77 K
  - SoftCal™ calibration available (just at 2-3 temperatures)
- PT-102 and PT-103 are the same, except that PT-102 is larger but costs 1/3 less



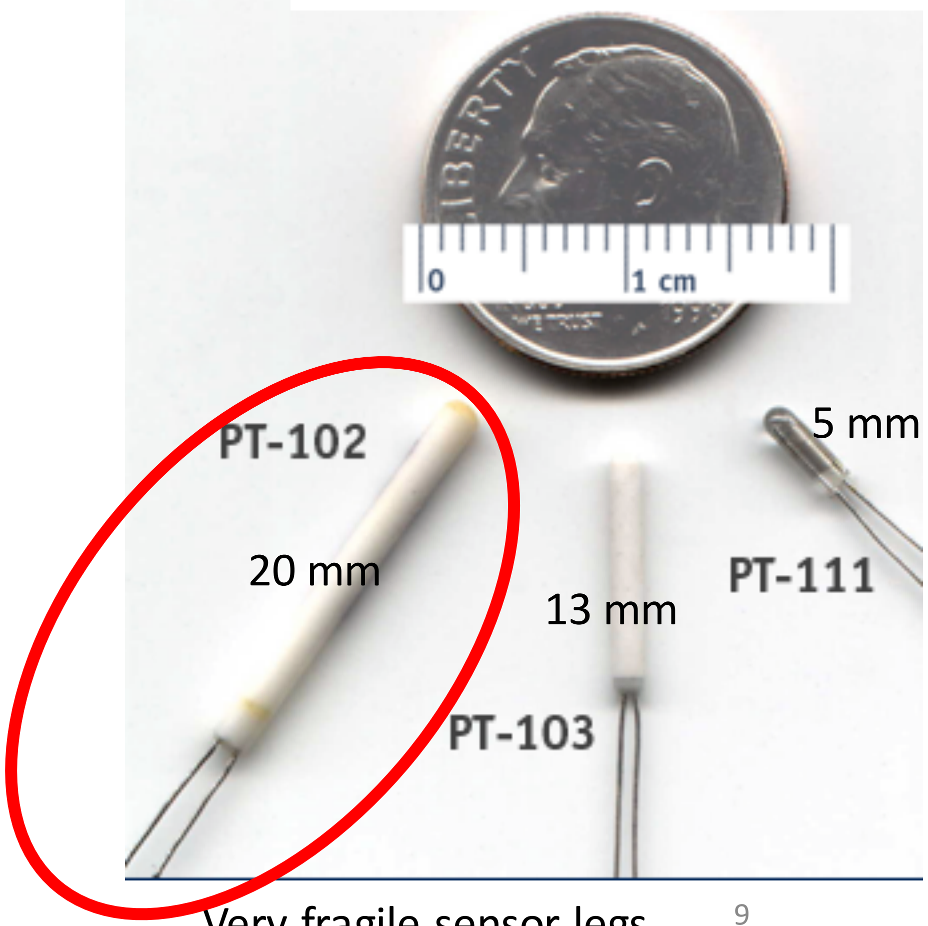
PT-102 has been selected for protoDUNE-SP.

Sensors can be calibrated (12 mK)

for accurate AND precise temperature profile

measurement.

Absolute calibration is very expensive ($92 vs.$500)

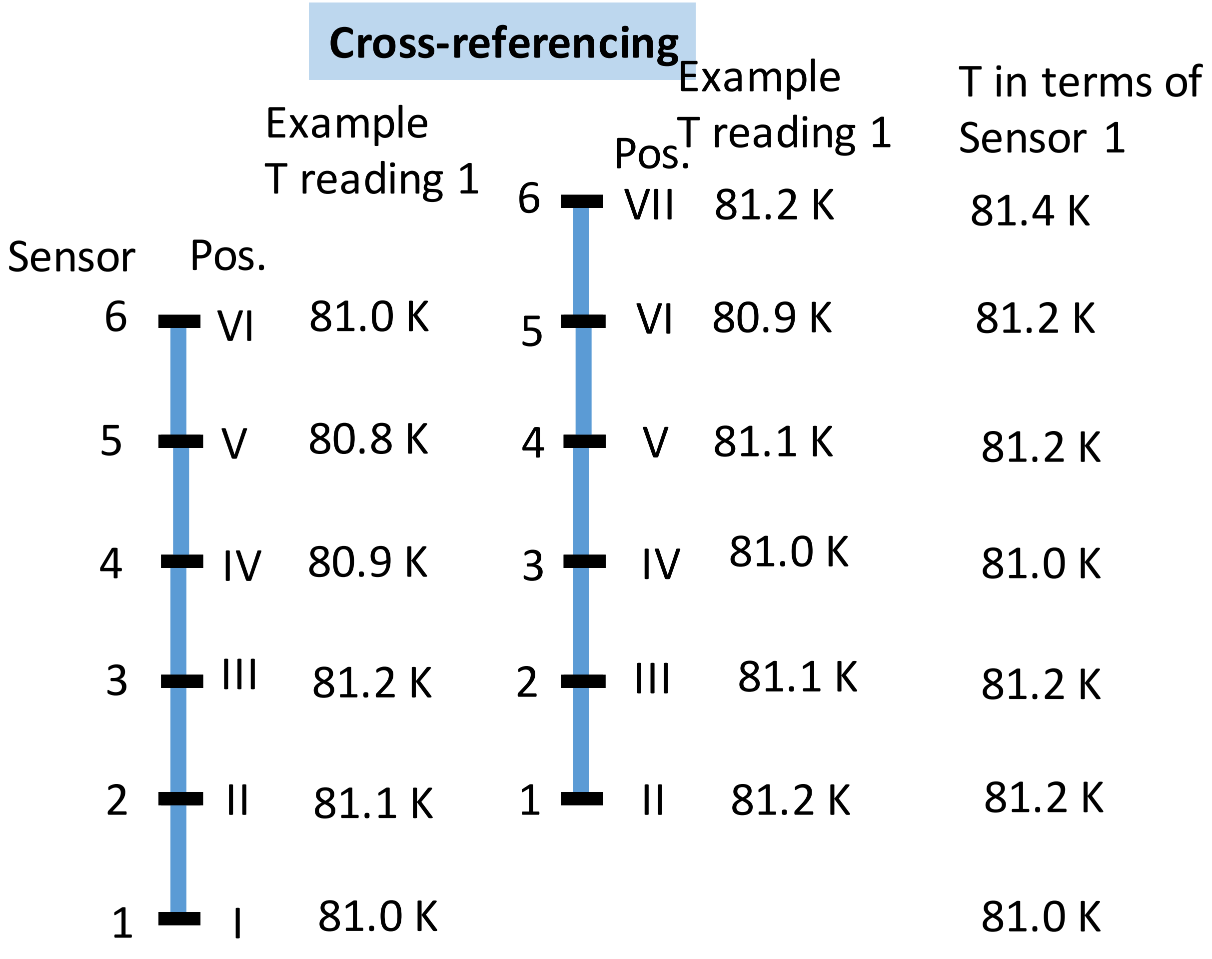


Very fragile sensor legs

Hawaii T-profiler – dynamic approach

- High precision measurement of 5 mK will be achieved by cross-calibration of sensors **<u>in-situ</u>**.

- The first temperature profile is built from two consecutive sets of temperature measurements:
  - T measurements with all sensors at their current location
  - The entire assembly slides up until the bottom sensor is at the location of its adjacent top neighbor and then the second T measurements is taken with all sensors
  - By comparison of T measurements with two sensors at each location, all sensors are referenced to sensor 1 and vertical temperature profile is created

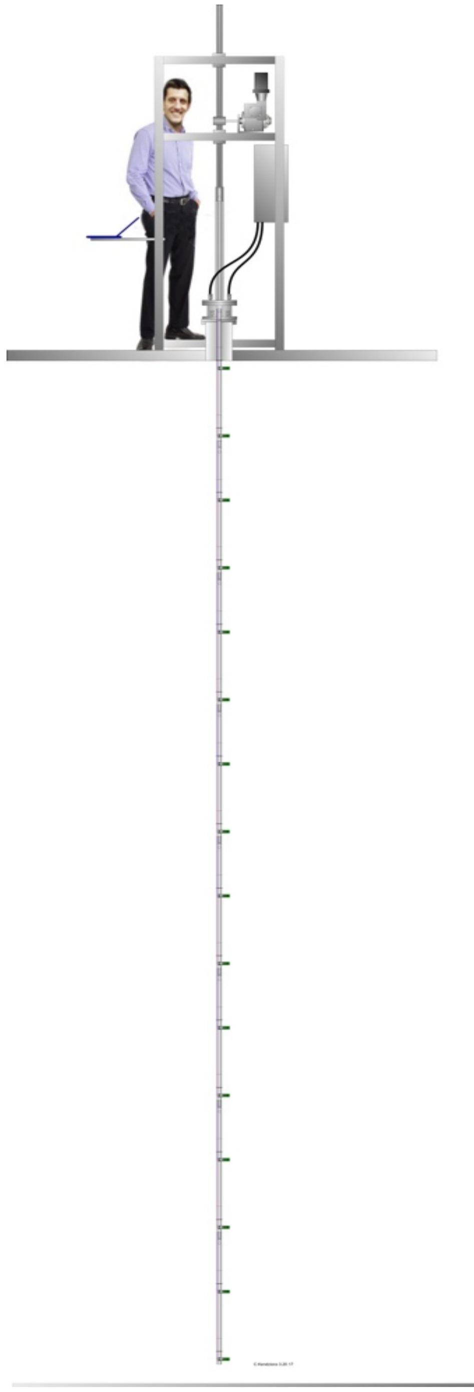


- Assuming that relative offset between sensors is stable – once sensors are cross-calibrated, this two-step process does not need to be repeated.

- Ideally, cross-calibration would take place when pumps are off.

