

# Verifying PROTO DUNE I Experimental Data using CFD

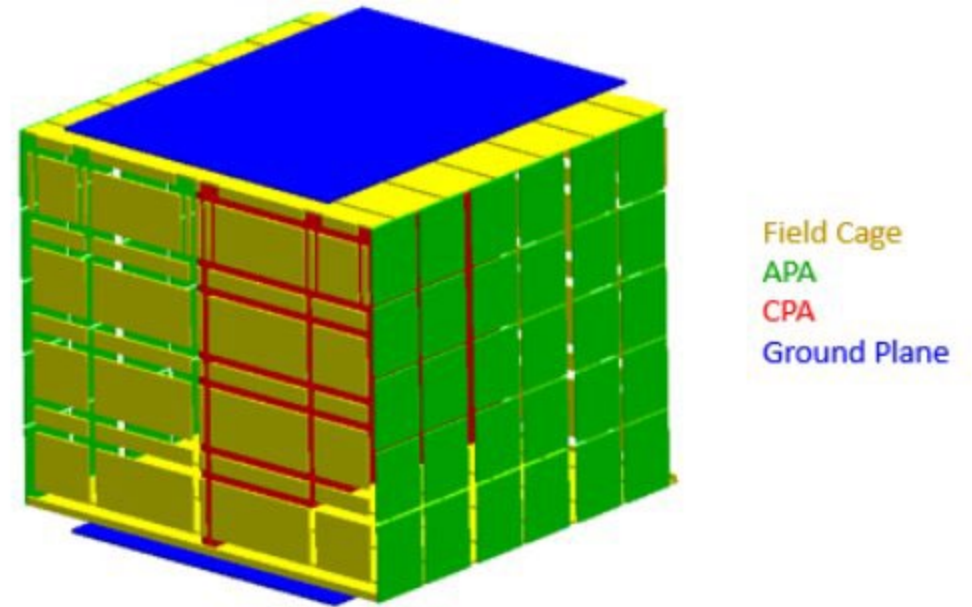
Sahil Sharma, Stephen Gent, Gregory Michna  
South Dakota State University

CALCI Consortium Meeting  
May 04, 2023



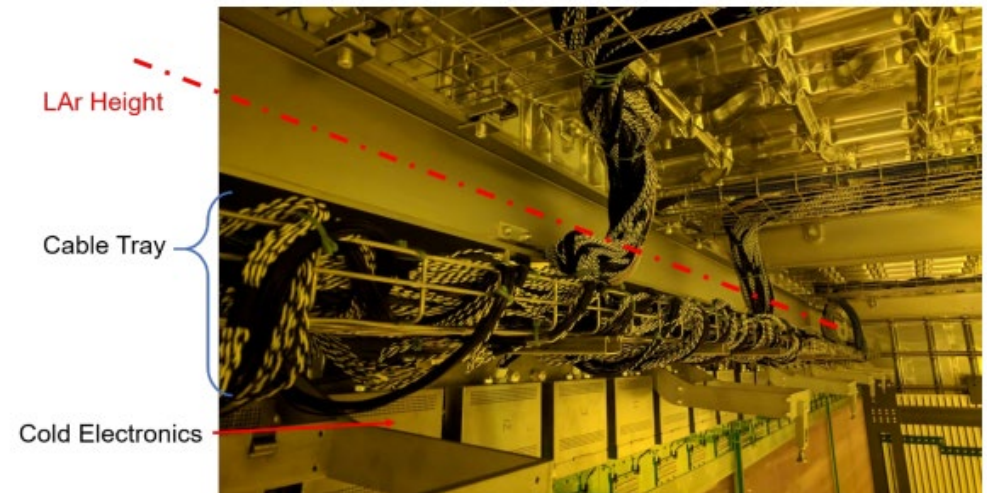
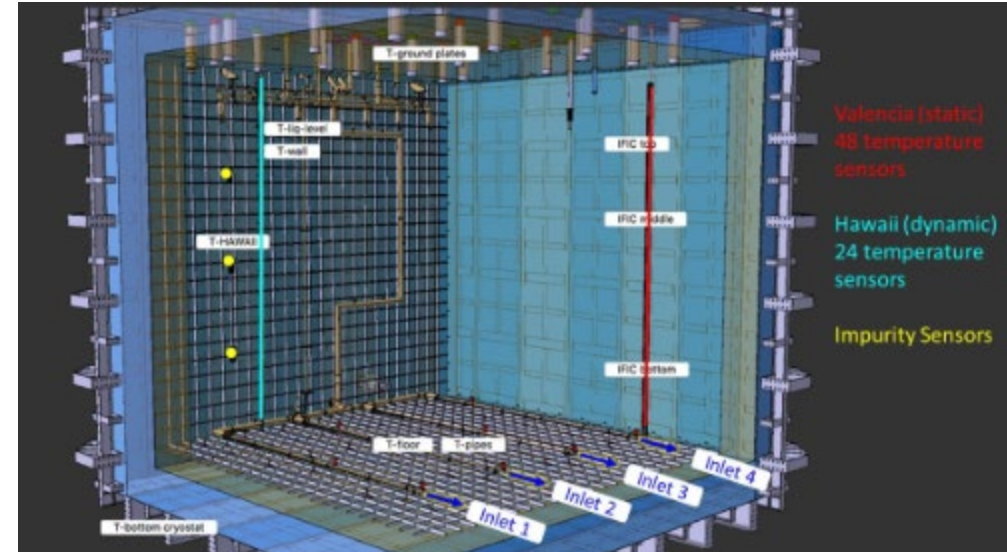
# Simulation Setup

- Liquid Argon Region of PROTO DUNE 1 Simulation
  - Anode Plane Assemblies (APA)
  - Cathode Plane Assemblies (CPA)
- Running flow simulations
- Monitoring Impurities
- Thermal Study
- Small Variations



# Baseline Simulation Conditions

Initial Conditions	Value
Inlet Temperature #1	88.519 Kelvin
Inlet Temperature #2	88.534 Kelvin
Inlet Temperature #3	88.503 Kelvin
Inlet Temperature #4	88.520 Kelvin
Electronic Heat Load	336 Watts
Liquid Argon Height	7.4 Meters
Room Temperature	26.1 °C



# Parametric Study

- **Inlet Temperature:**  $\pm 0.1\text{K}$ ,  $\pm 0.2\text{K}$ ,  $\pm 0.3\text{K}$
- **Electronic Heat:**  $\pm 10\%$ ,  $\pm 20\%$ ,  $\pm 30\%$
- **LAr Height:**  $\pm 0.05\text{m}$ ,  $\pm 0.1\text{m}$
- **Room Temperature:**  $\pm 5^\circ\text{C}$ ,  $\pm 10^\circ\text{C}$

# Chi Squared Analysis

- A chi-square test is a statistical test that is used to compare observed and expected results.

$$X_H^2 = \sum \left( \frac{(H_{\text{Experiment,Chi,Column 2}} - H_{\text{CFD,Chi,Column 2}})^2}{(H_{\text{CFD,Chi,Column 3}})^2} \right)$$

$$X_V^2 = \sum \left( \frac{(V_{\text{Experiment,Chi,Column 2}} - V_{\text{CFD,Chi,Column 2}})^2}{(V_{\text{CFD,Chi,Column 3}})^2} \right)$$

- Chi Squared per Degree of Freedom value

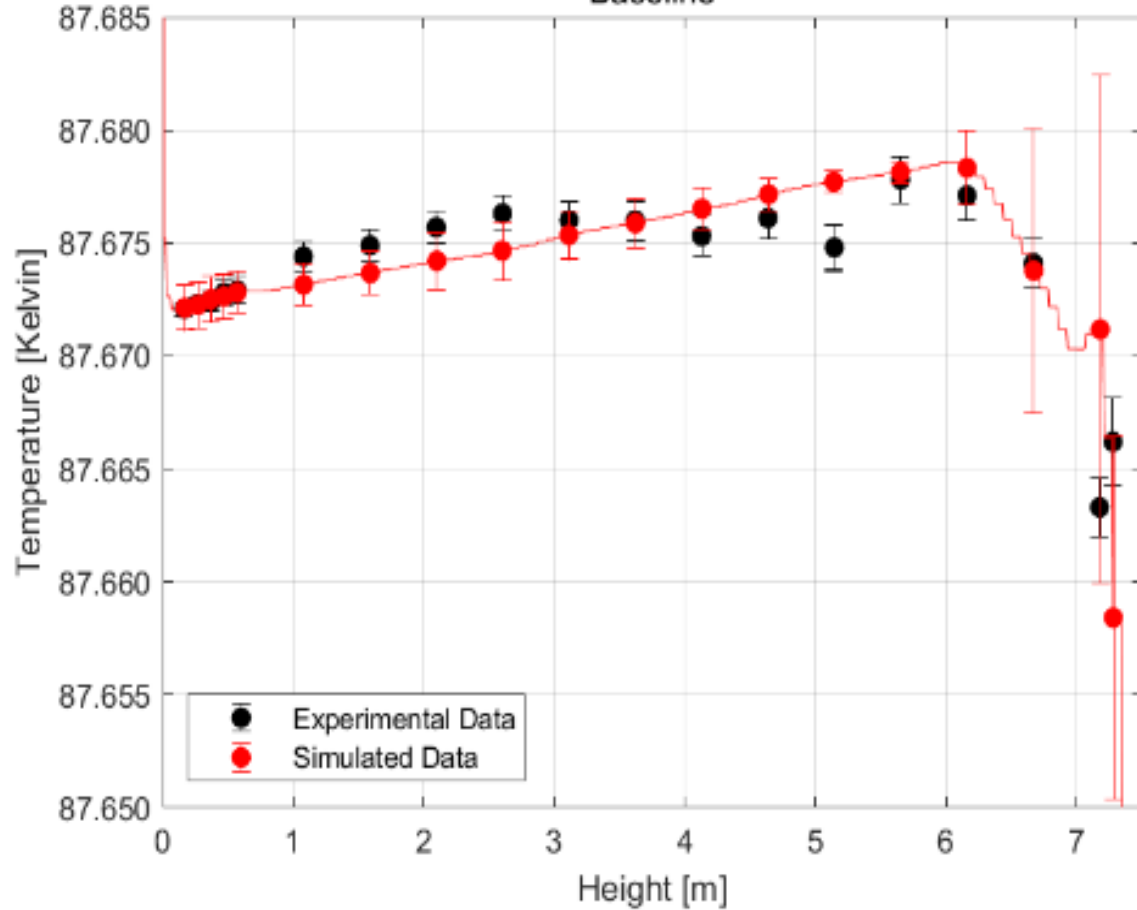
$$\text{DOF} = X^2/N$$

- N is number of data points for the temperature profile
- $X^2$  is the Chi Square value that was calculated from above

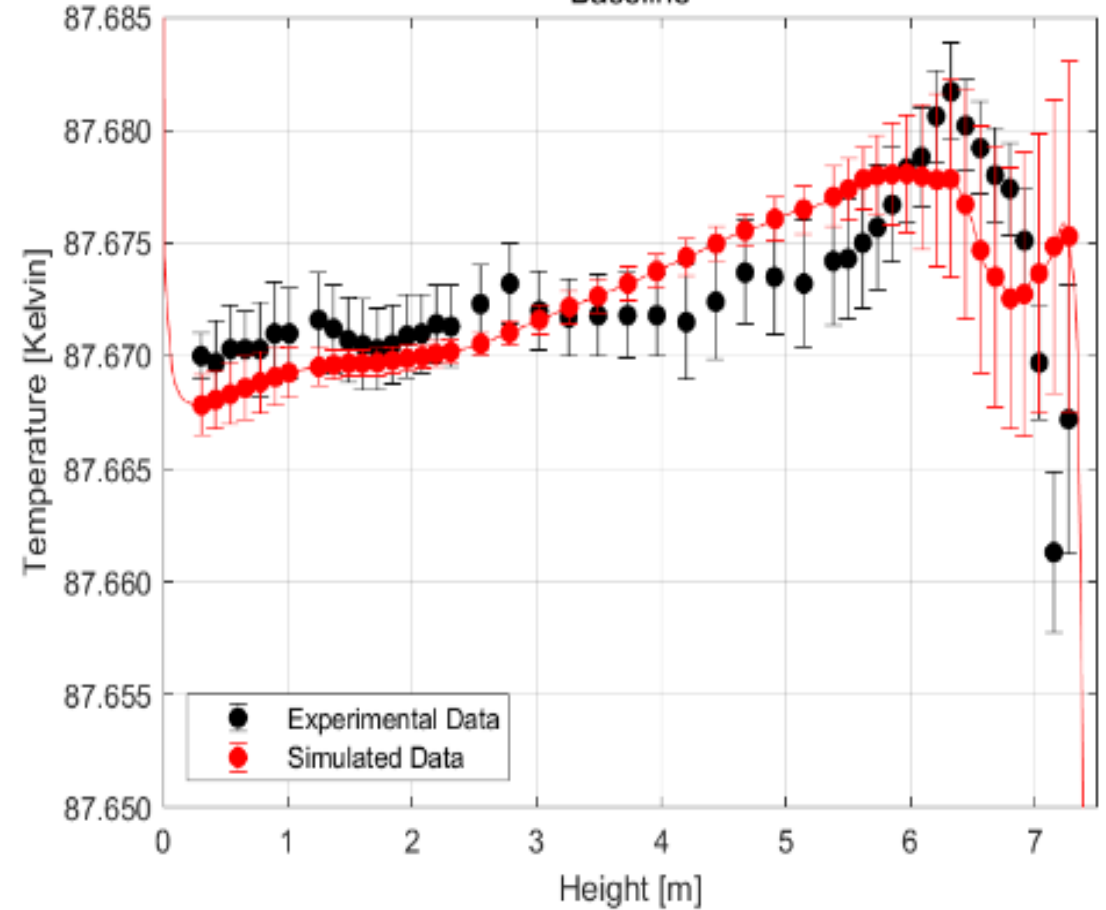


# Baseline Results

Hawaii  
Baseline

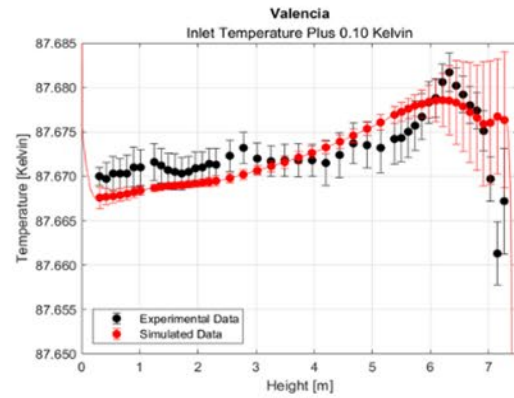
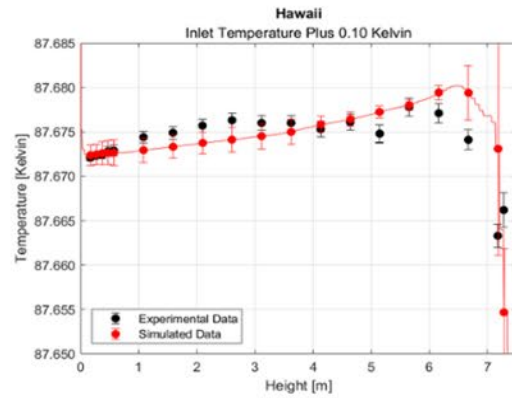
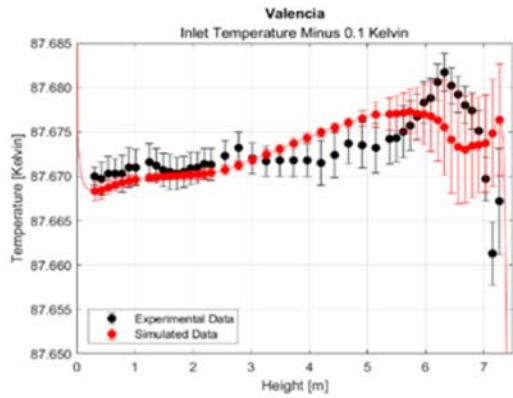
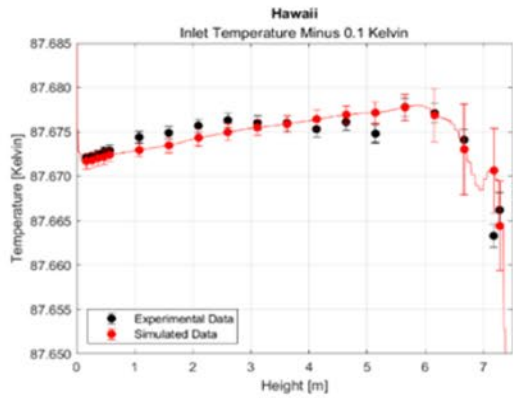