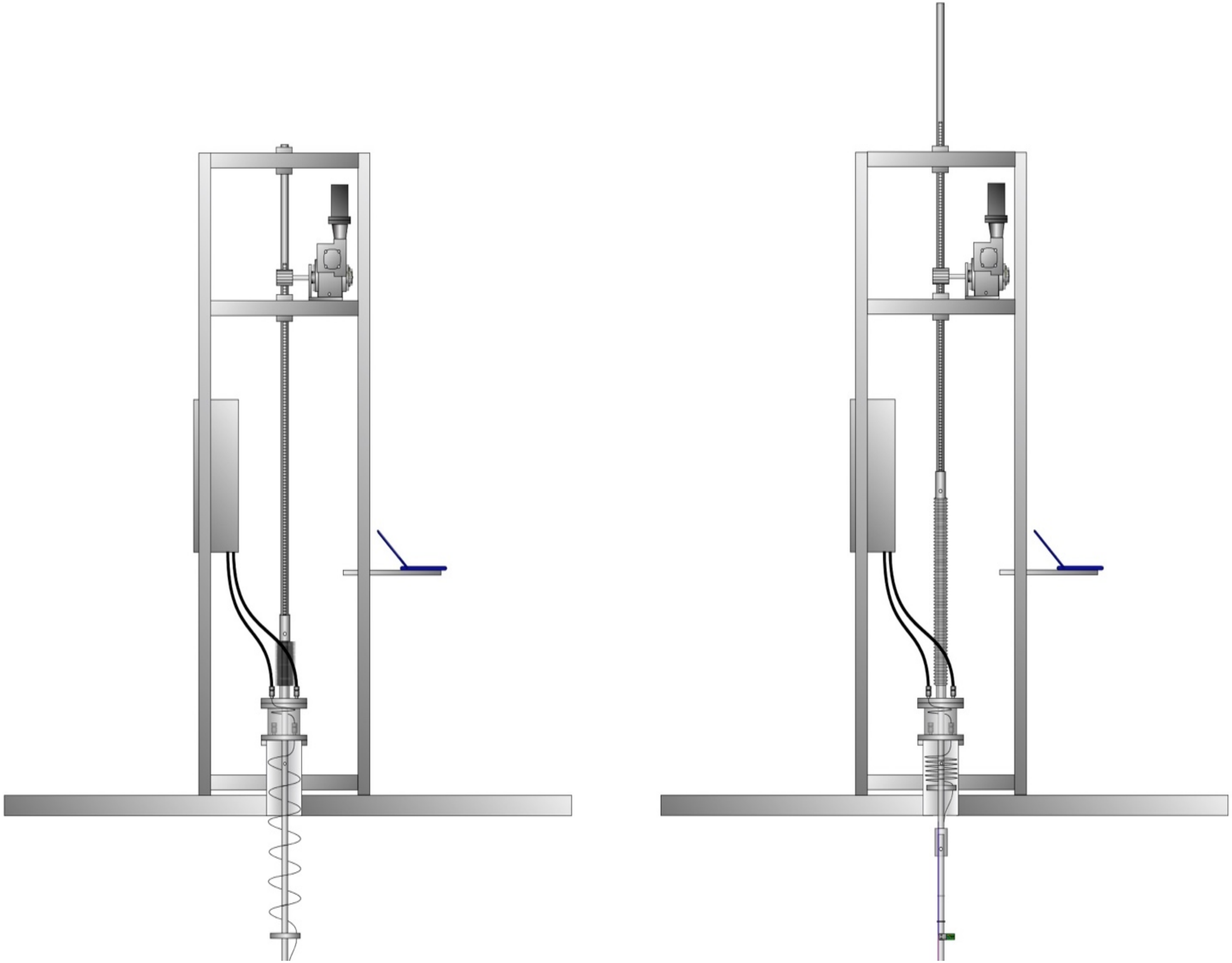
Hawaii T-profiler overview

- 1 m long segments with 2 sensors each (every 50 cm) made of stainless steel.
- Array confined at the bottom with a cup made of stainless steel mash 1 m high – to avoid lateral motion in the vicinity of sensitive anode plane assembly while allowing free LAr flow.
- Drive assembly located at the top with enclosure allowing entire T-profiler to move up.
- *Flexible motion steps for finer T-gradient measurement.*
- *1 m motion range: moving the array by 25 cm, 50 cm, 75 cm and 1 m upward we can cross-reference sensors with 25 cm sampling rate and have redundancy factor in case of a failed sensor.*
- 10 cm spacing for the bottom 50 cm and top 50 cm to sample area with faster T variation
- We will use 22 sensors for this purpose.



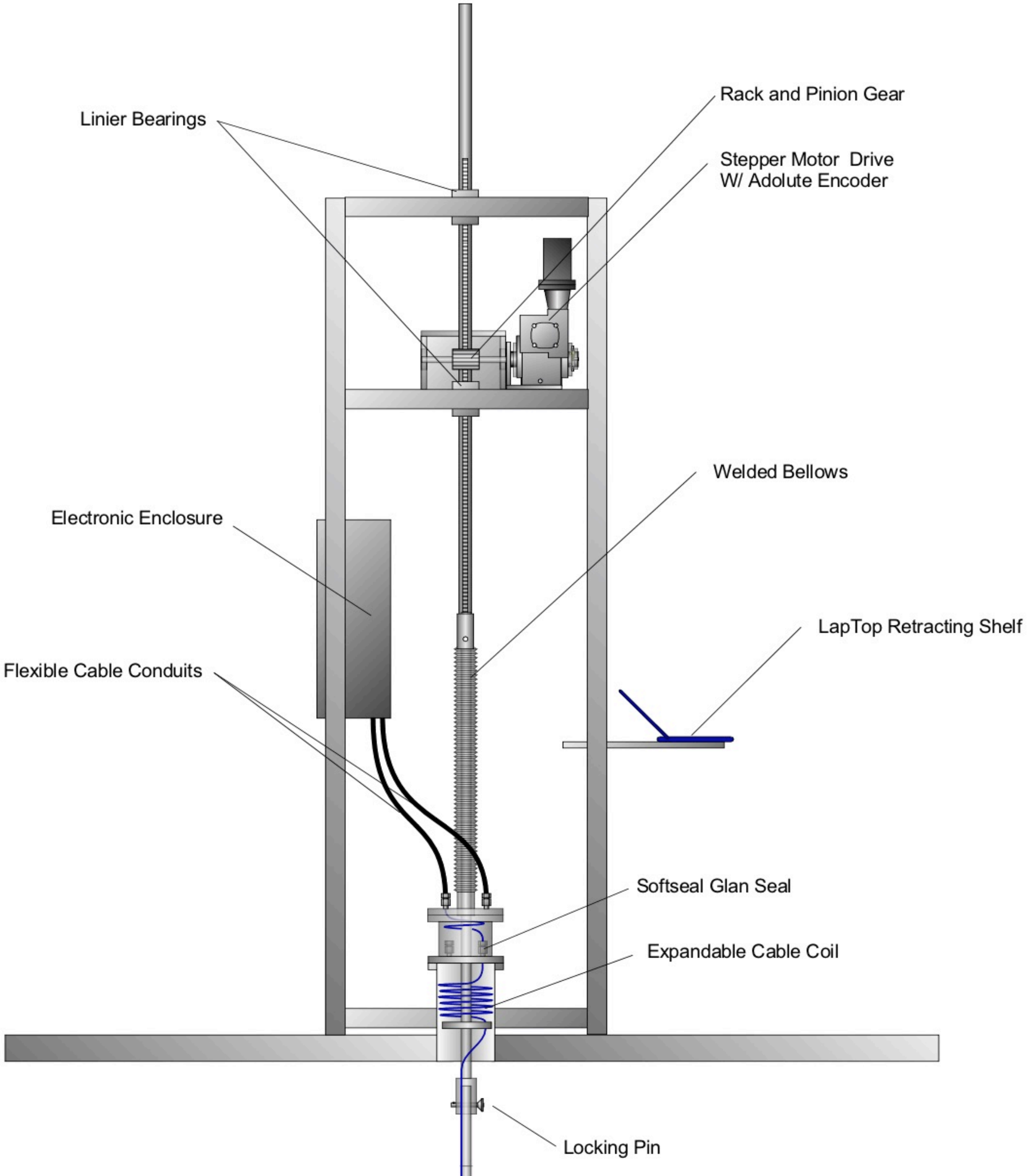
Sealing the Dynamic System

- A bellows is welded to the top of the flange to secure cryostat integrity during motion.
- Housing above the sensor array provides room to move the array upwards as needed.



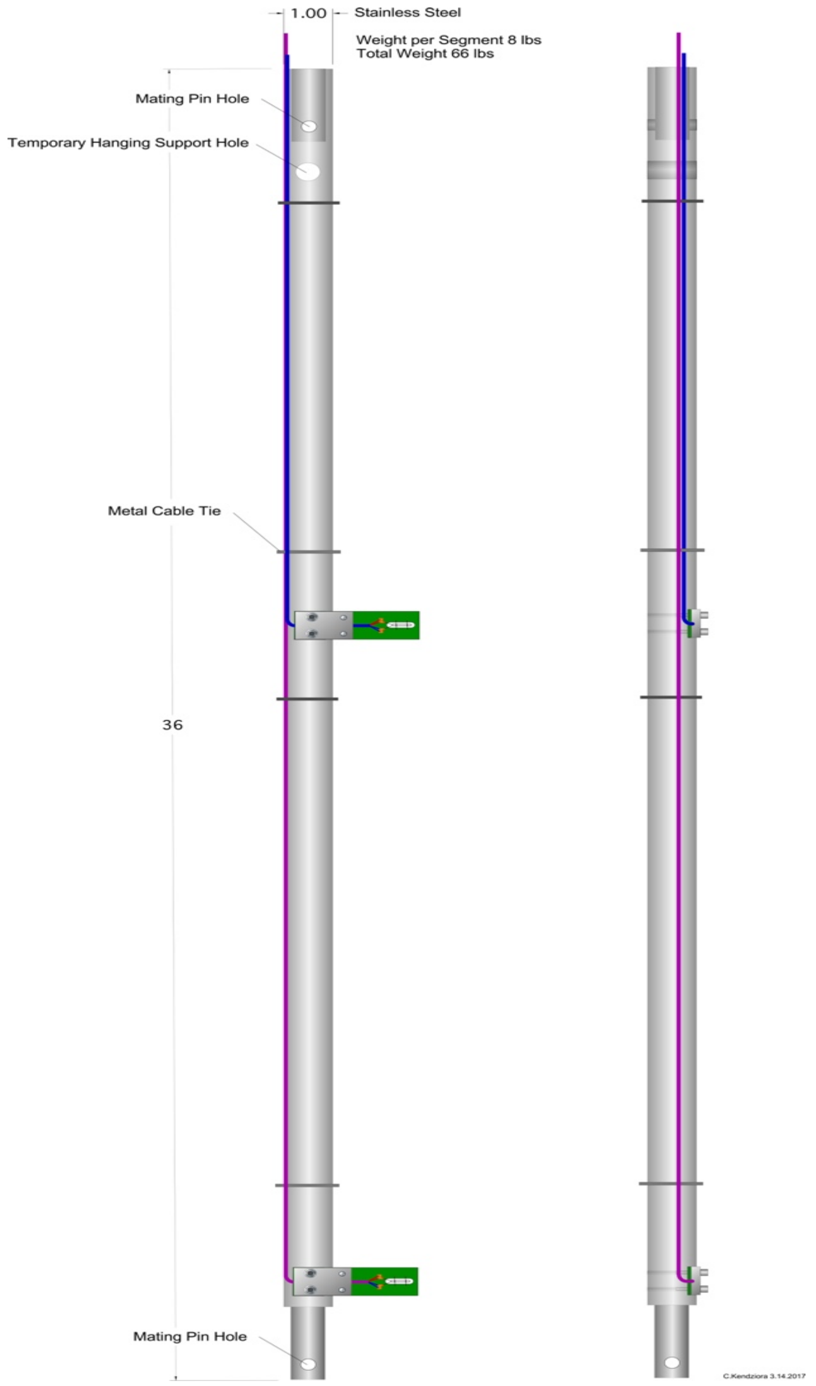
Drive assembly

- Rack and pinion gear connect the top of the bellows to a stepper motor responsible for moving the array.
- To address potential electronic noise associated with the motor, it will be completely disconnected when not in use.
- Another option is use of a manual system to move the sensor array.



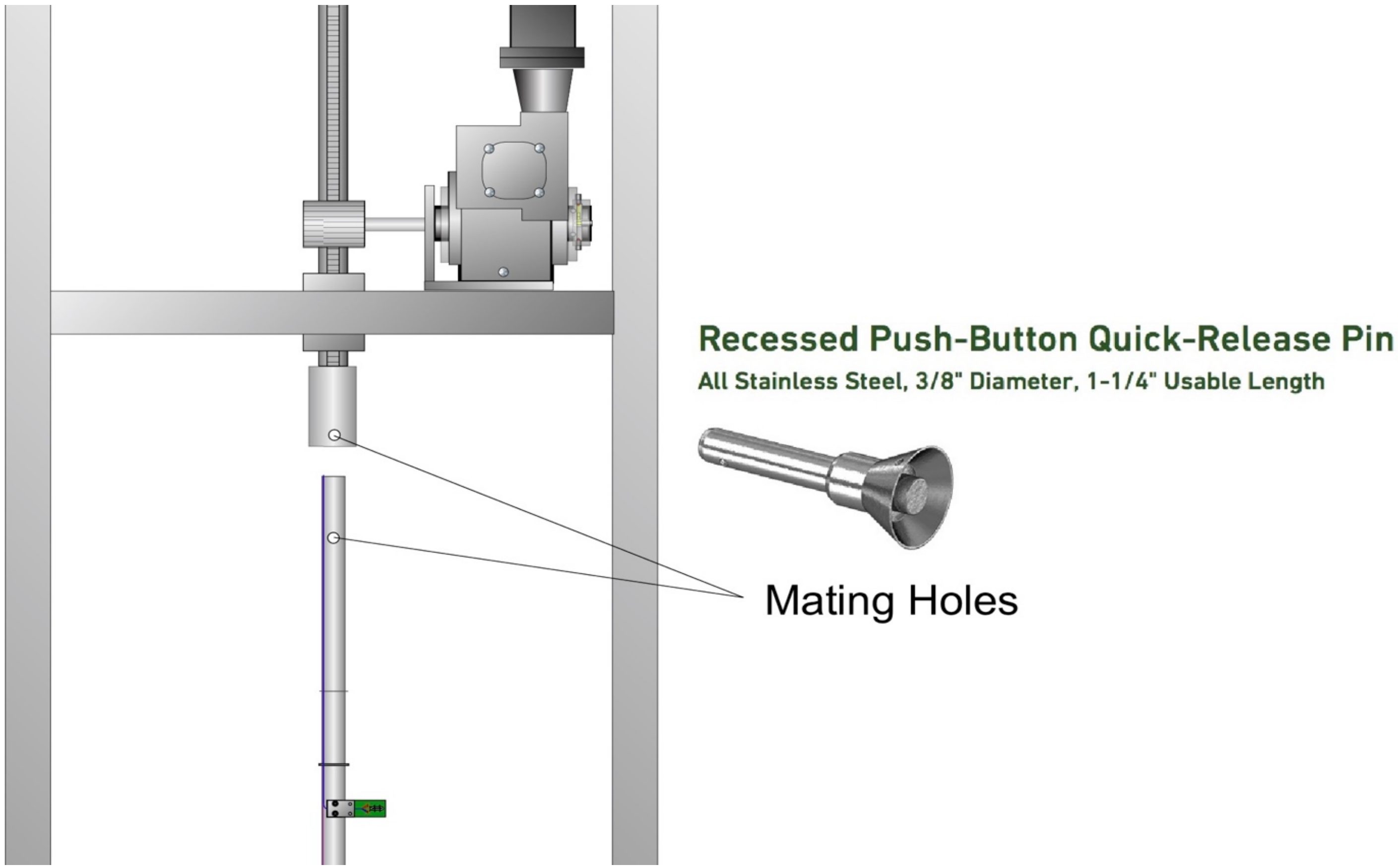
Sensor board mounting

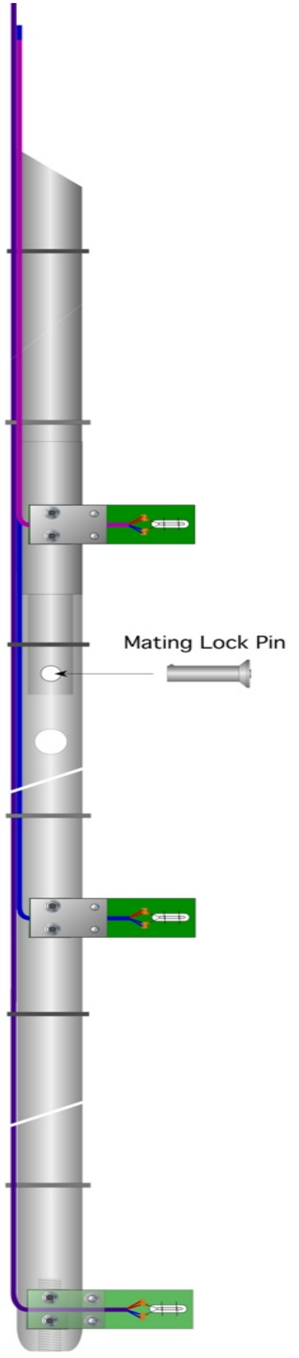
- Sensor boards will be mounted to the stainless steel rods that are close to 91.44 cm in length (36 in).
- Two sensors per rod, spaced by 50 cm for redundancy and attached by two screws.
- Each SS rod weighs 3.632.kg (8 lb)
- The total weight of the system is 30 kg (66 lb).
- Cables are tied to the rod by cable ties for even mass distribution.



Connecting the rods

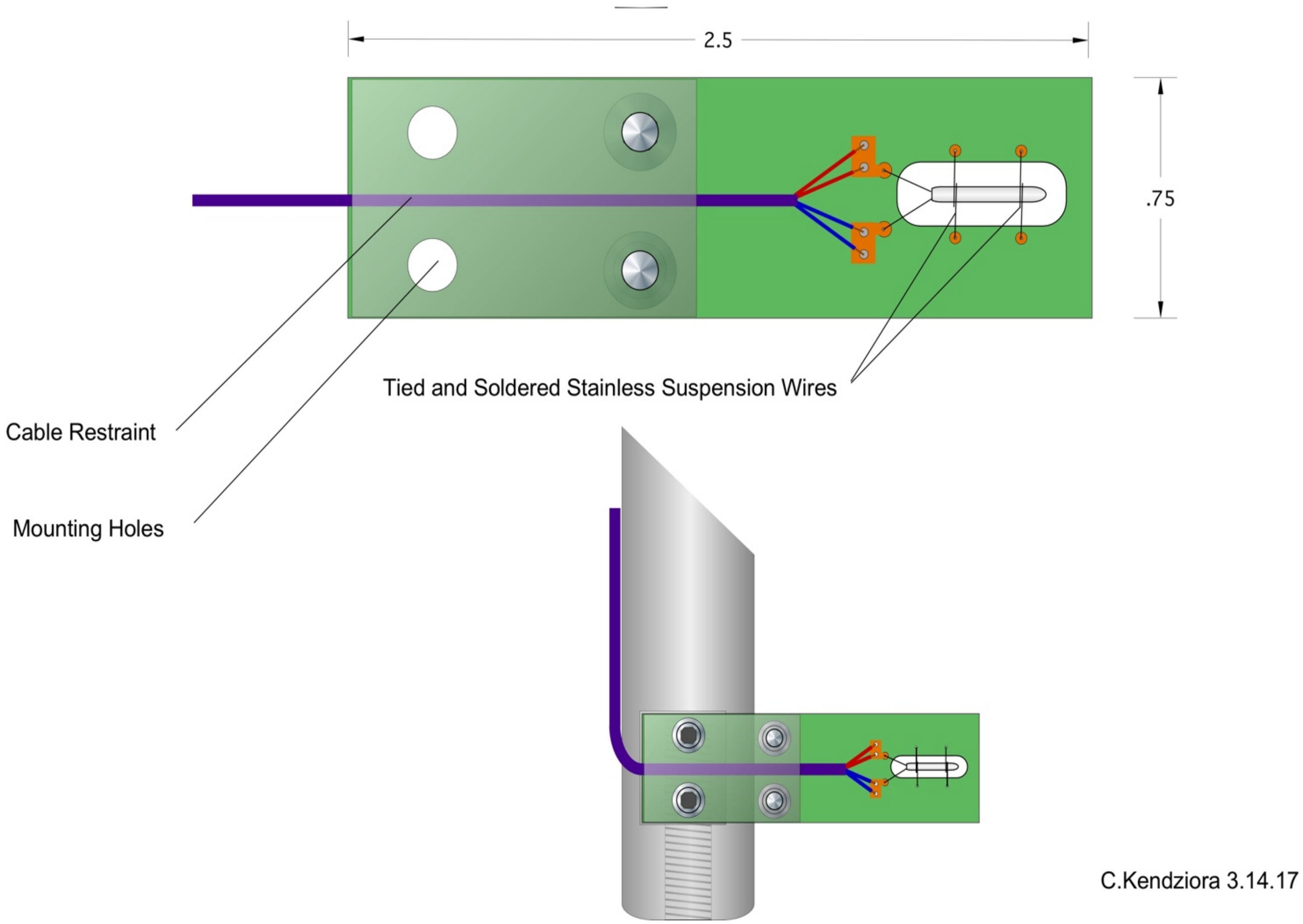
- Rods are connected by lock pins: recessed push-button quick release pins
- These pins cannot accidently fall out.