Valencia  
Baseline



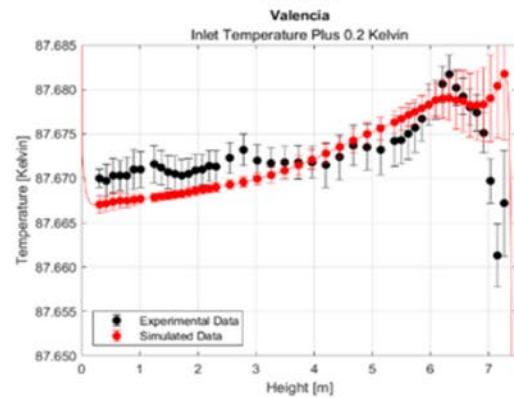
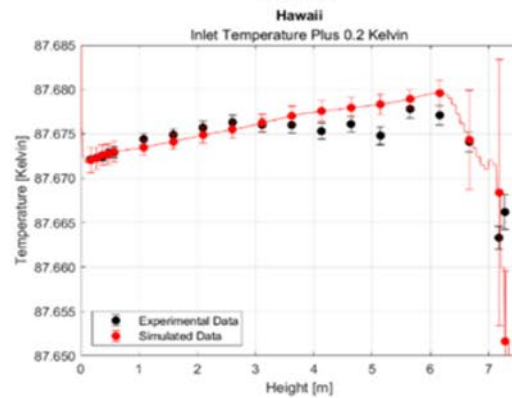
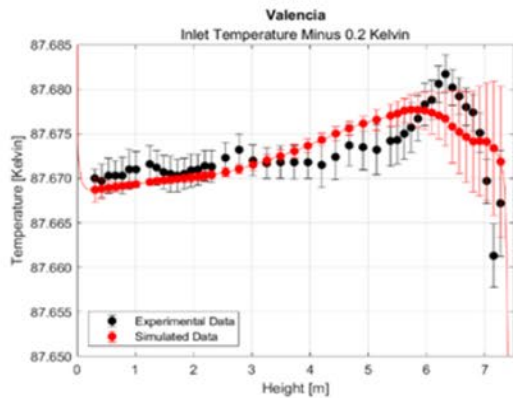
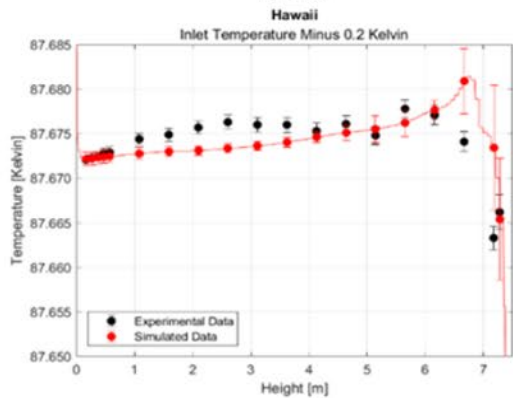
# Inlet Temperature: $\pm 0.1K$ , $\pm 0.2K$ , $\pm 0.3K$

-0.1K



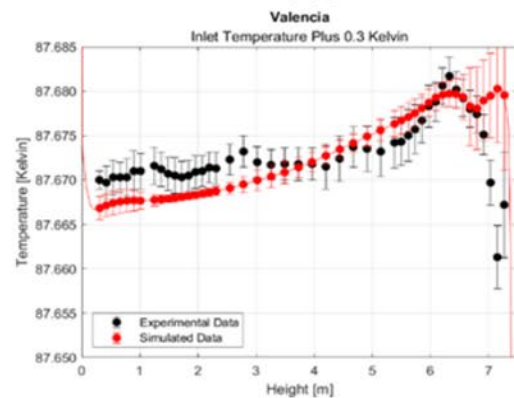
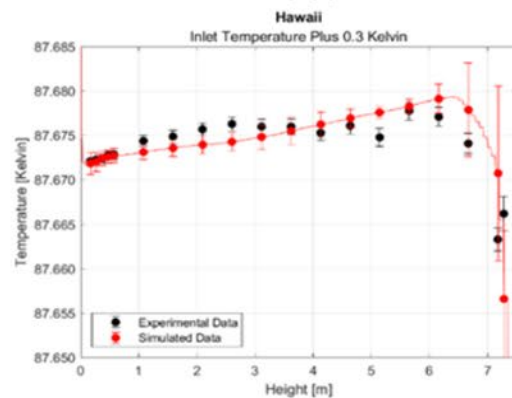
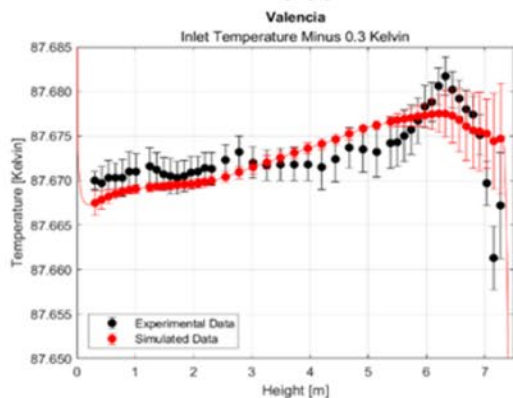
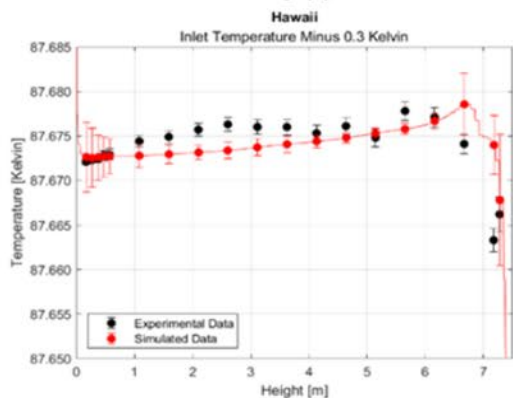
+0.1K

-0.2K



+0.2K

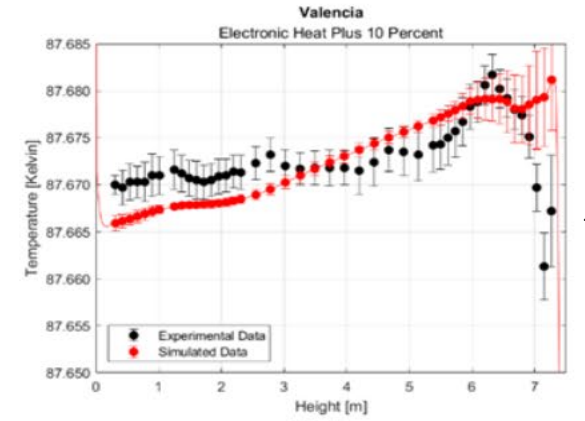
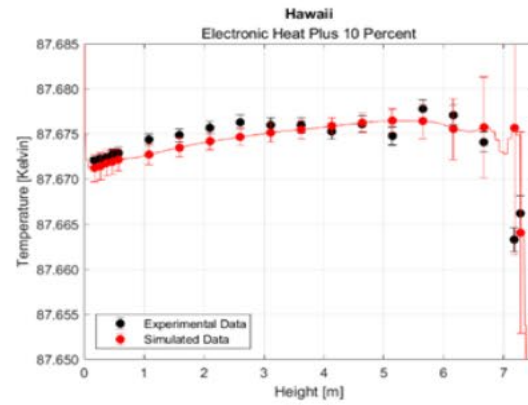
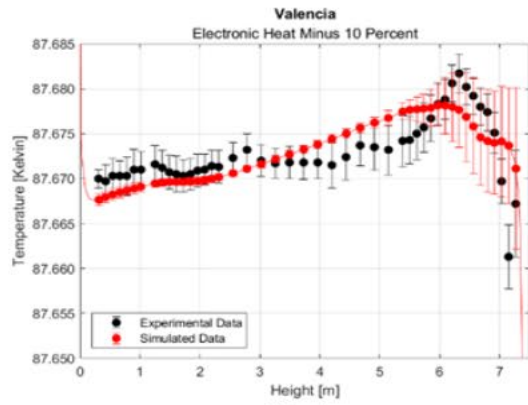
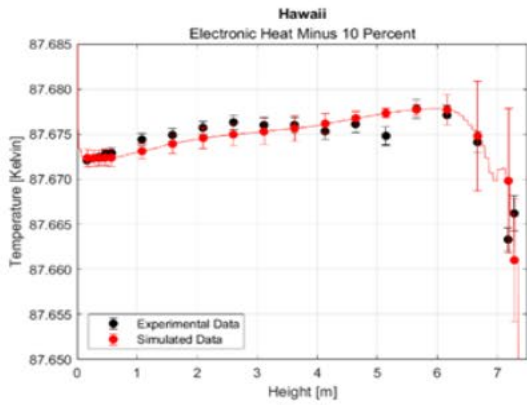
-0.3K



+0.3K

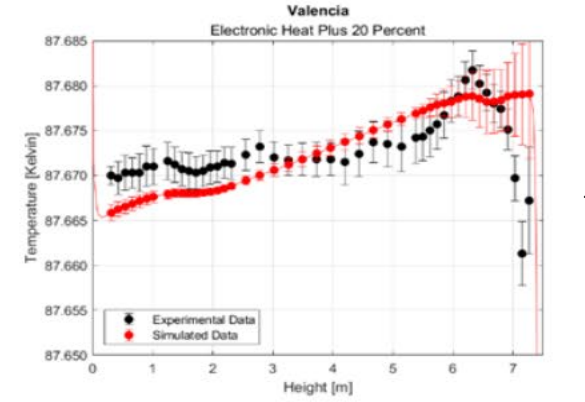
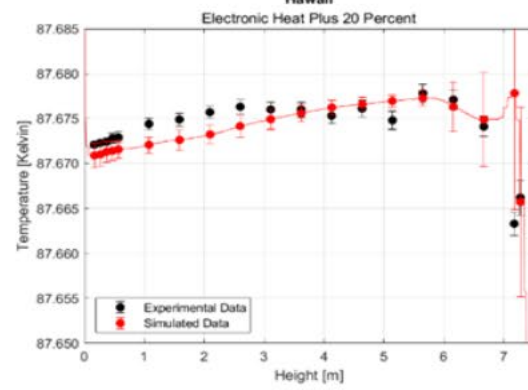
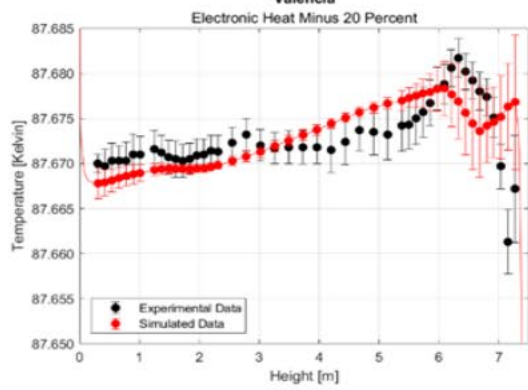
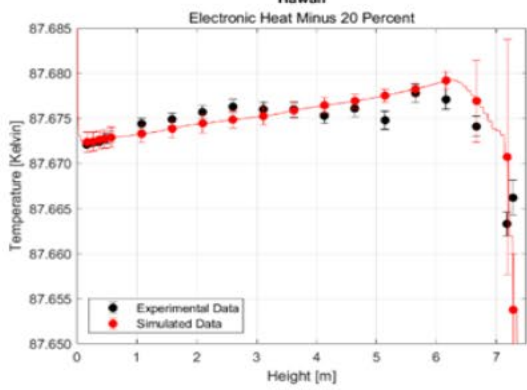
# Electronic Heat: $\pm 10\%$ , $\pm 20\%$ , $\pm 30\%$

-10%



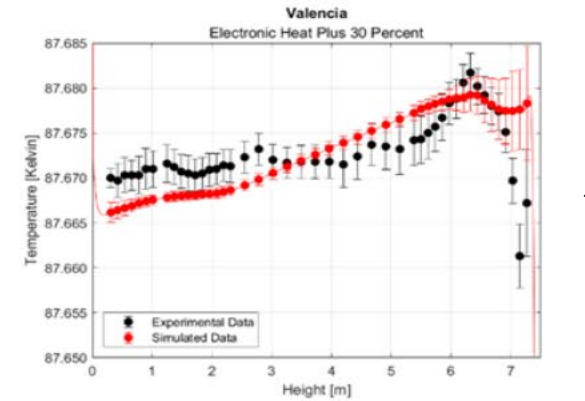
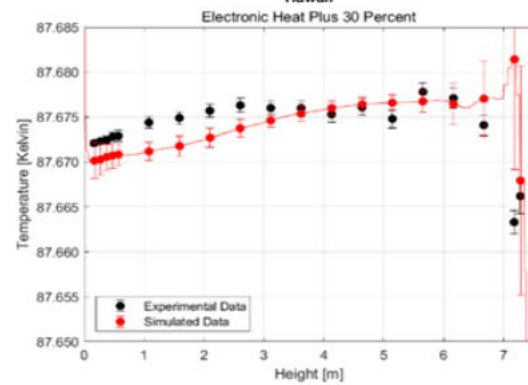
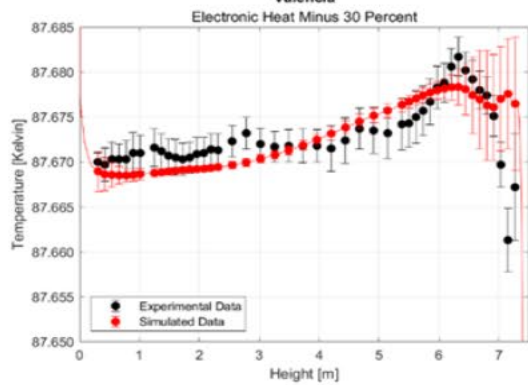
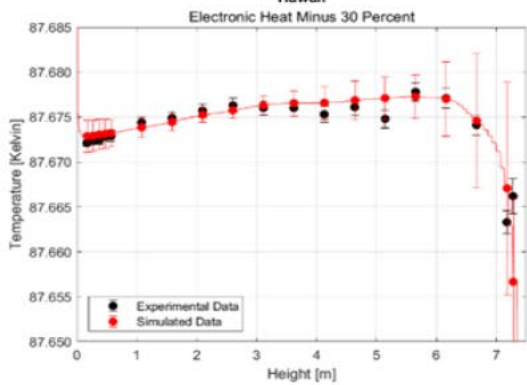
+10%