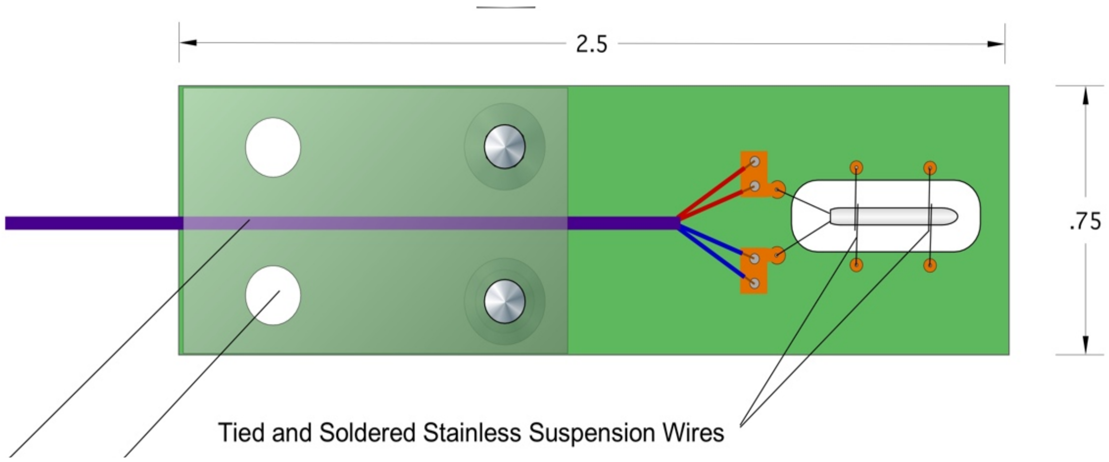
Sensor board

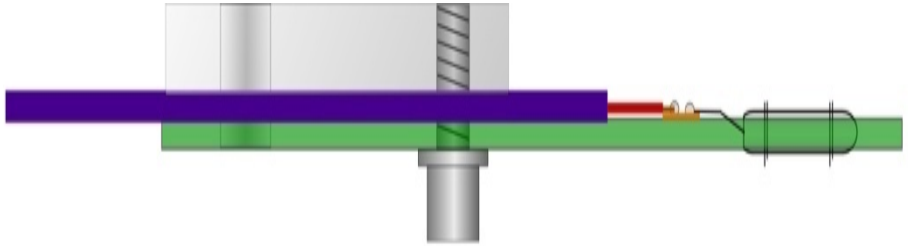
- Sensor is soldered on PCB
- PCB around sensor is cut out for easy argon flow
- Sensor is kept in place by loop-around wires soldered to the edges of the cut out.
- An overlap of two boards is used to release any strain on the four point sensor connections.



Cable restraint at the sensor board

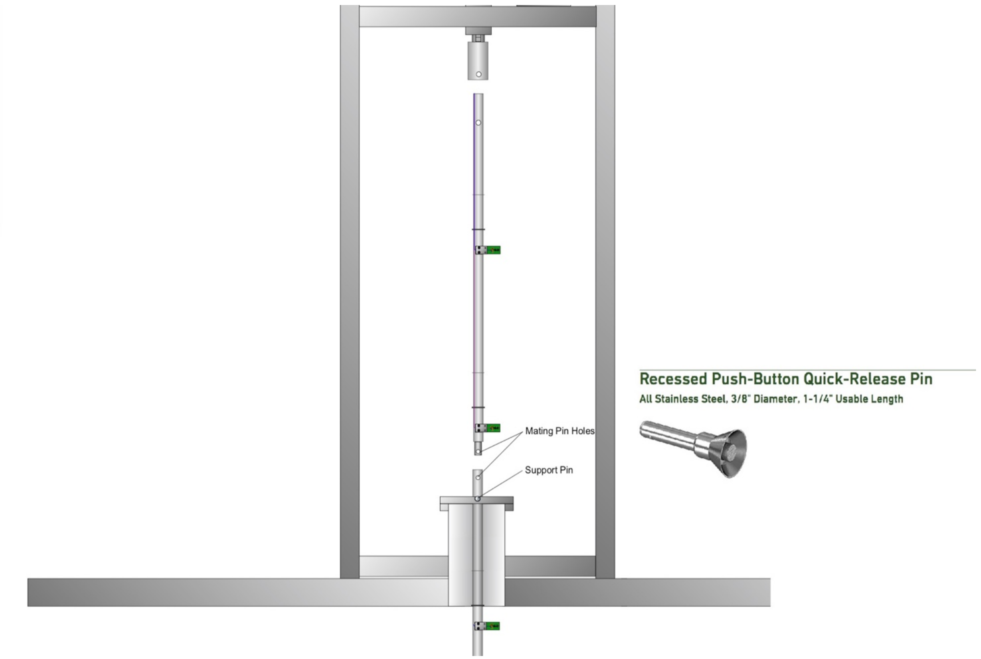
- Cable is sandwiched between the PCB and SS rod mount.
- Thus, there is no tension on the sensor soldering joints
- PCB is slightly extruded to position the cable along it.

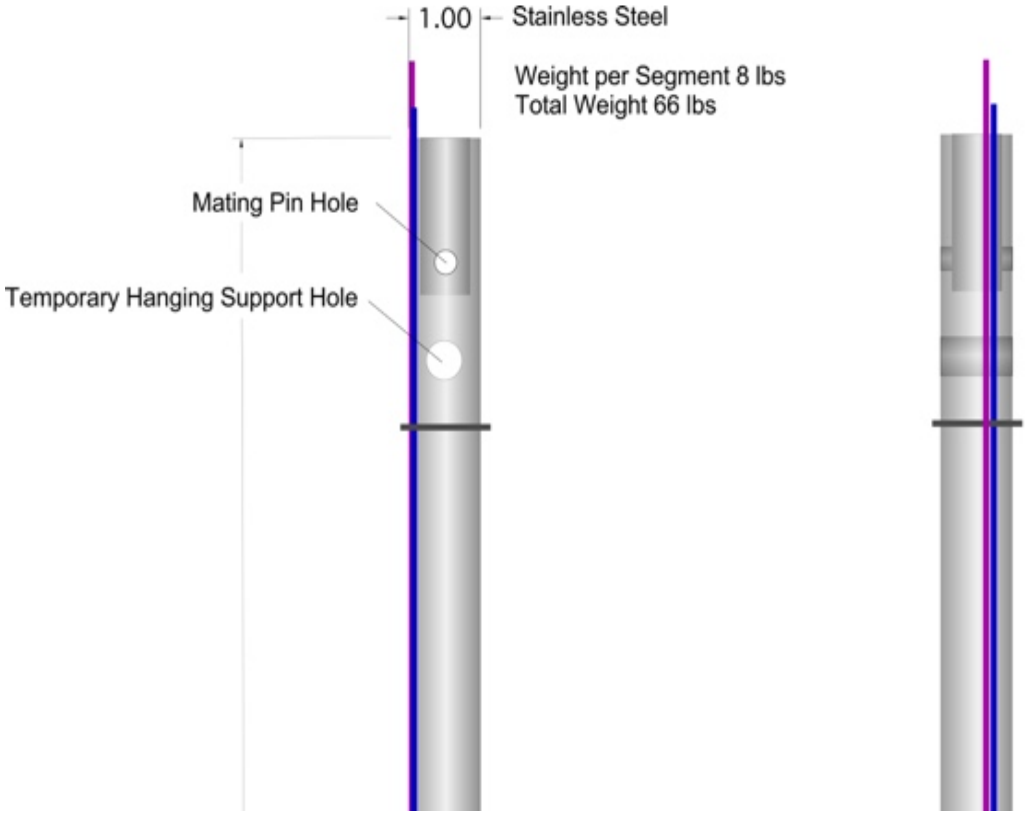




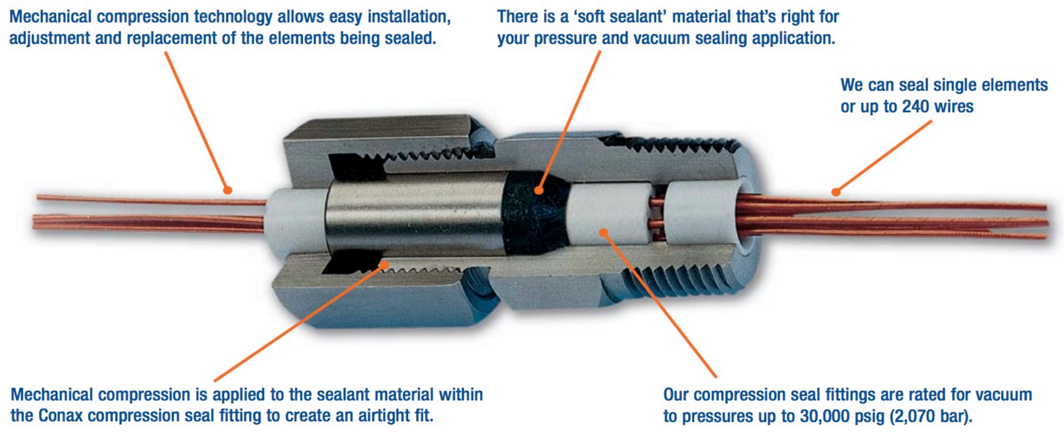
Assembly in ProtoDUNE-SP

- Hawaii T-profiler modular design allows installation through the flange by sequentially lowering and connecting the segments.





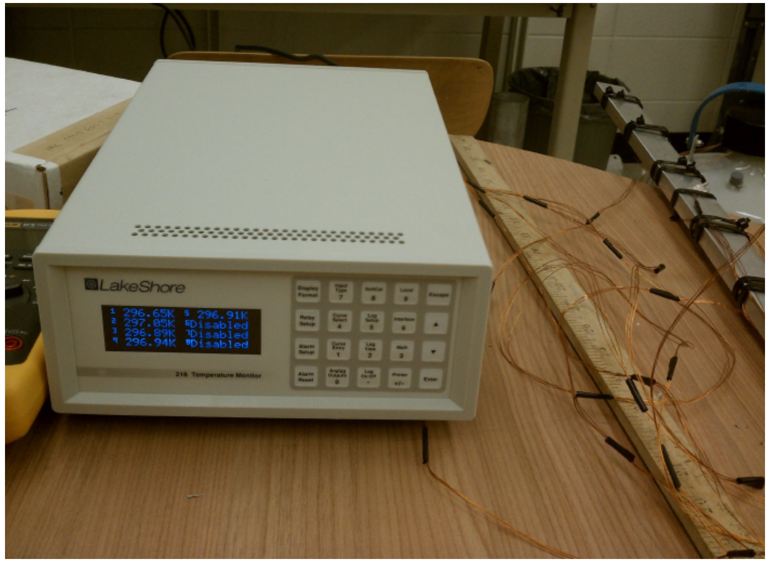
Feedthroughs and Readout

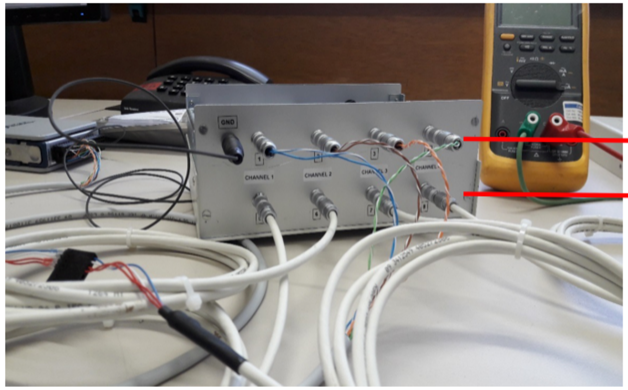


- Plan to use twisted ribbon cables for higher density
- Assuming up to 22 sensors (every 50 cm) that amounts to 88 wires that need to be pulled up
- Plans to use D-sub 25 connectors – 4 connectors will suffice.
- All wires same length
- Possibility to have single uncut cable– solder at sensor and readout with Connex compression feedthroughs
- Two readout options:
  - Lakeshore monitor
  - CERN in-house model made Xavier Pons and Giovanna Lehmann Miotto
  - Comparison test of two systems in Hawaii and in LAPD at FNAL

Temperature Readout

- Two different readouts have been under consideration:
  - Lakeshore temperature monitor 218
  - CERN DT readout

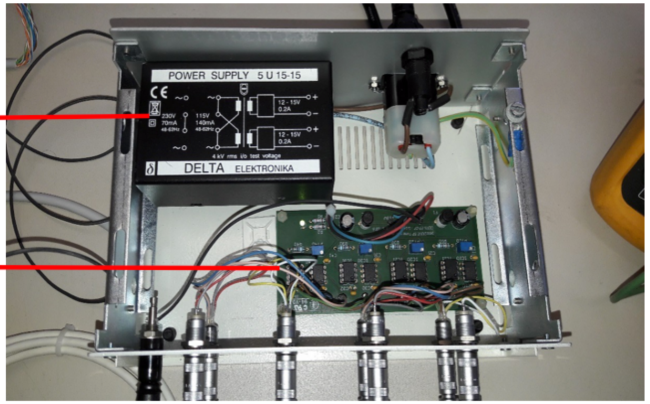




Up to 4 PT100 channels

PT100 signal to National Instruments module

4 wires connections to PT100



220 Vac or 115 Vac to ±15VDC power supply

PT100 current source circuit x 4
Calibrated to 1000 μA with FLUKE 87

Room Temperature Test Runs Taken on Mar 10th 2017

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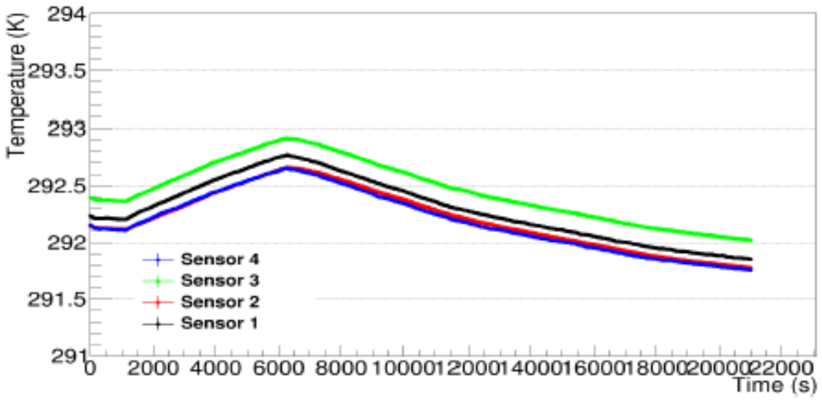
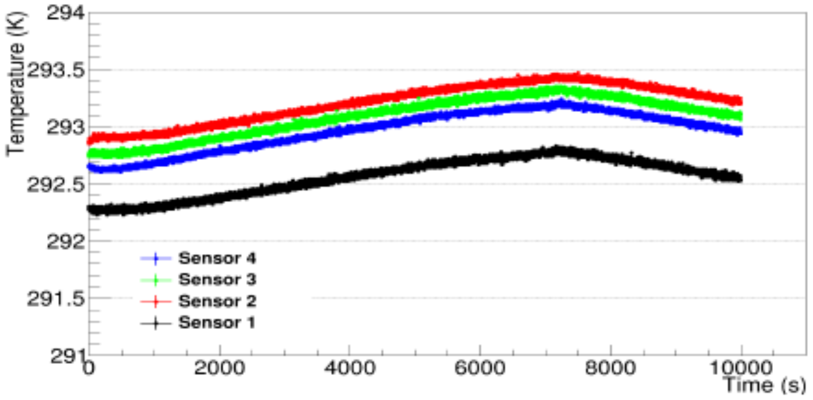


CERN DT Readout



LakeShore 218S

- To confirm the result on 8th.
- Since they are uncalib sensors, overall offsets are possible, as long as they are consistent.
- T-diffs among sensors are consistent within one readout, but different between 2 readouts.

CERN DT setup

Sensor 2 ≈ Sensor 1 – 0.1 K
Sensor 3 ≈ Sensor 1 + 0.2 K
Sensor 4 ≈ Sensor 1 – 0.1 K

LakeShore 218S

Sensor 2 ≈ Sensor 1 + 0.6 K
Sensor 3 ≈ Sensor 1 + 0.5 K
Sensor 4 ≈ Sensor 1 + 0.4 K

Calibrating sensors and readout offsets

- Readout offsets can be calibrated out by using the same resistor at each readout slot
- Done with 100 ohm resistor (correspondent to room T) and 22 ohm resistor (correspondent to LAr temperature)
- Sensors can be calibrated by inserting each sensor at all slots.

- At the moment easier with CERN DT readout than with Lakeshore temperature monitor (requires desoldering and resoldering)

Readout Calibration Using One 100 ohm Resistor

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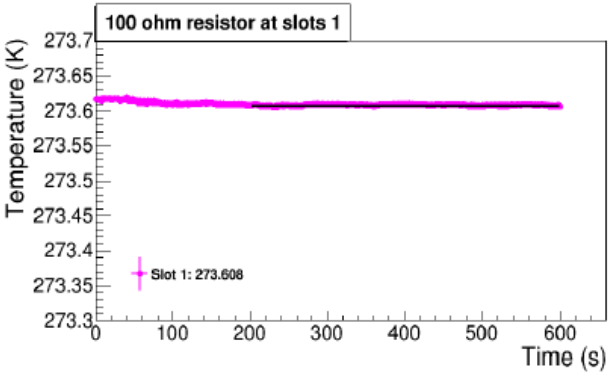

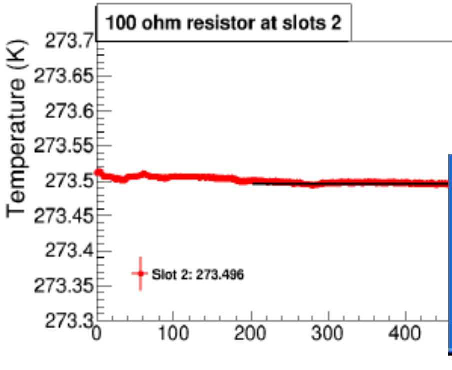

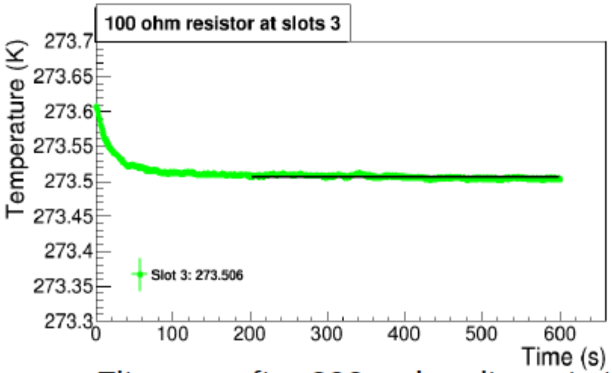

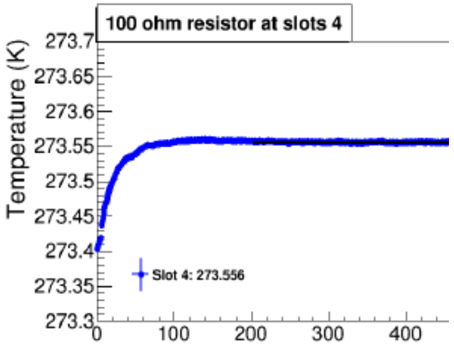

Fit curve after 200s when it went stable.
Disconnect and connect after each measurement.

Readout Calibration Using One 22 ohm Resistor

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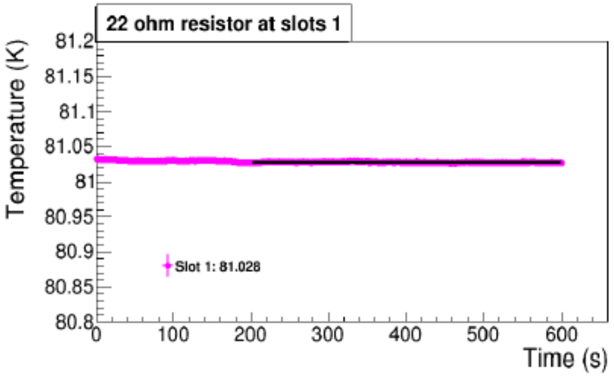
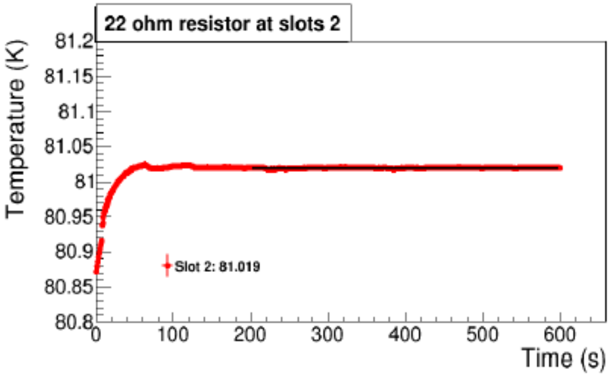
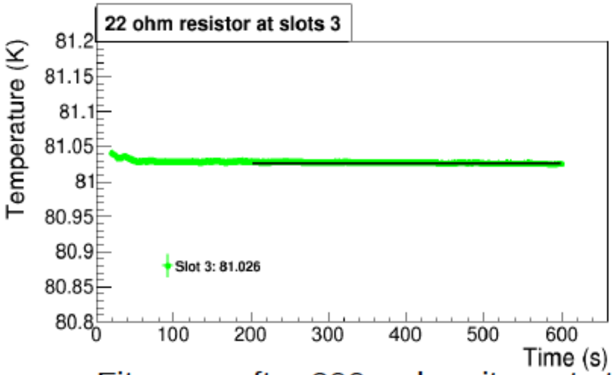
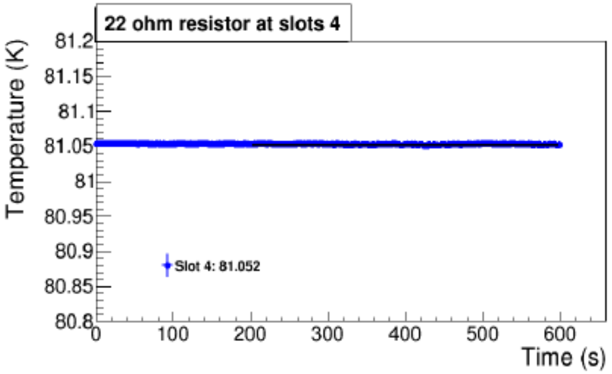