-20%



+20%

-30%

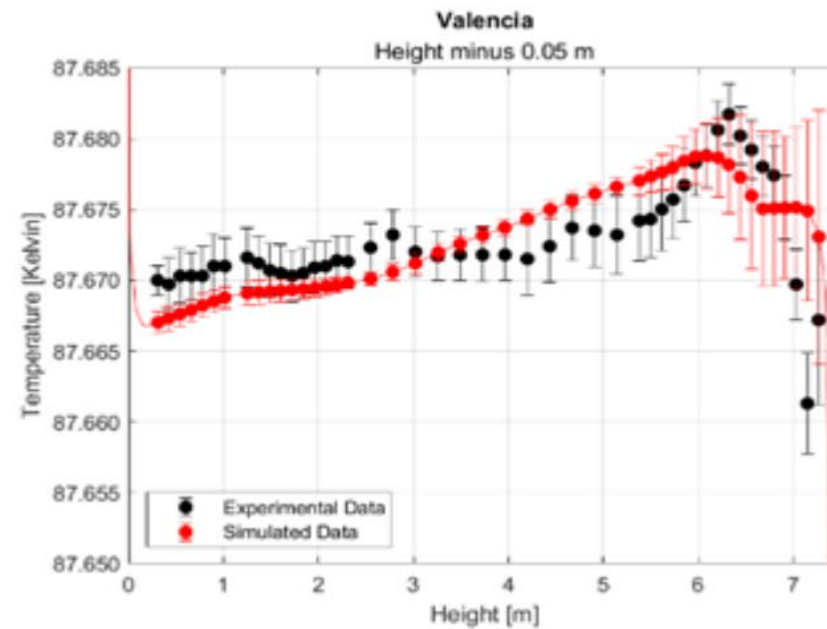
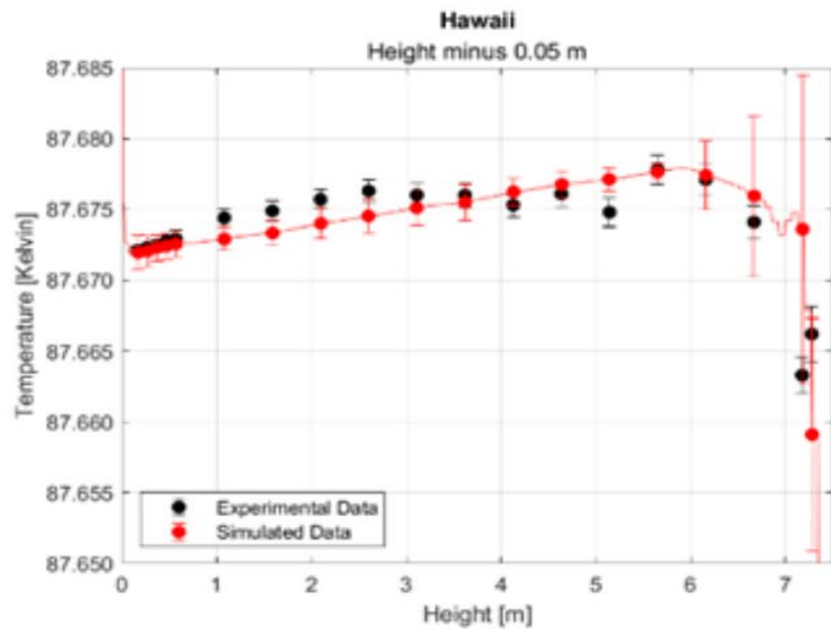
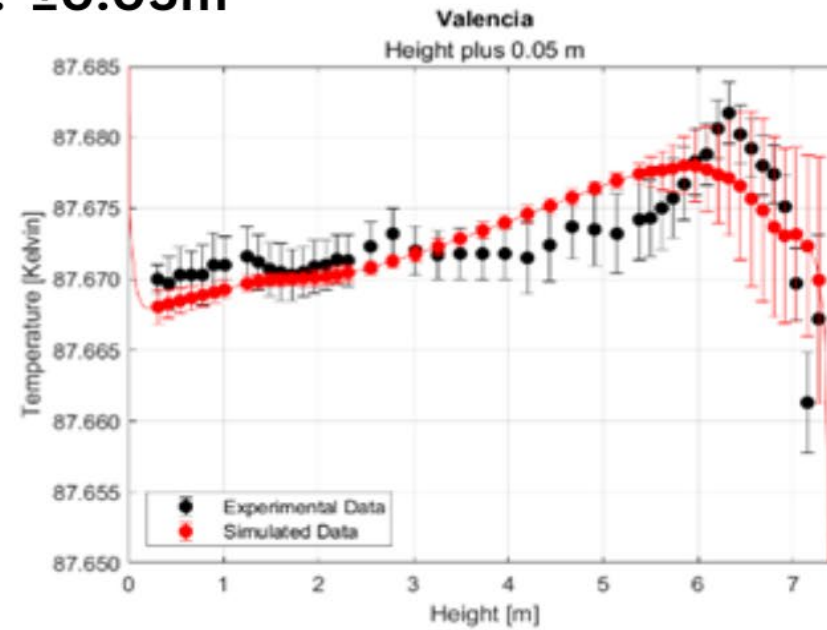
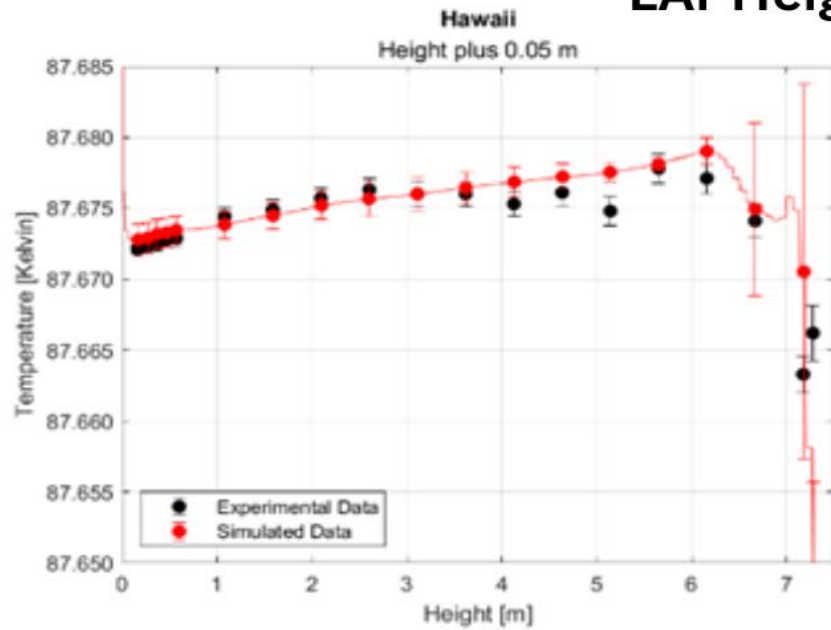


+30%

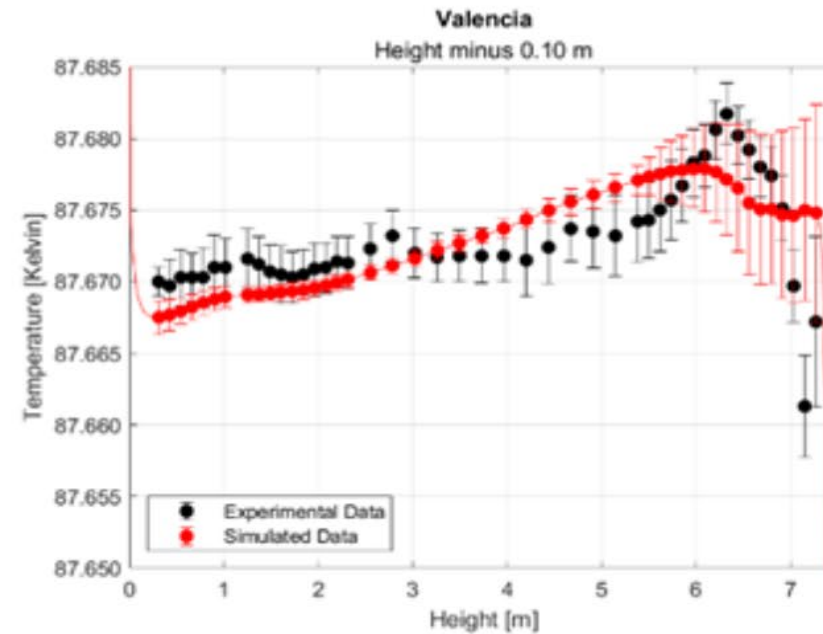
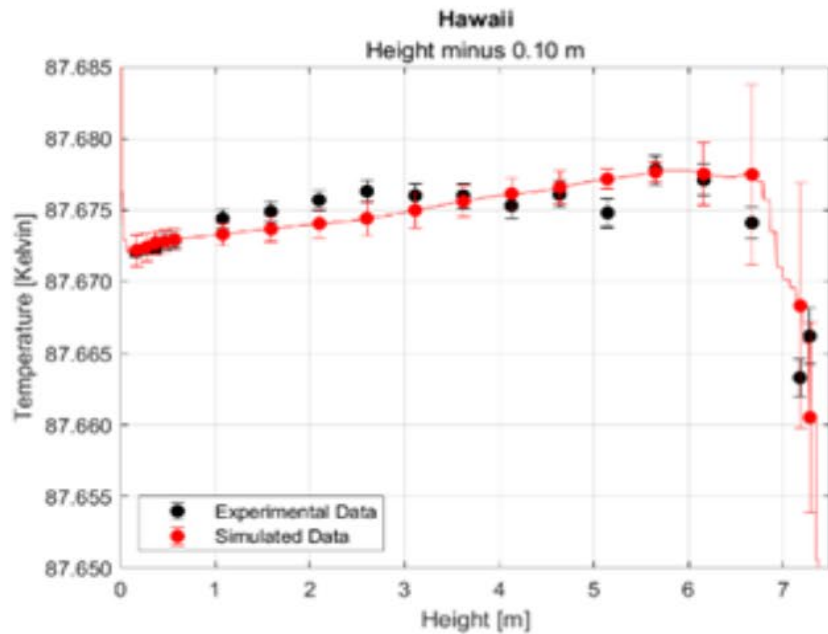
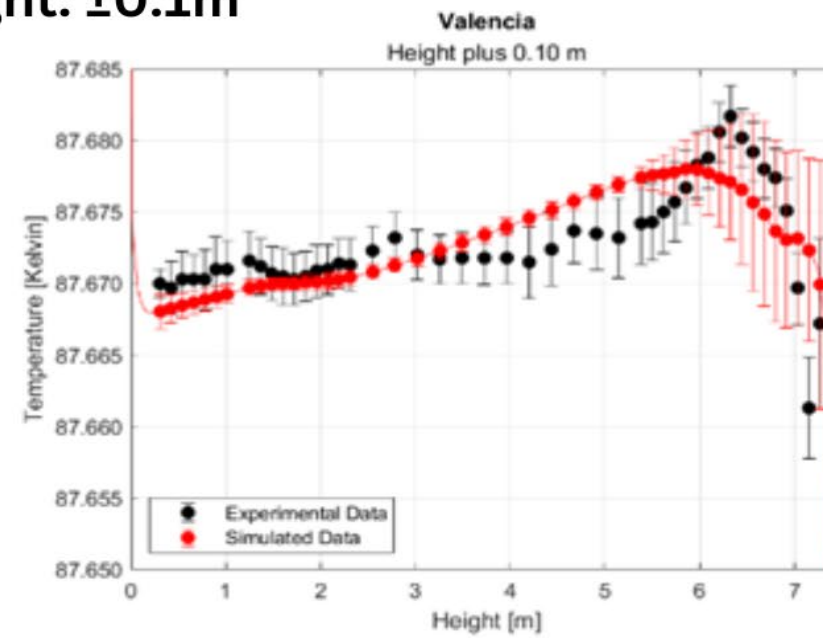
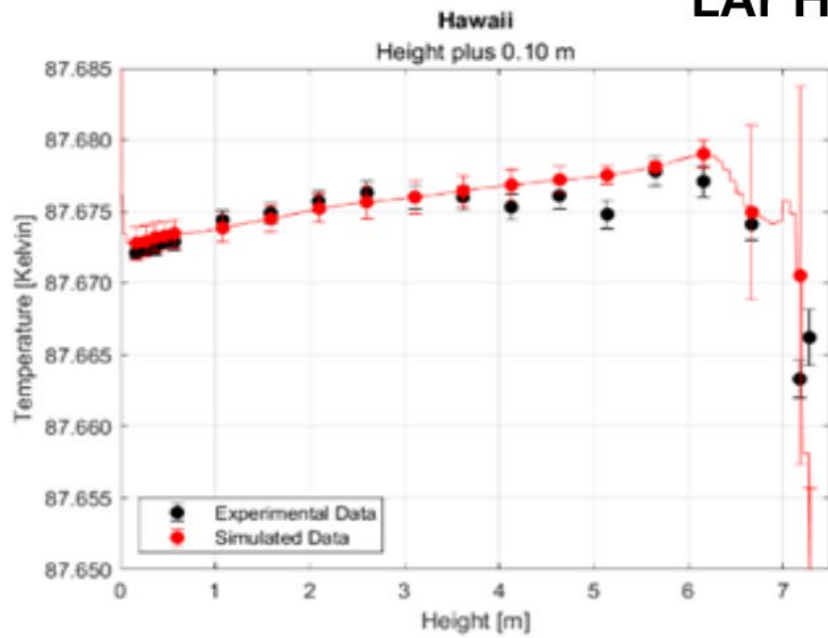




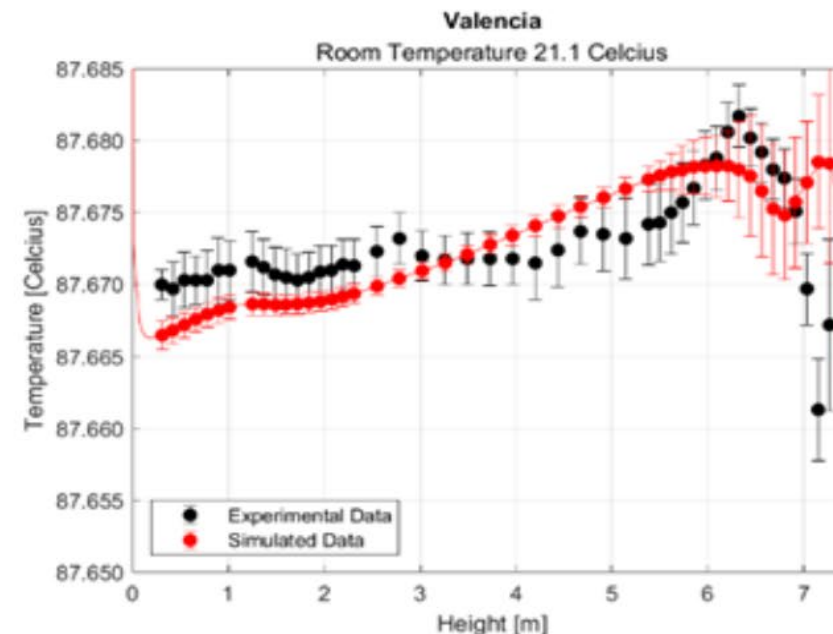
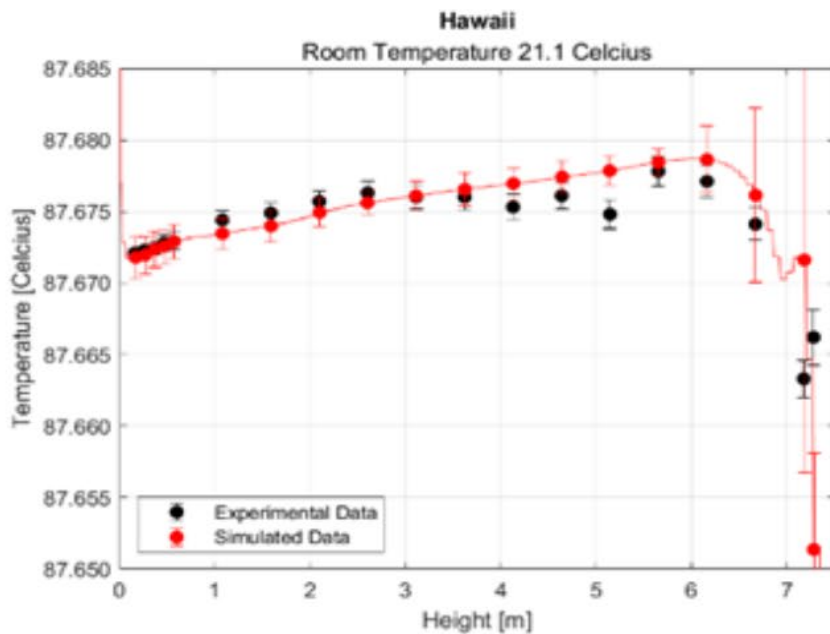
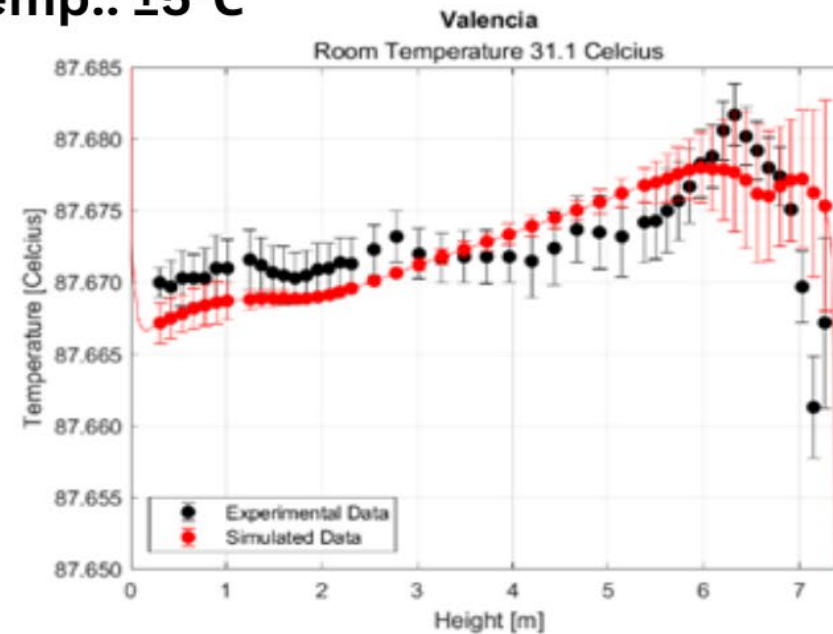
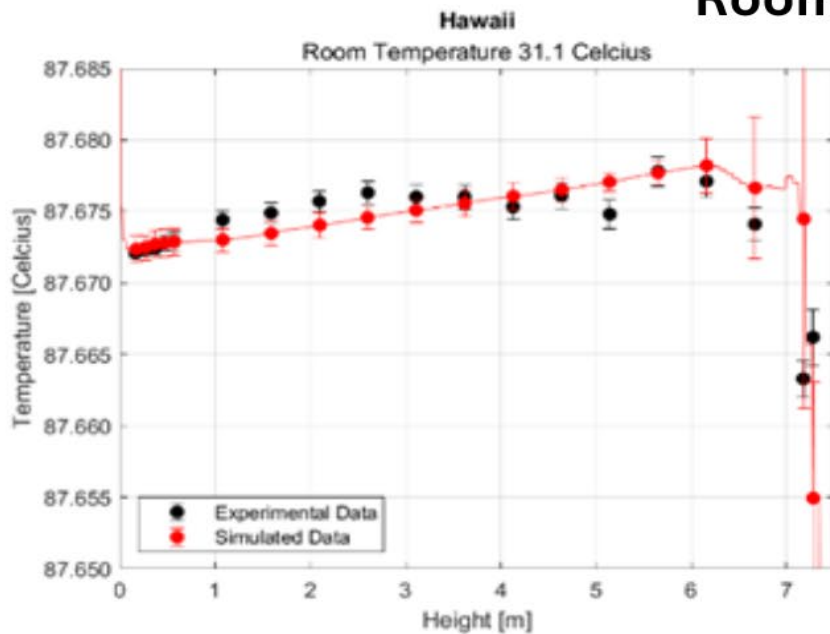
# LAr Height: $\pm 0.05\text{m}$



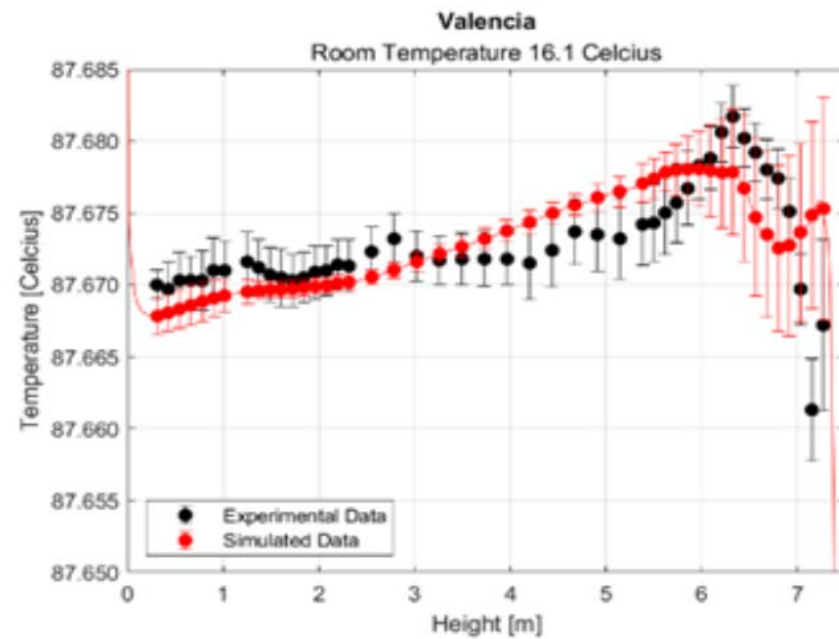
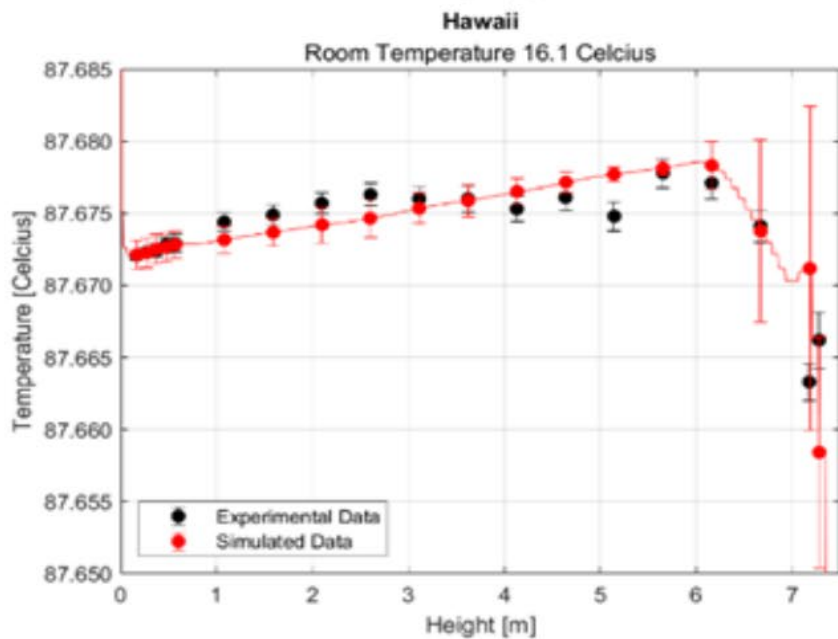
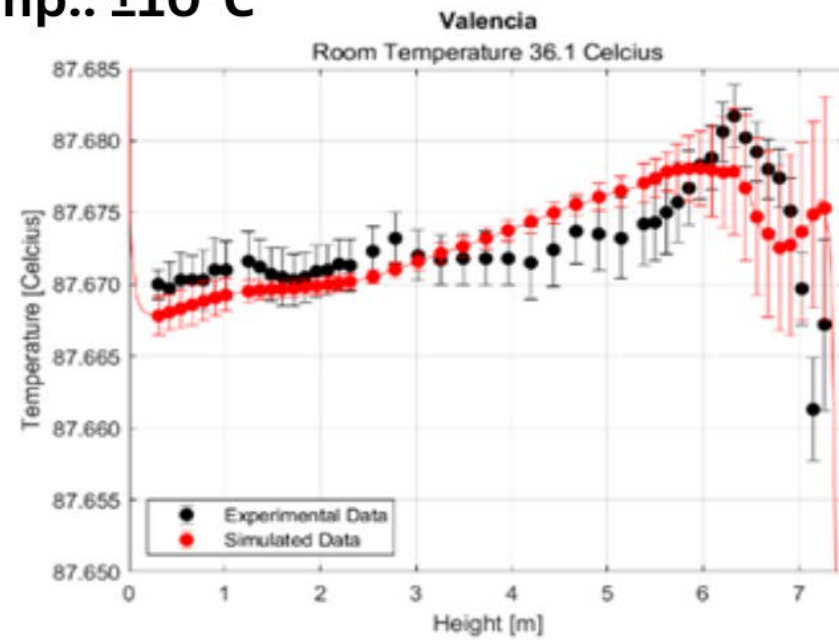
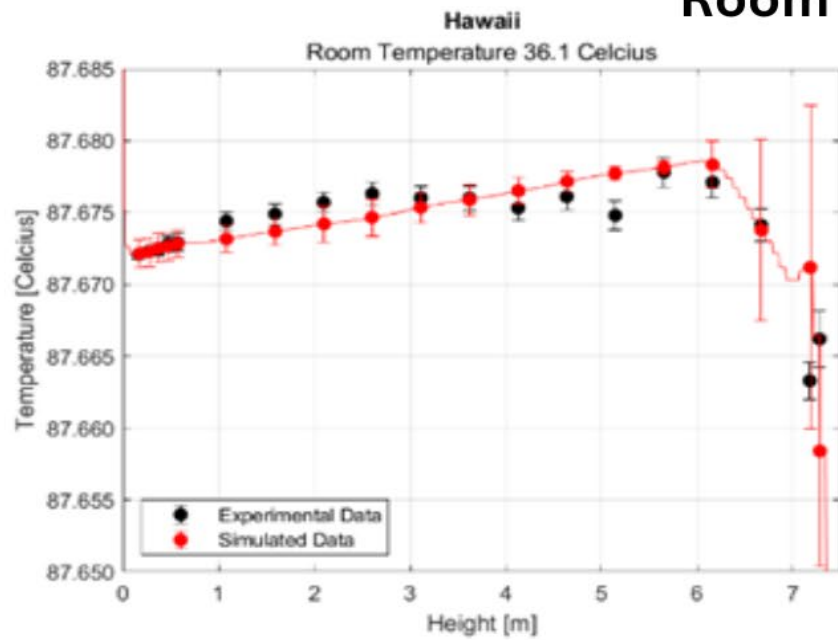
# LAr Height: $\pm 0.1\text{m}$