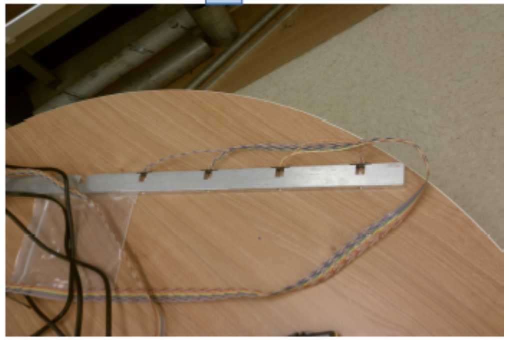


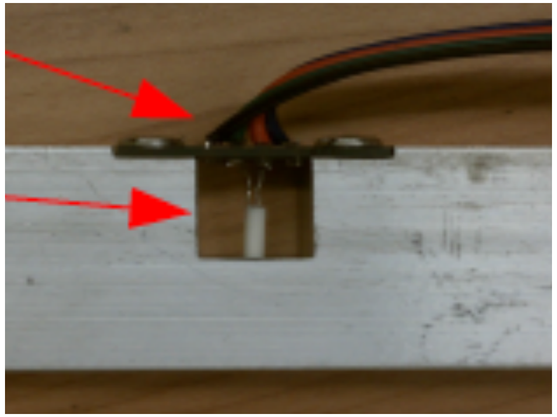


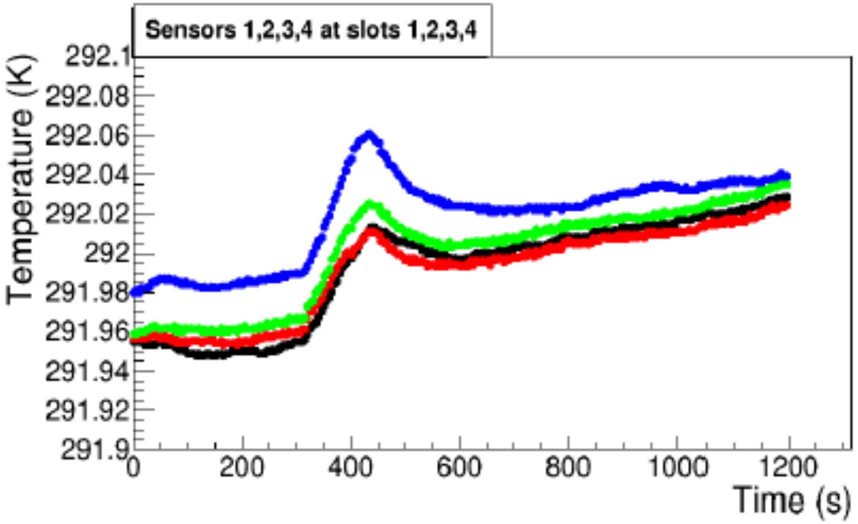


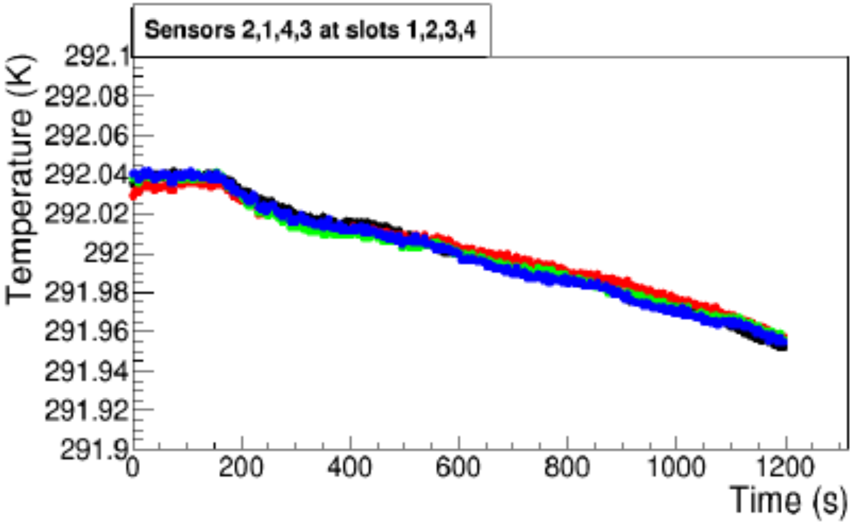
Fit curve after 200s when it went stable.
Disconnect and connect after each measurement.