# Room Temp.: $\pm 5^\circ\text{C}$

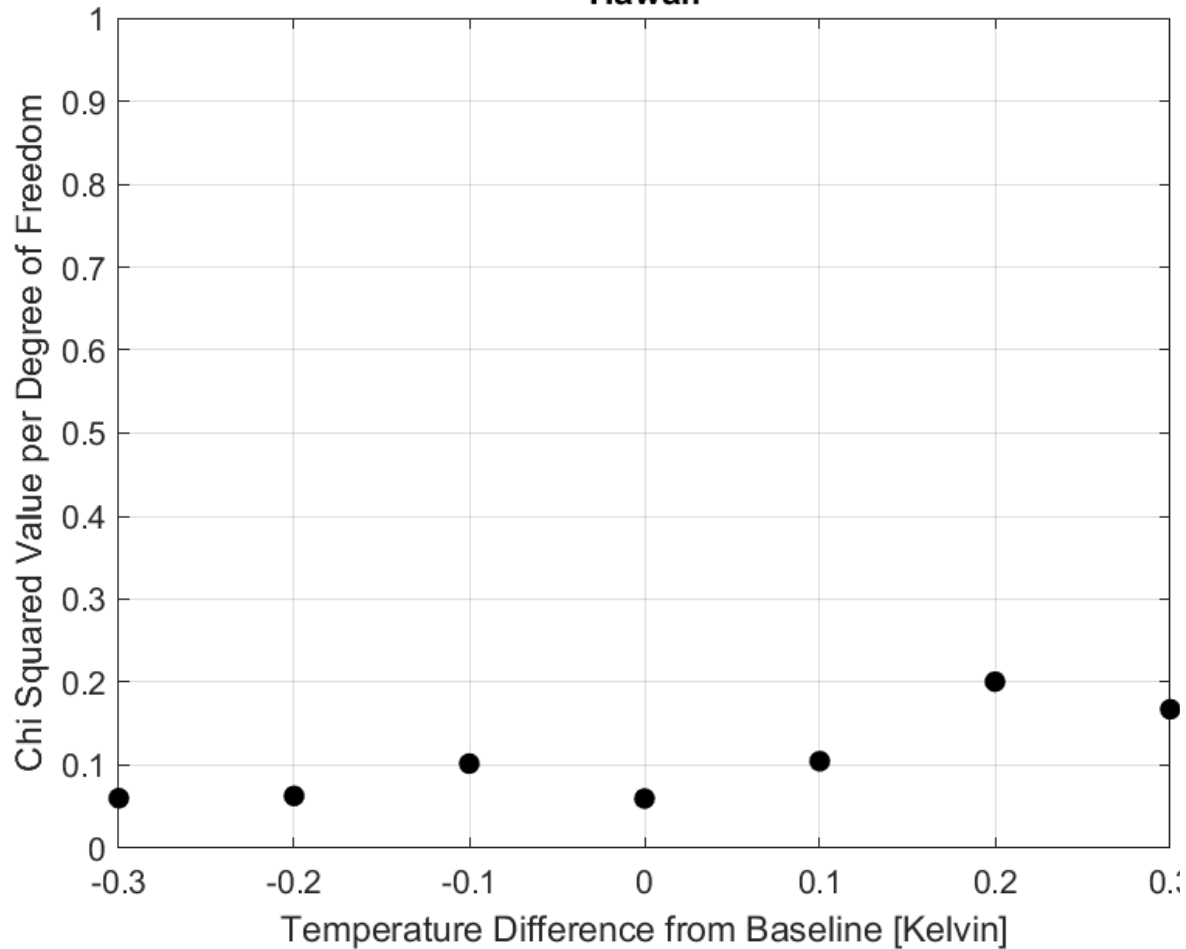


# Room Temp.: $\pm 10^{\circ}\text{C}$

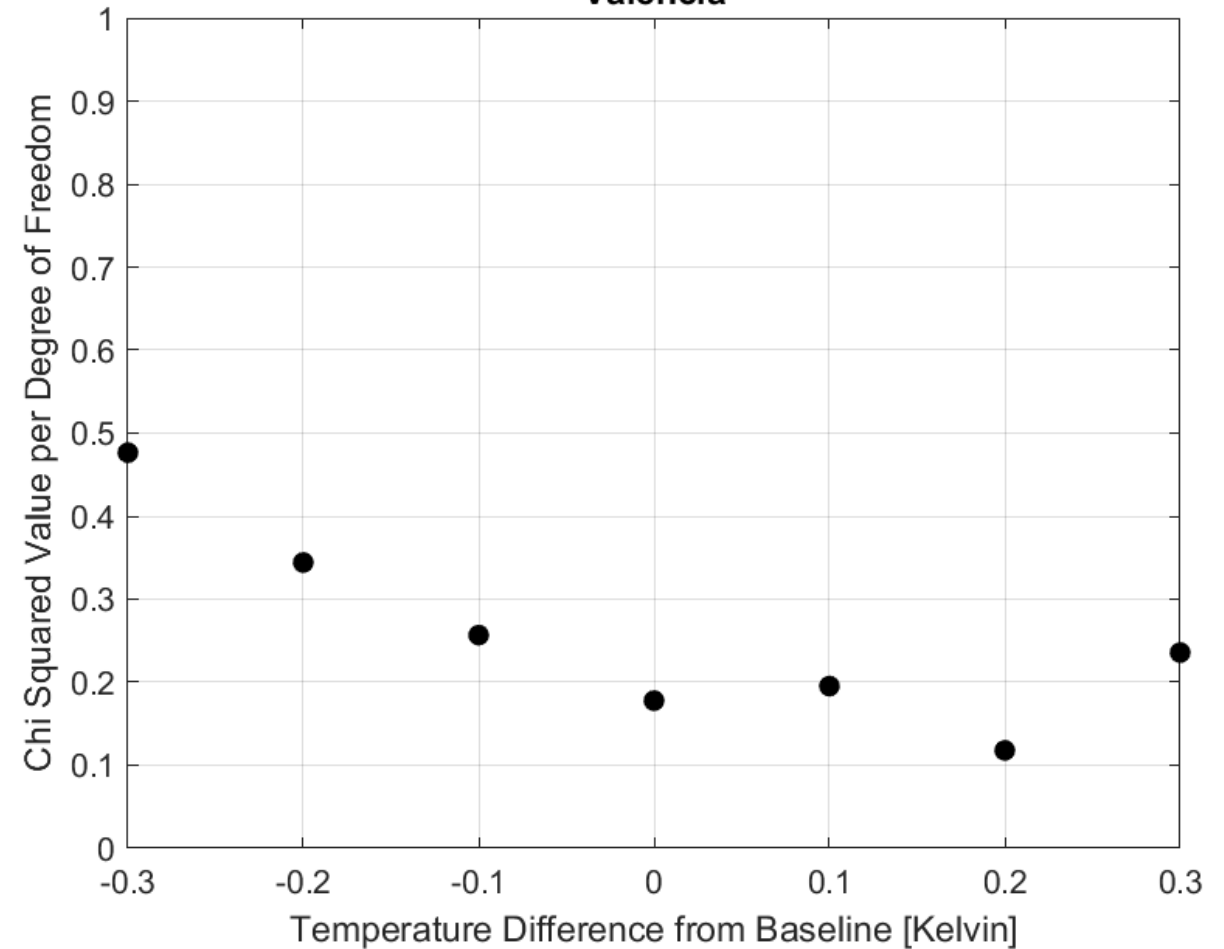


# Chi Square Analysis (Inlet Temperatures)

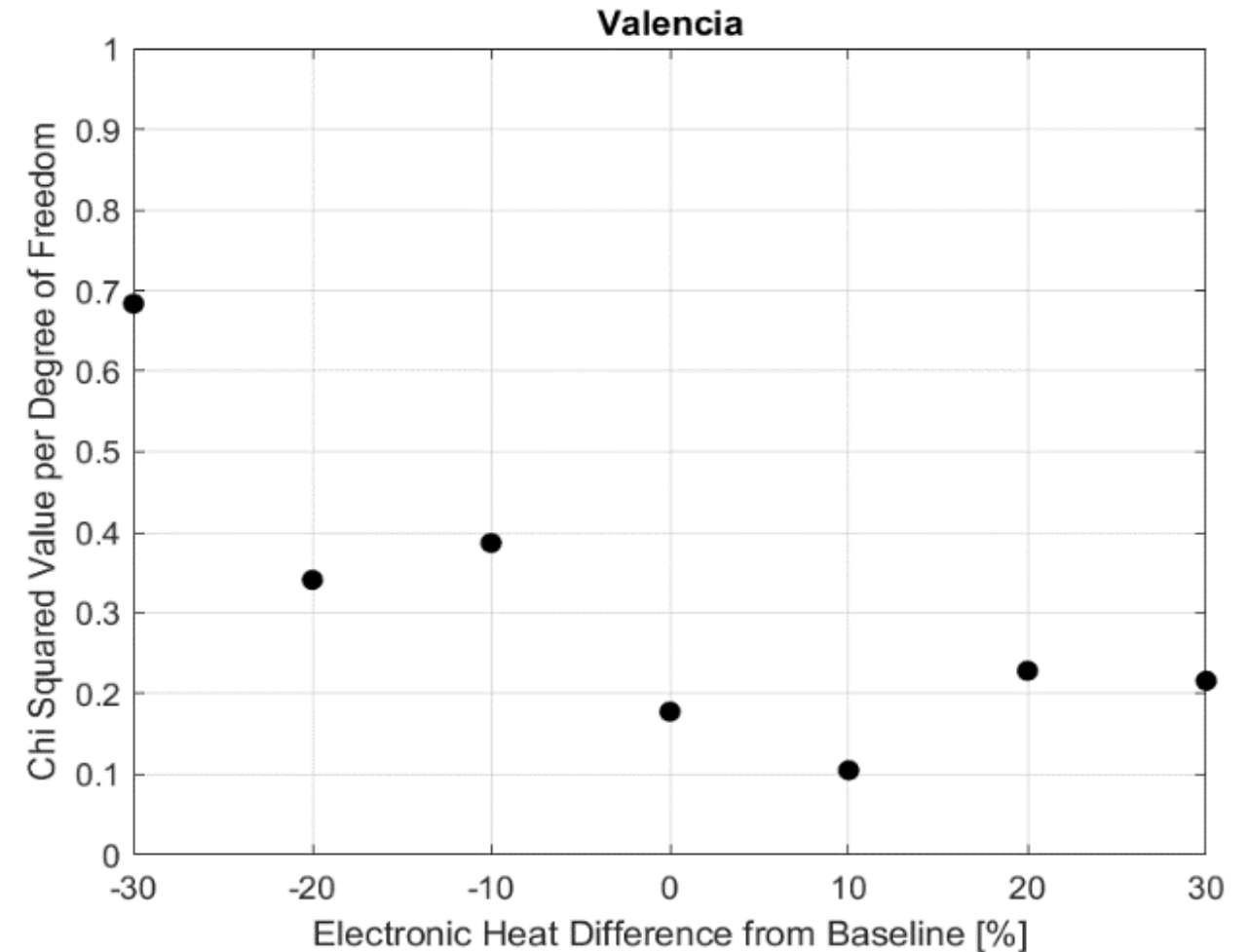
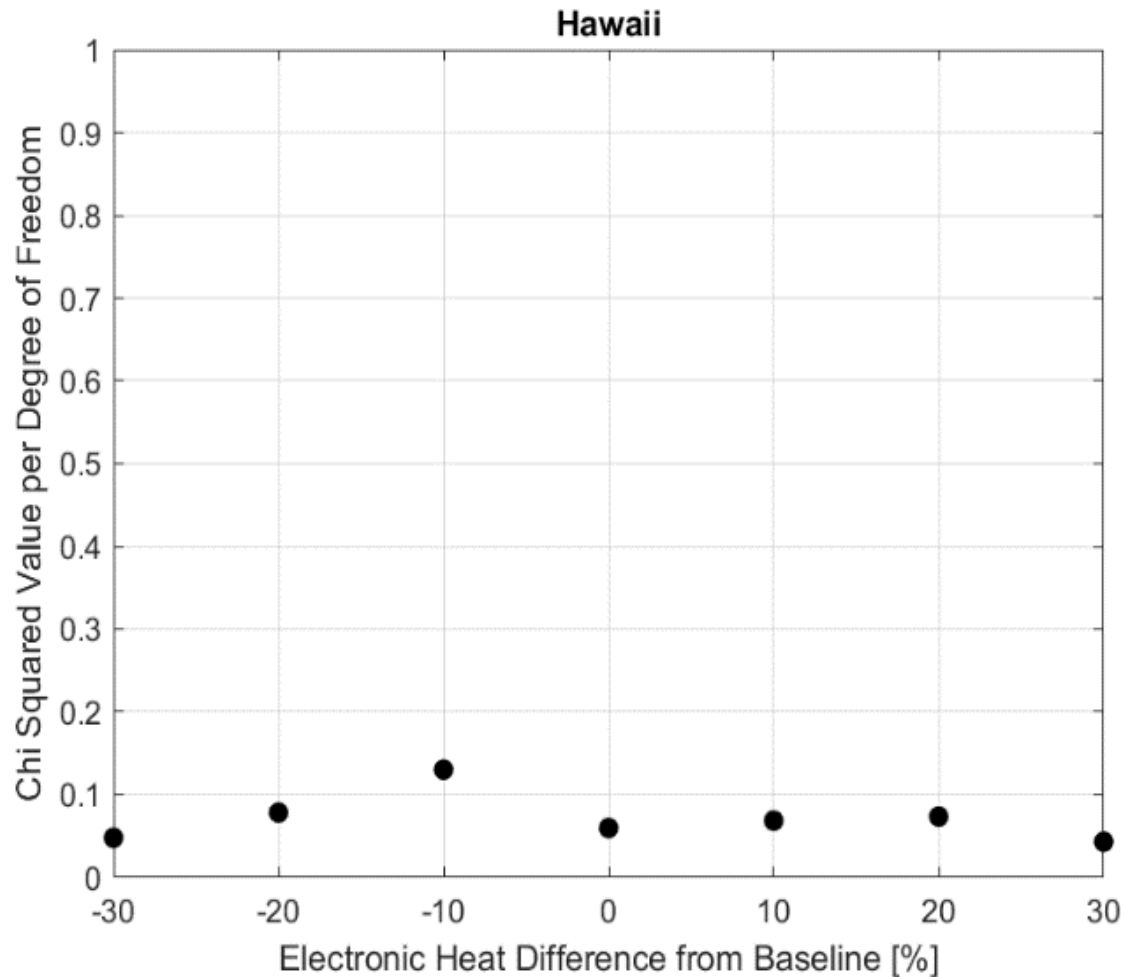
Hawaii



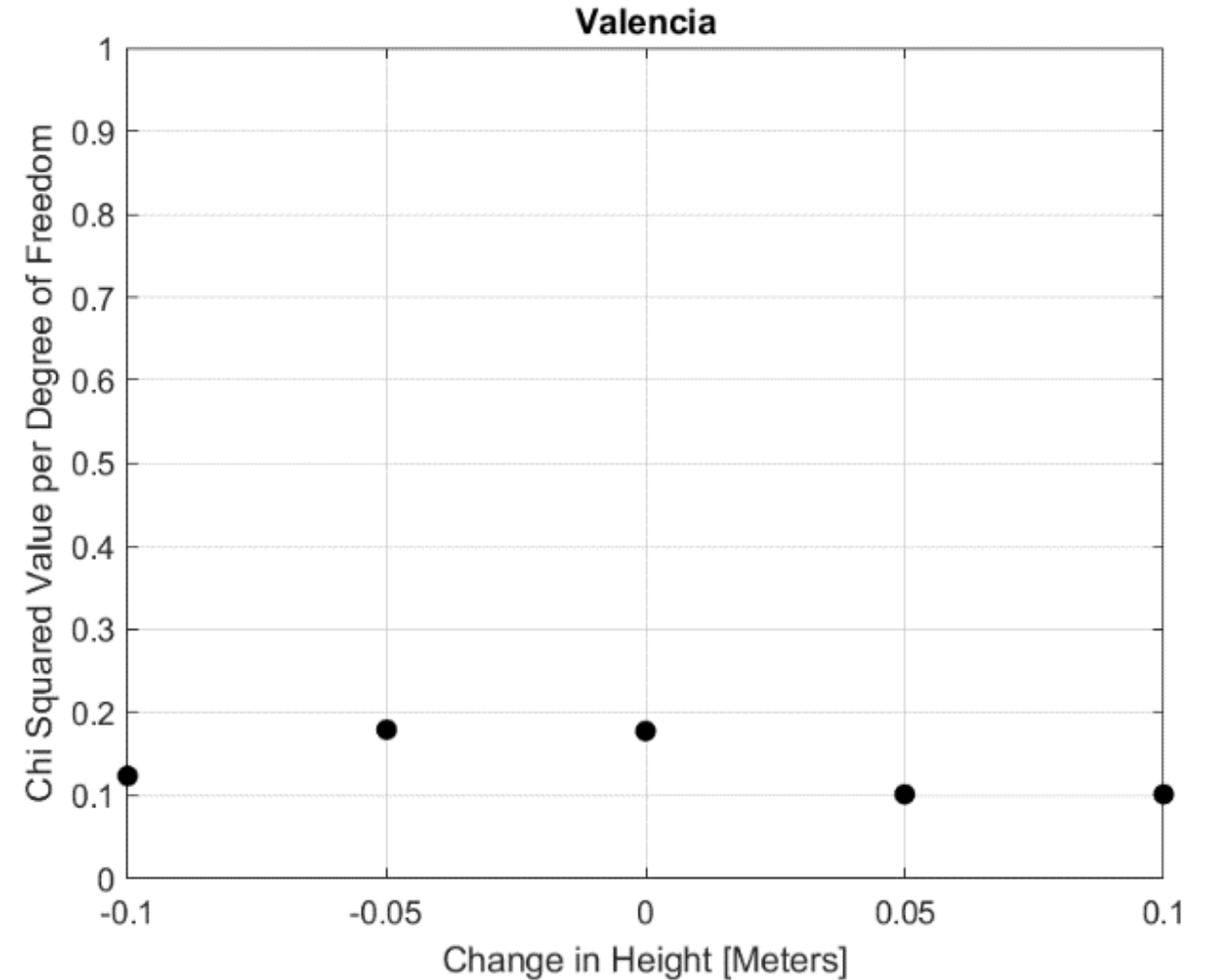
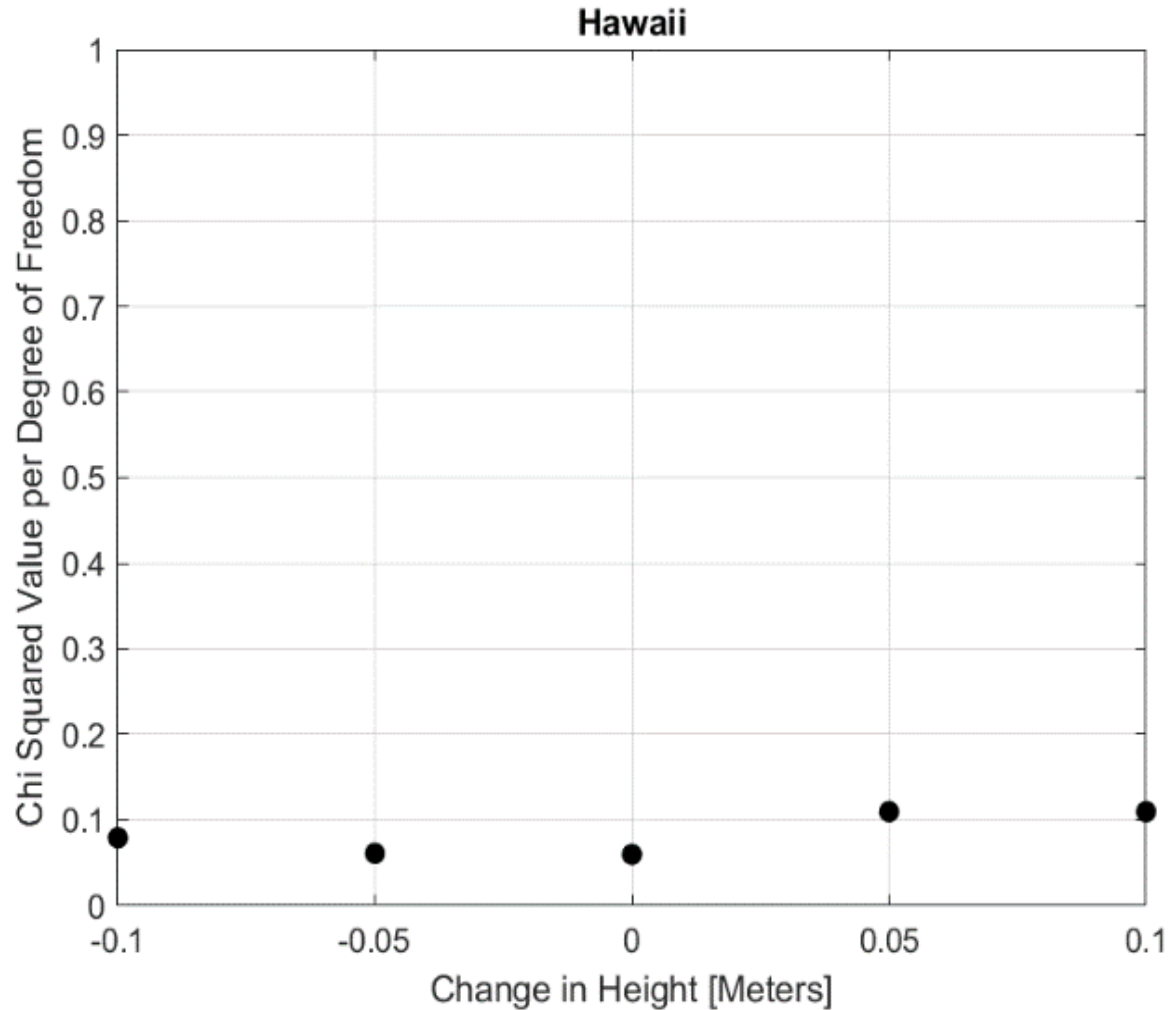
Valencia



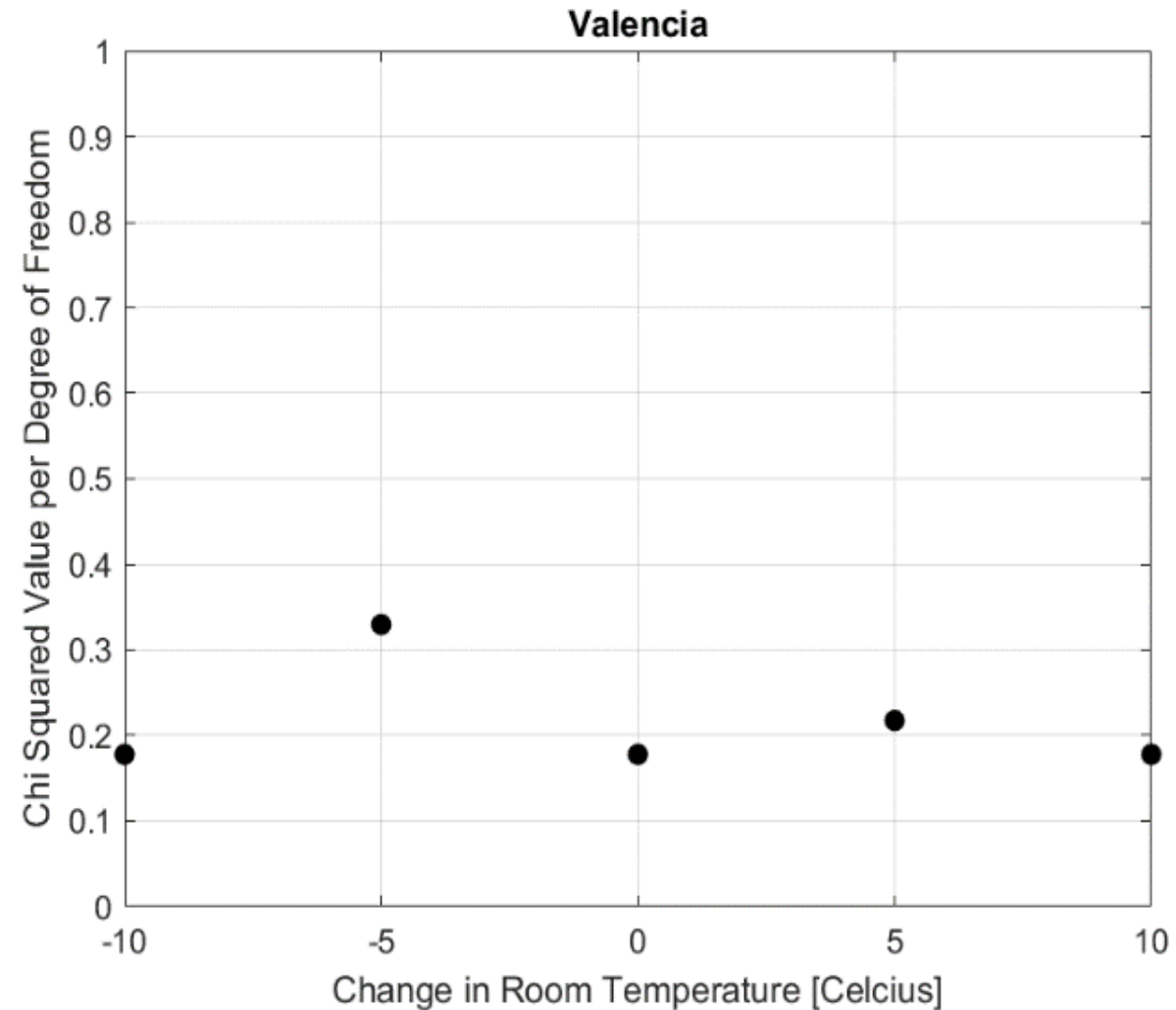
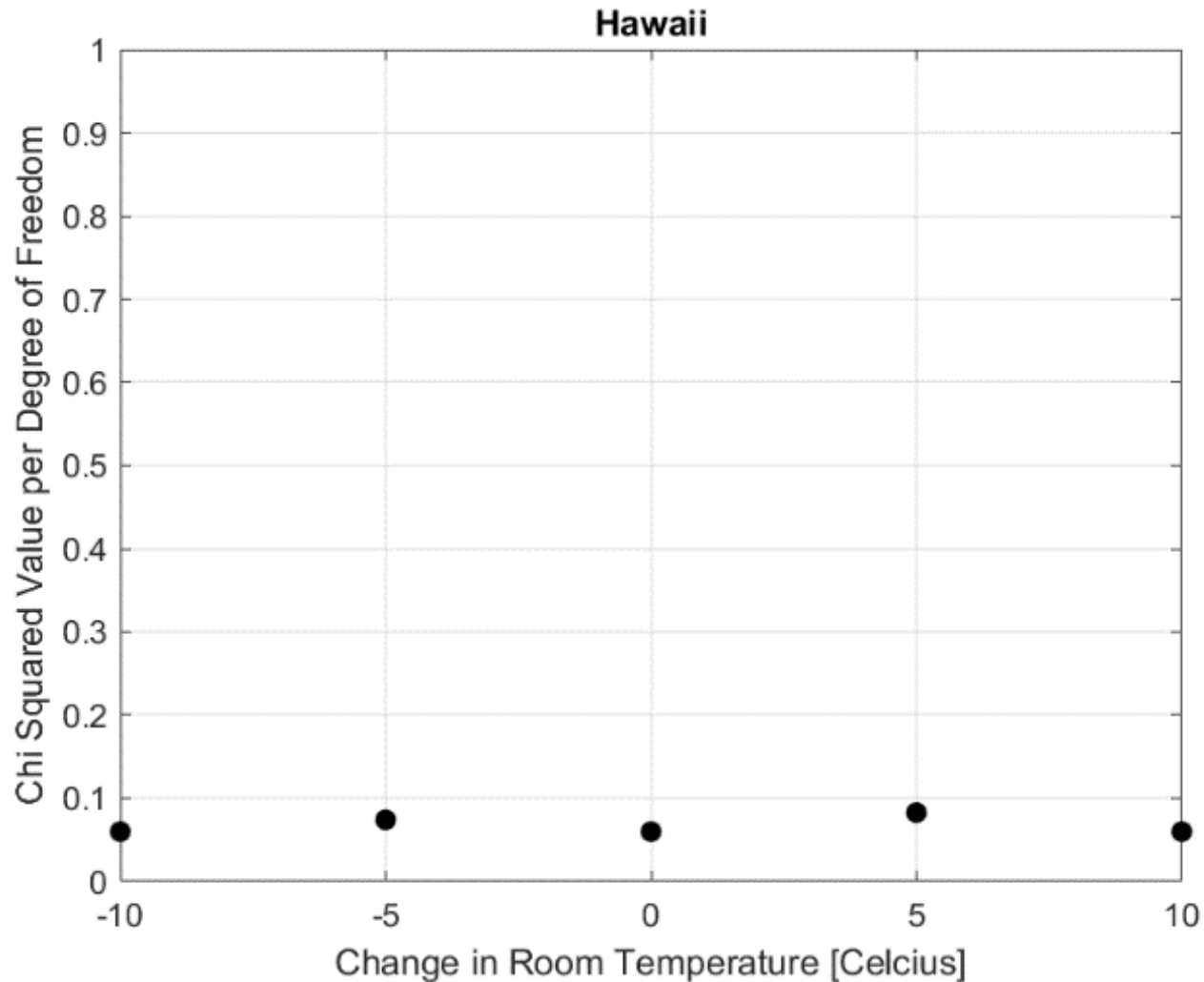
# Chi Square Analysis (Electronic Heat)