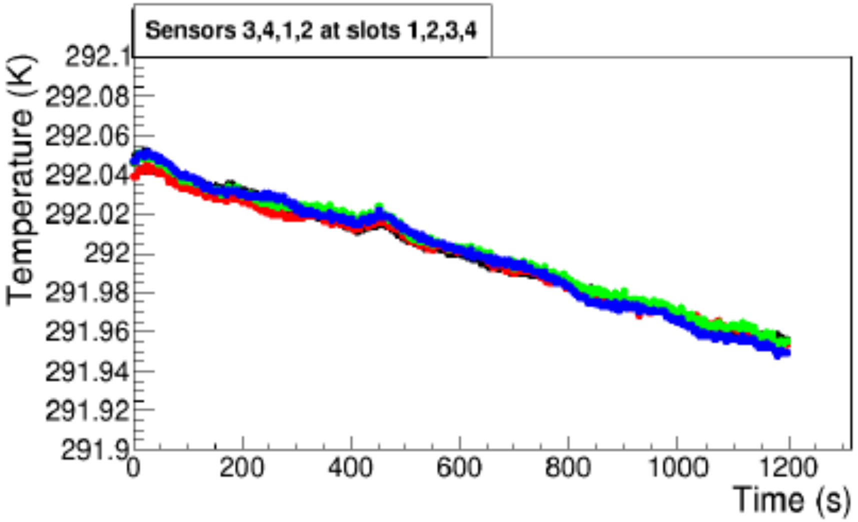
Sensor + Readout Calibration

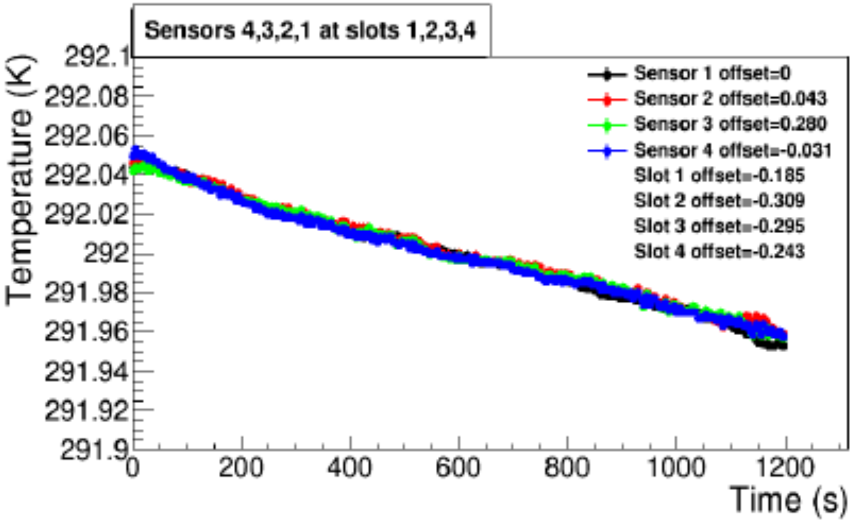












Sensor + Readout Calibration

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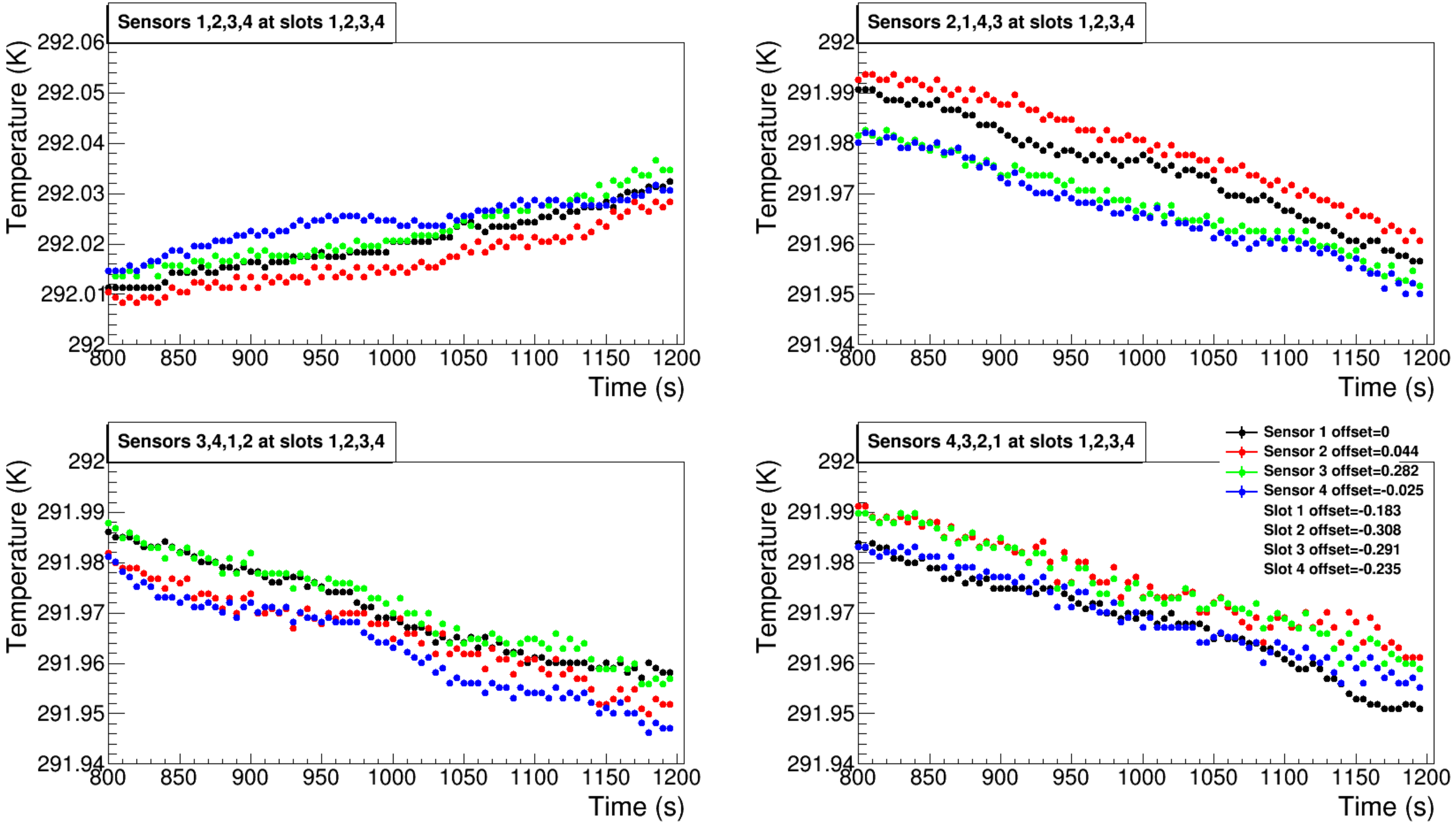
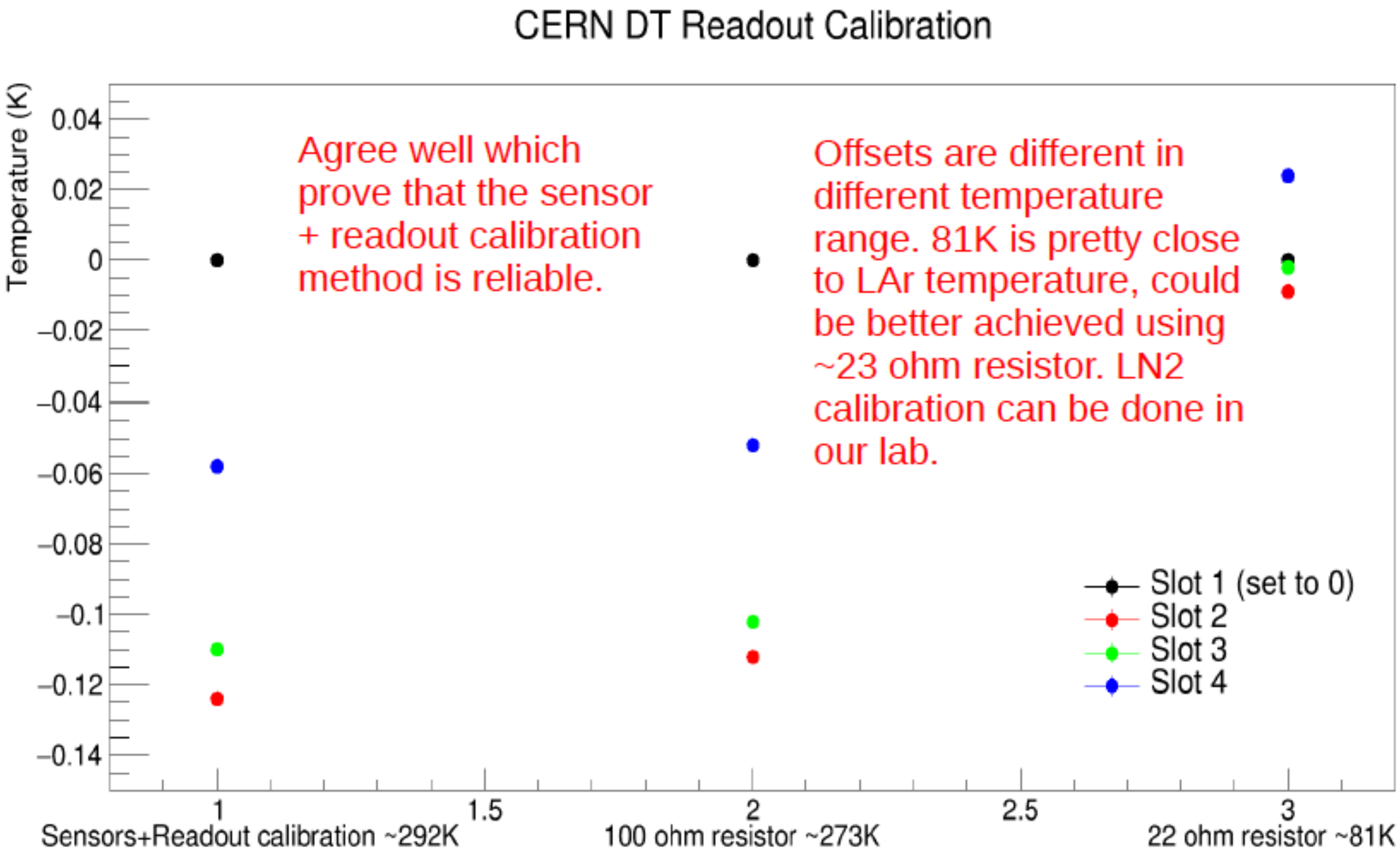