# Chi Square Analysis (LAr Height)



# Chi Square Analysis (Room Temperature)

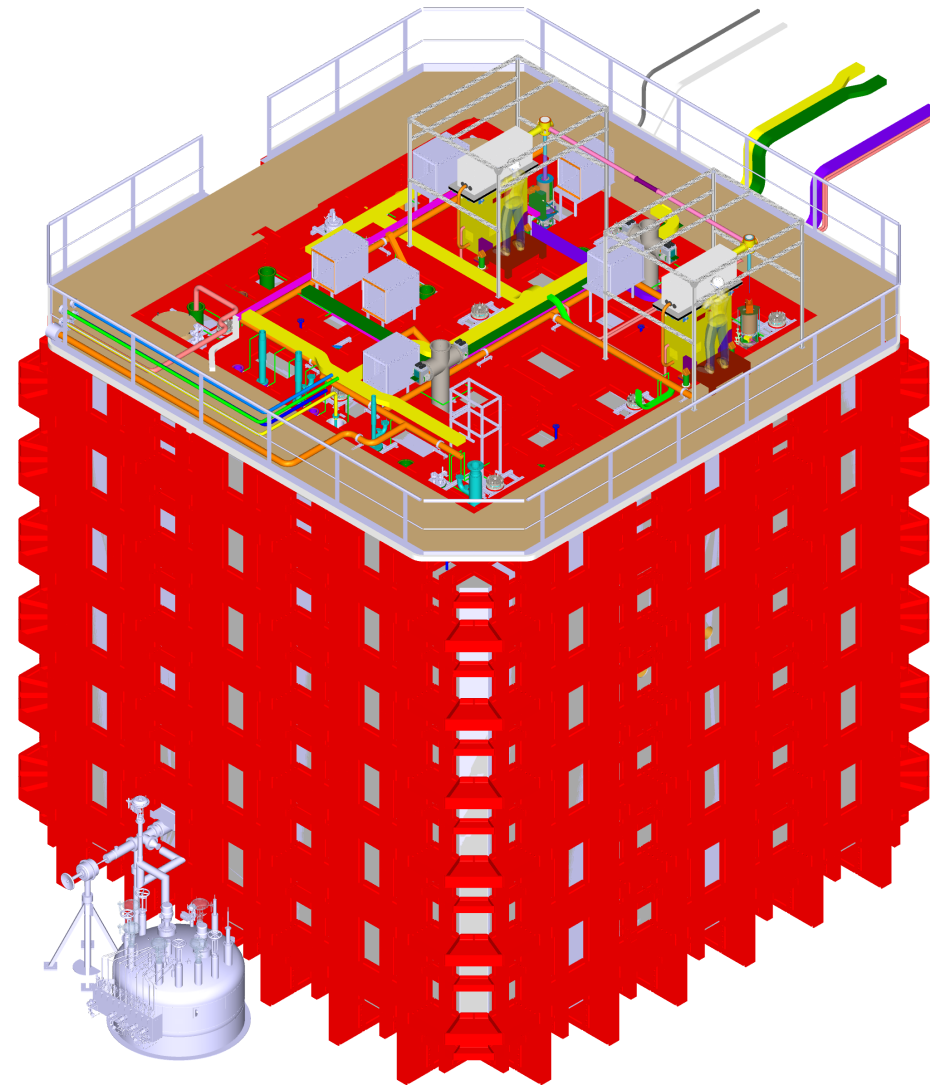




# Stepping into PROTO DUNE II

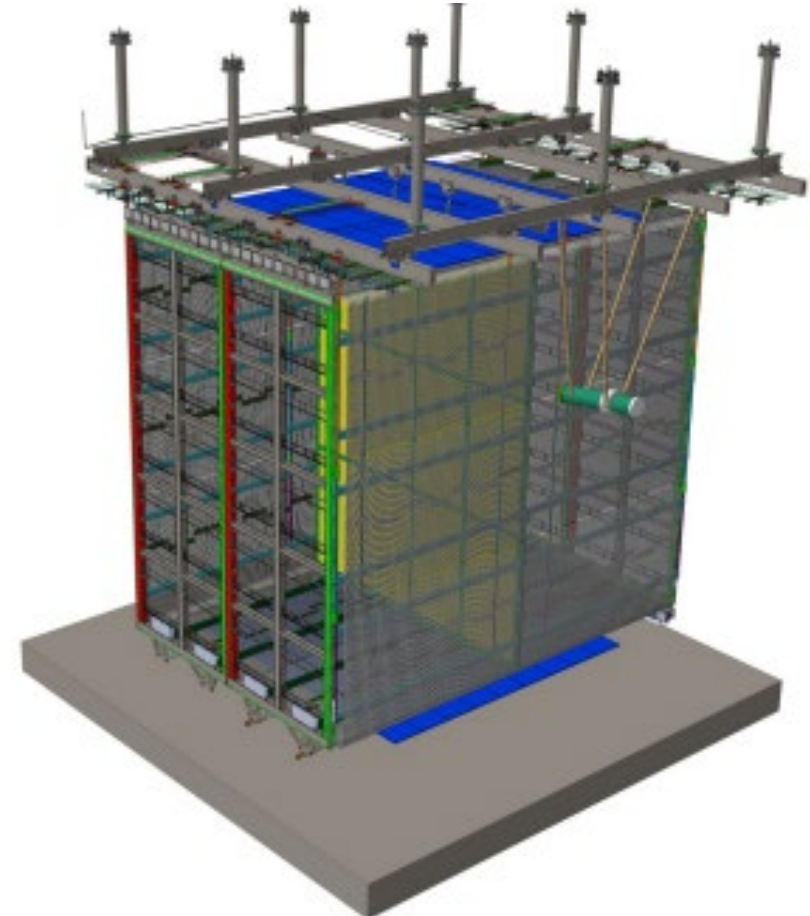
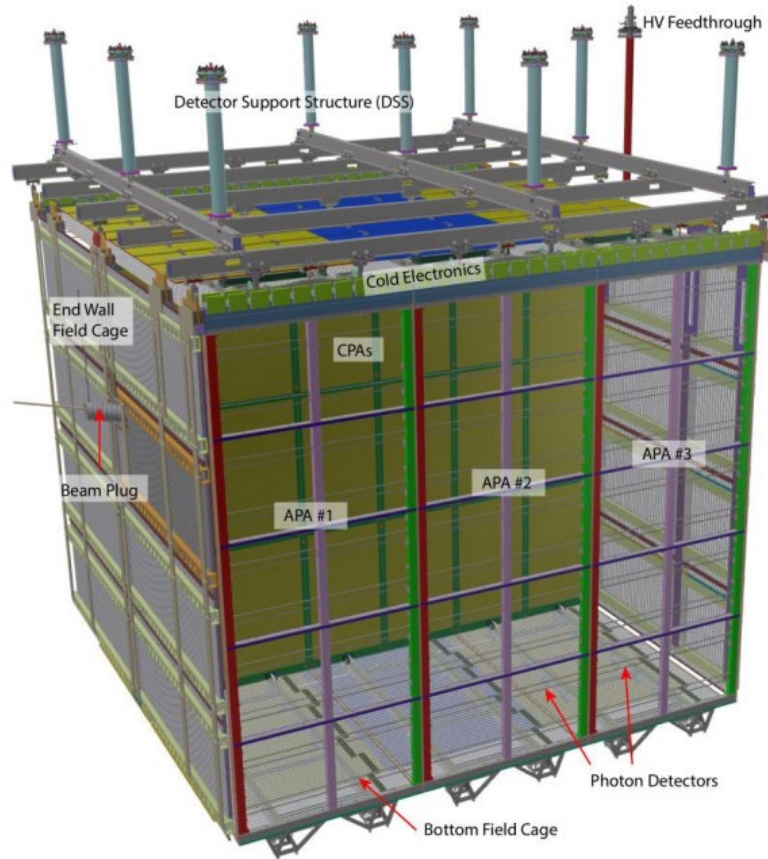


# PROTO Dune II Complete 3D Model



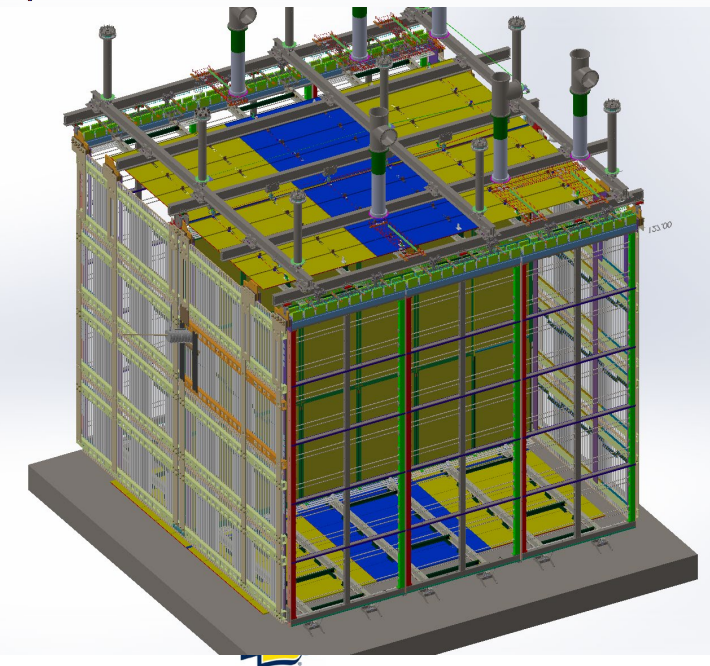
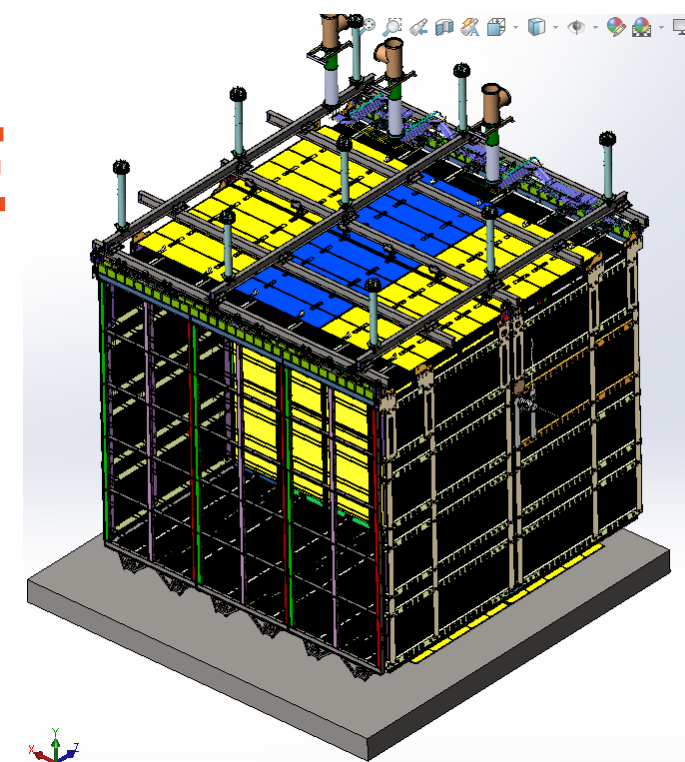
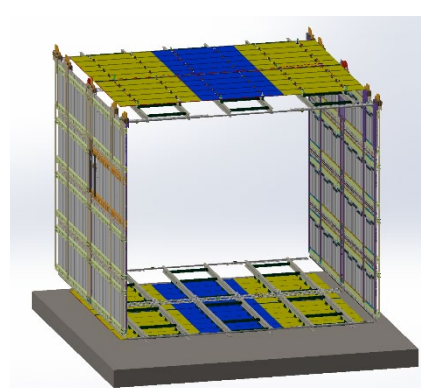
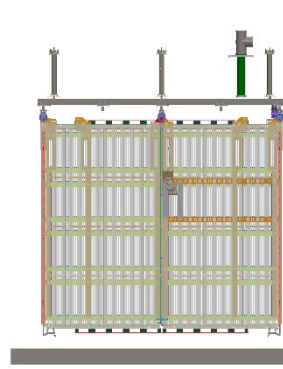
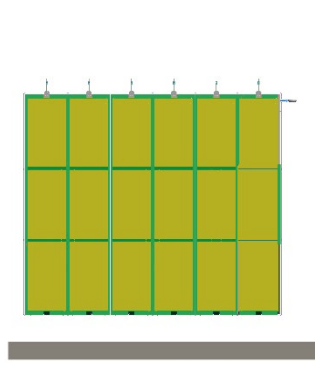
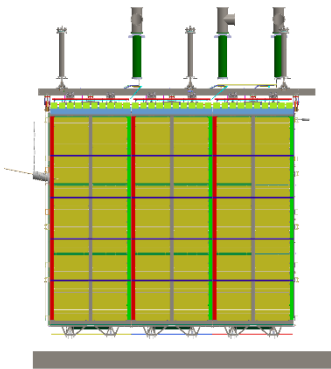
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# ProtoDUNE-I and ProtoDUNE-II

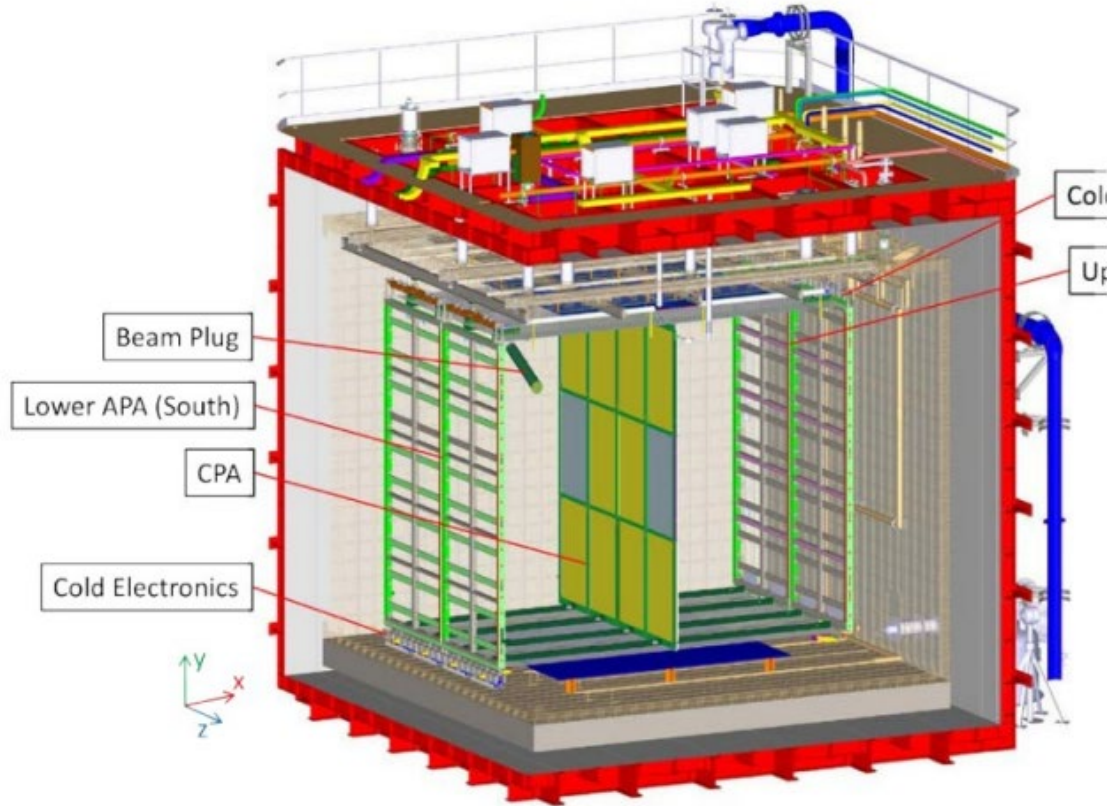


# Specifications for ProtoDUNE

Detection Element	Approx Dimensions	Quantity
APA	6 m H by 2.4 m W	3 per anode plane, 6 total
CPA module	2 m H by 1.2 m W	3 per CPA column, 18 total in cathode plane
Top FC module	2.4 m W by 3.6 m along drift	3 per top FC assembly, 6 total
Bottom FC module	2.4 m W by 3.6 m along drift	3 per bottom FC assembly, 6 total
End-wall FC module	1.5 m H by 3.6 m along drift	4 per end-wall assembly (vertical drift volume edge), 16 total
PD module	2.2 m × 86 mm × 6 mm	10 per APA, 60 total