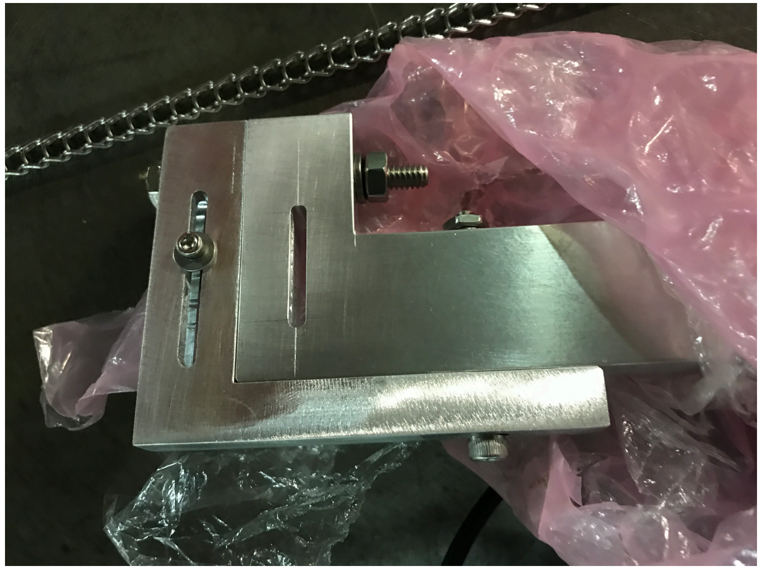
Comparison of Calibration Results

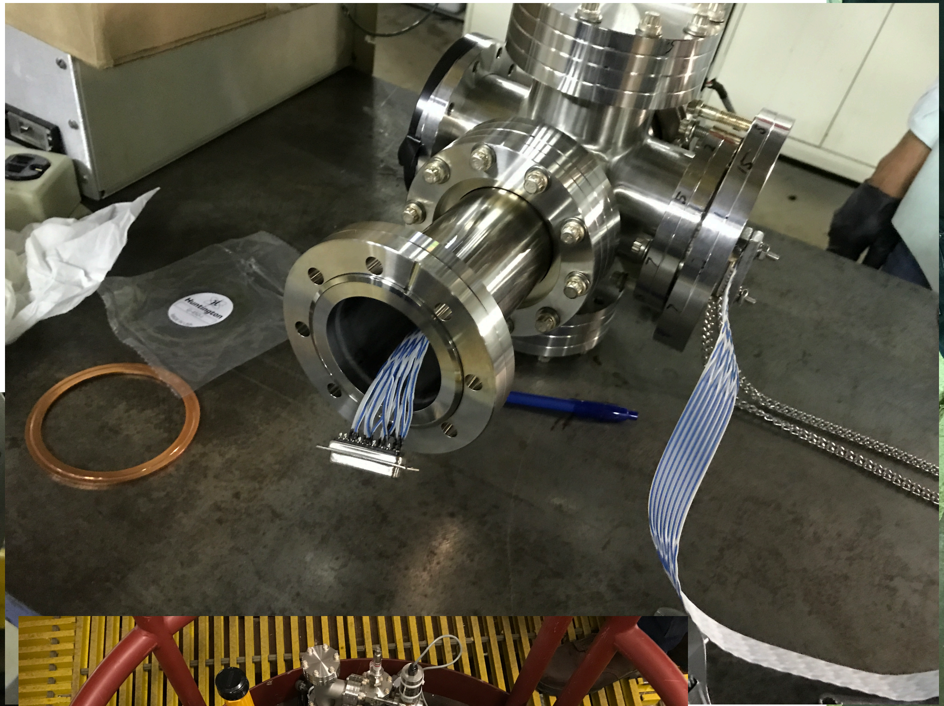


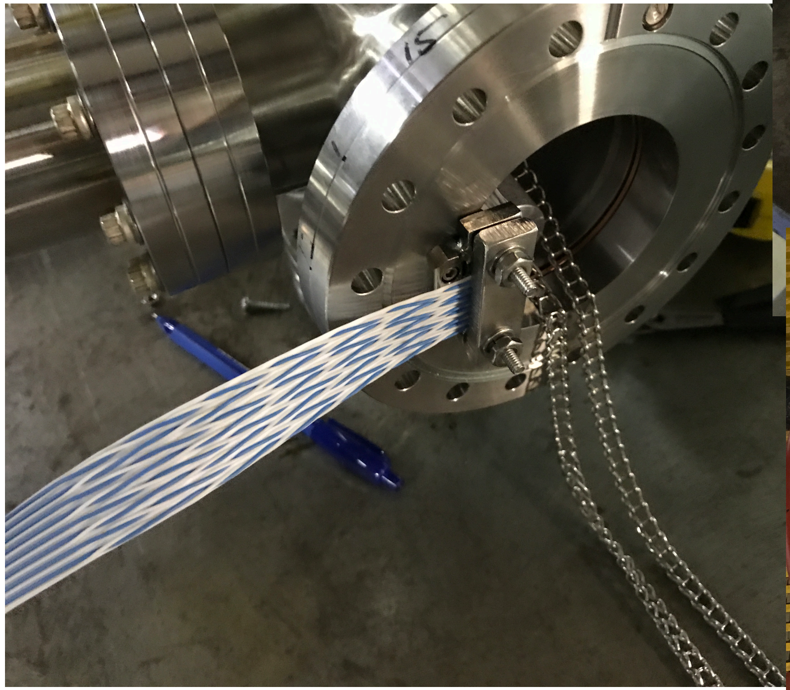
Tests in LAPD cryostat

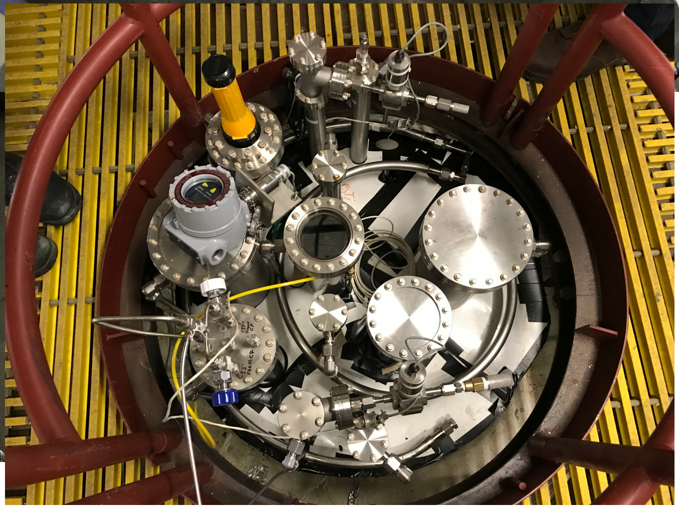
- The precision of the cross-referencing approach will be tested at LAPD at FNAL
- The set of 4 sensors have been installed by Yujing on the RTD spooler and can be moved over 6 m height
- Currently room temperature measurements have been taken
- Measurements taken remotely from Hawaii
- LAPD will soon be filled with LAr for cryogenic measurements.

Installation in LAPD

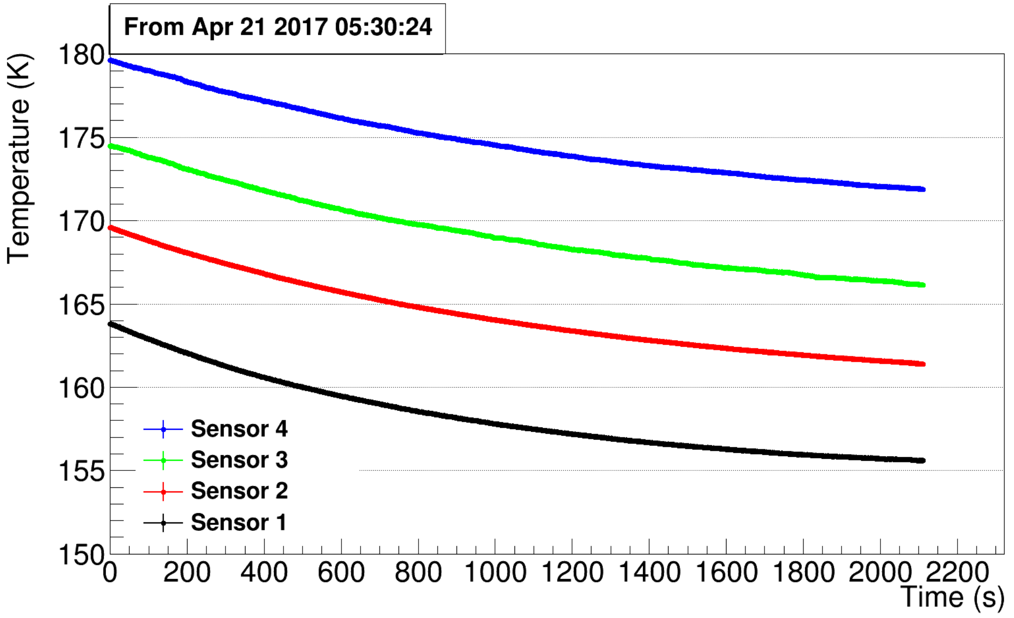


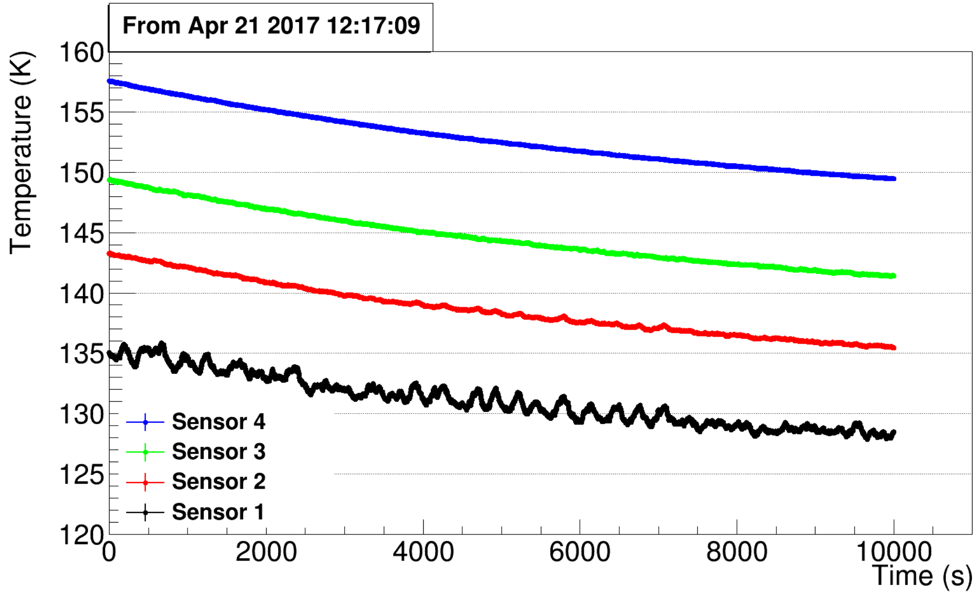


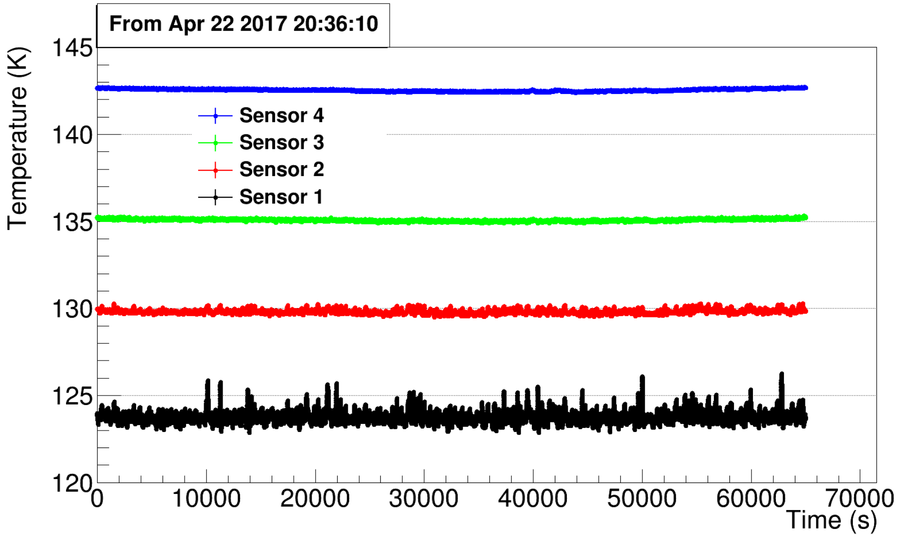


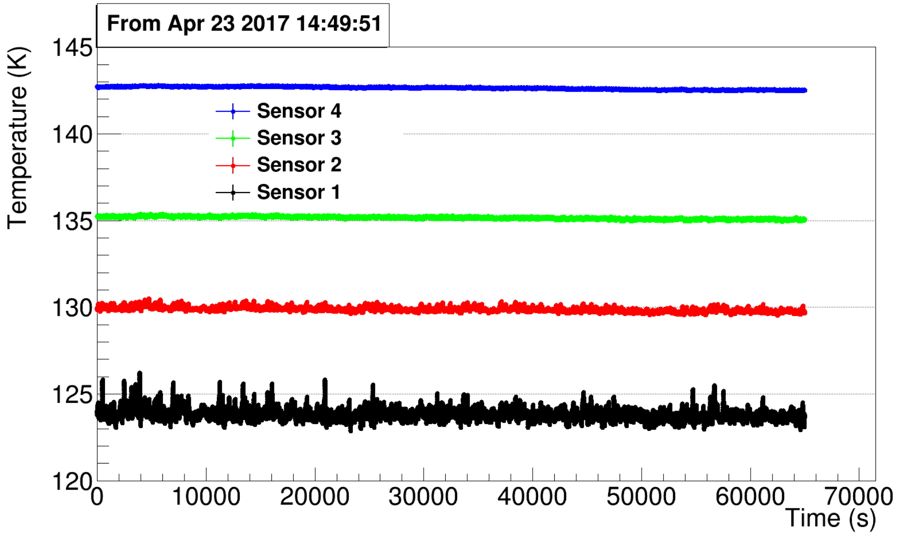


T measurement from LAPD









Development toward DUNE

- We believe that the dynamic choice of the Hawaii T-gradient monitor meets the requirements allowing easy installation with its modular design.
- The entire assembly is put together by connecting 36 inches (91.44 cm) stainless steel segments on which the PCB boards with sensors are mounted.
- The system is rather light and doubling the height needed for DUNE does not present additional engineering challenges.

Schedule

- LAPD testing will take place in May and inform us how well we can cross-calibrate the sensors as well assess the effect of feedthroughs
- Design will be finalized by early Fall.
- Fabrication will take about one month in the Fall.
- Test installation and quality control tests will be conducted in winter 2018
- Expected installation at CERN in the Spring 2018.

Summary

- Based on the combined experience from 35 ton and expectations for the SP ProtoDUNE
  - Sampling temperature at the rate of 50 cm to 1 m is sufficient – good news for the number of sensors, feedthroughs and cables → hopefully less noise too.
  - High precision measurement required at few mK level precision → cross-calibrating sensors with RTD slider
- Conceptual design of the T-profiler presented → benefits from the 35 ton test experience → similar motion mechanism, but confined to avoid damaging nearby APA plane.
- LAPD testing will inform us about two readout systems as well as sensor cross-calibration.