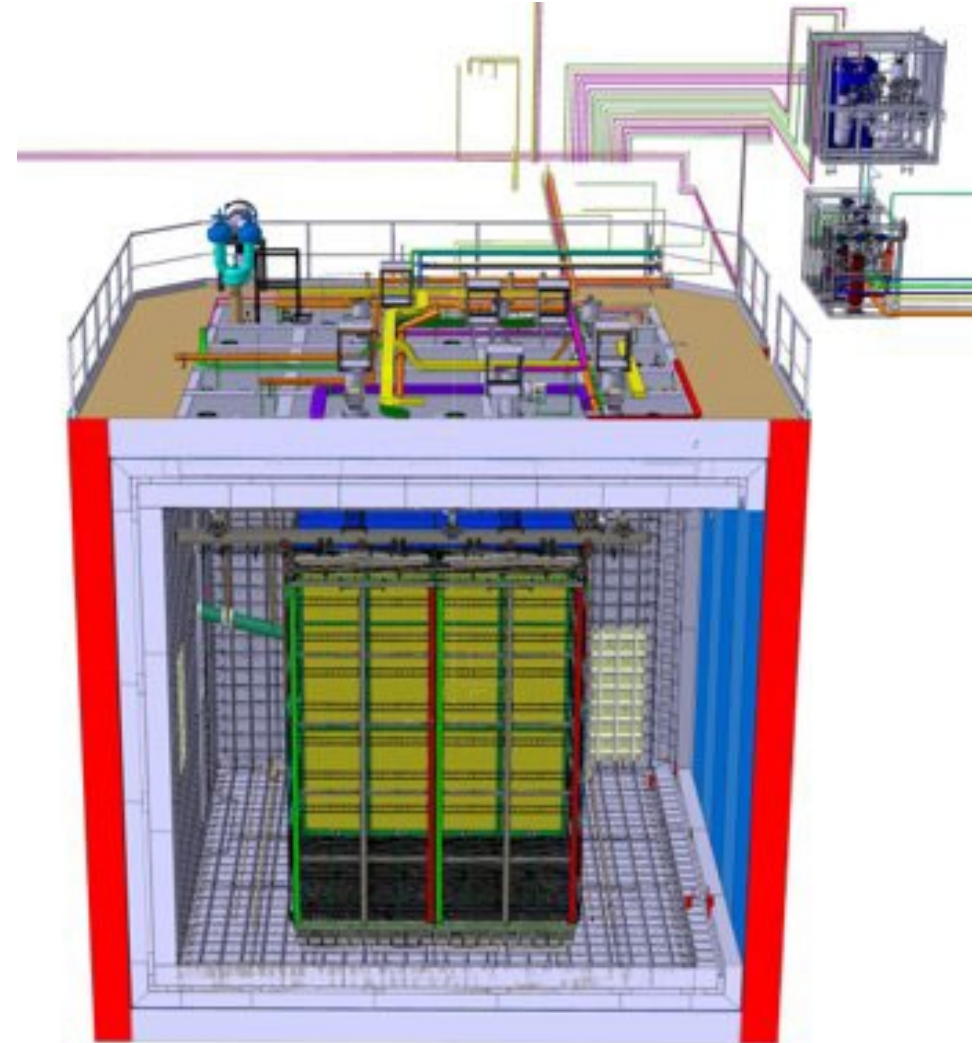
# PROTO DUNE II Configuration

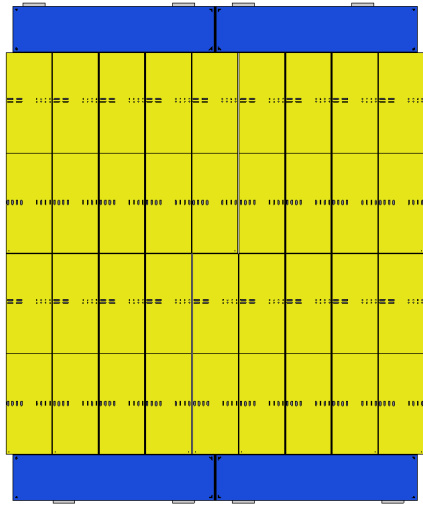


- 4 APAs instead of 6
- Flipped APAs on one-side (electronics on bottom)
- New Beam Plug
- Temperature Sensors on APAs
- 6 Purity Monitors (4 Standard & 2 Long)
- 2 PrM within recirculation (inline)- before & after LAr

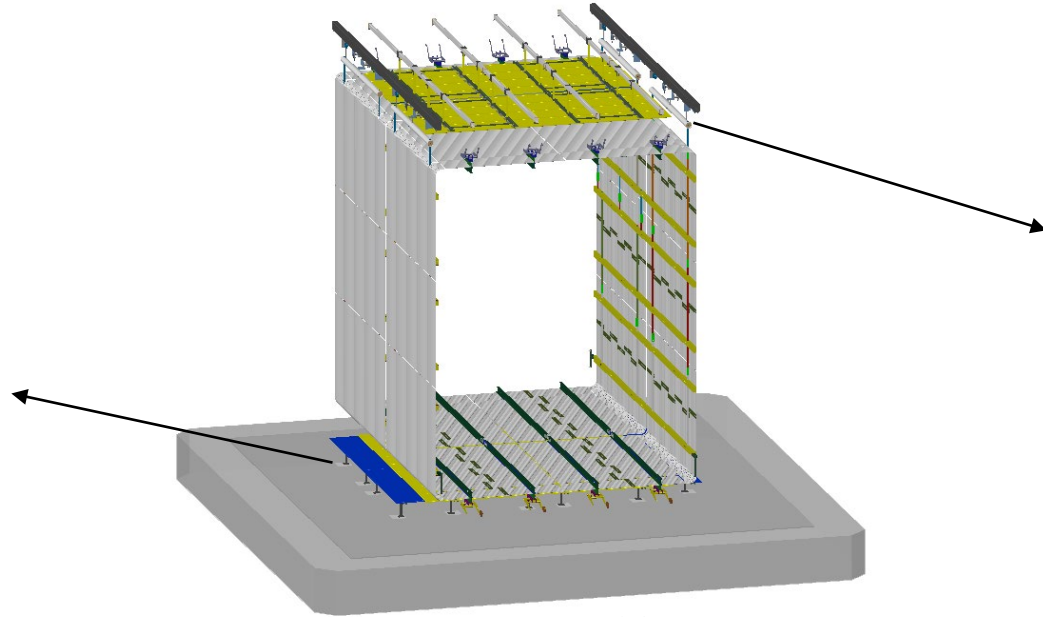
# PROTO DUNE I vs. PROTO DUNE II

- Maintain the cryostat of PROTO DUNE I
- Same cryogenics systems (based on experience from PROTO DUNE SP-I and PROTO DUNE DP) with minor improvements
- DUNE-like distances between Cryostat and Field Cage End Wall
- New calibration and cryogenic instrumentation (laser, neutron source, temperature sensors on APAs, etc.)

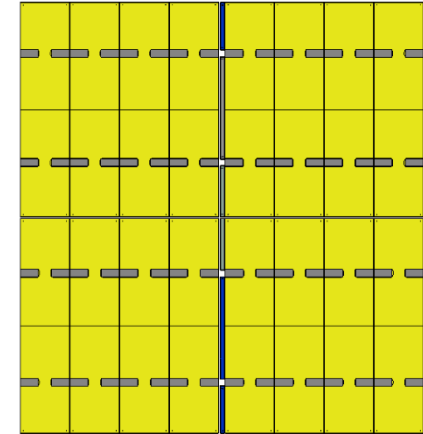




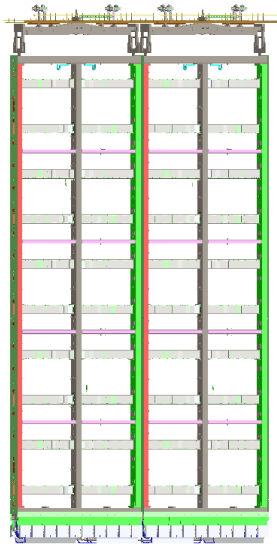
Bottom GP



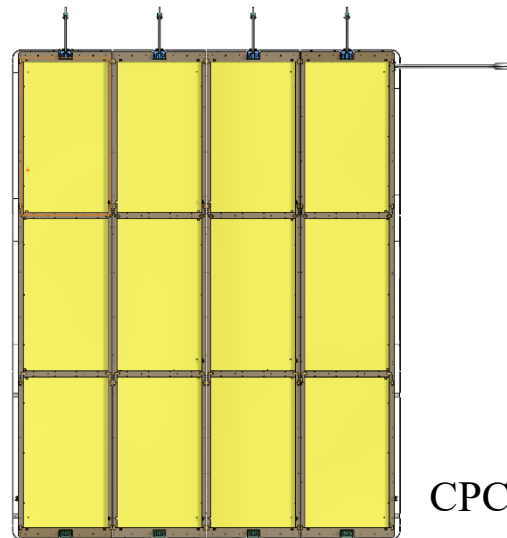
Field Cage



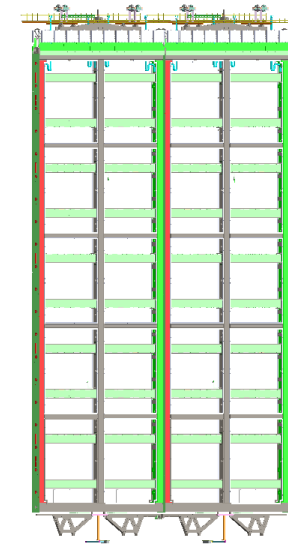
Top GP



APA Inverted

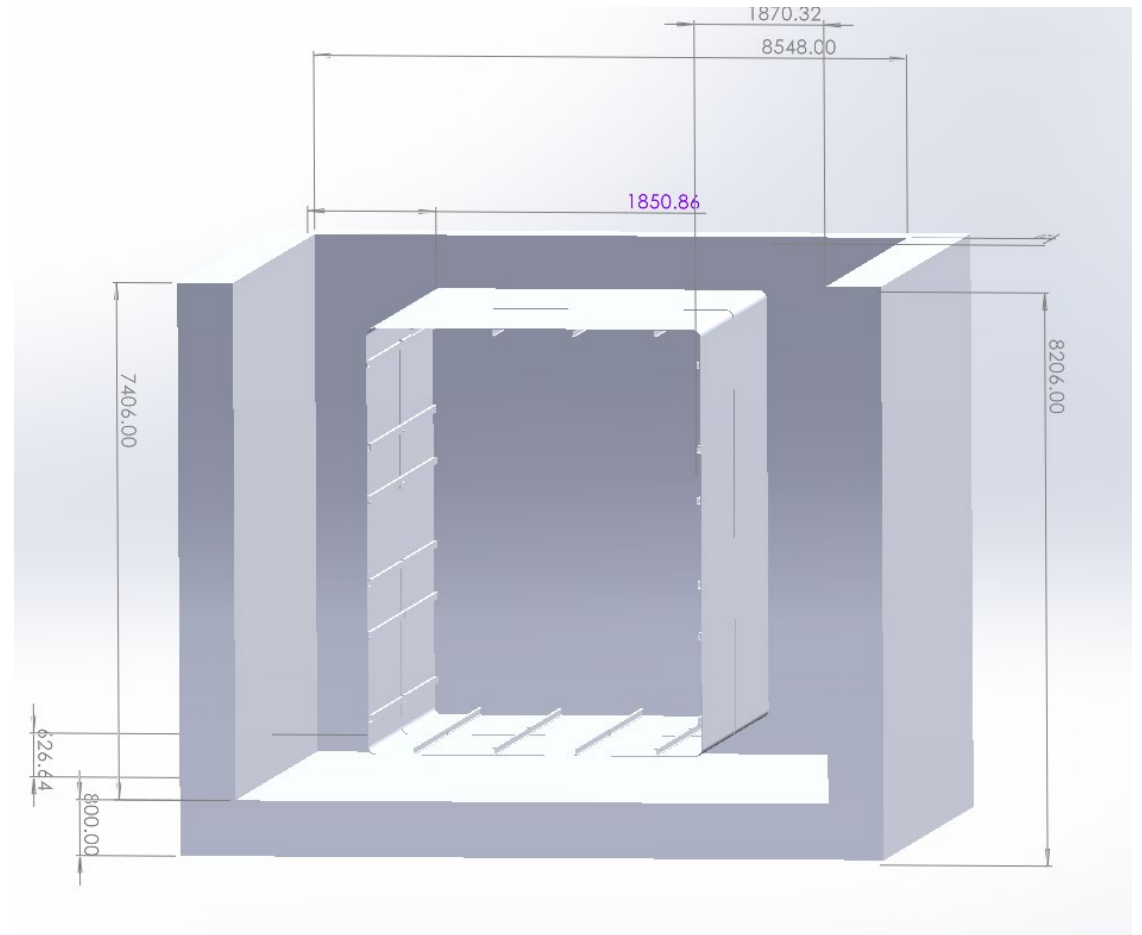
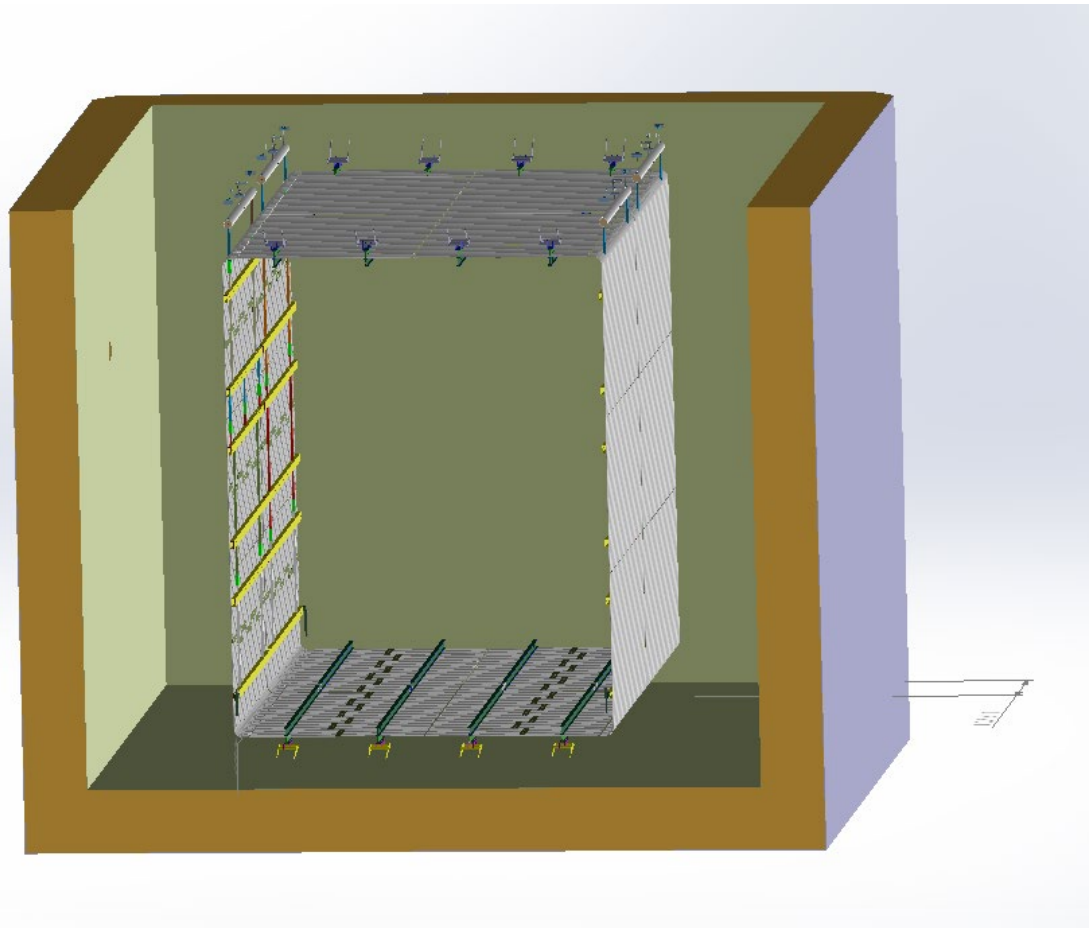


CPC



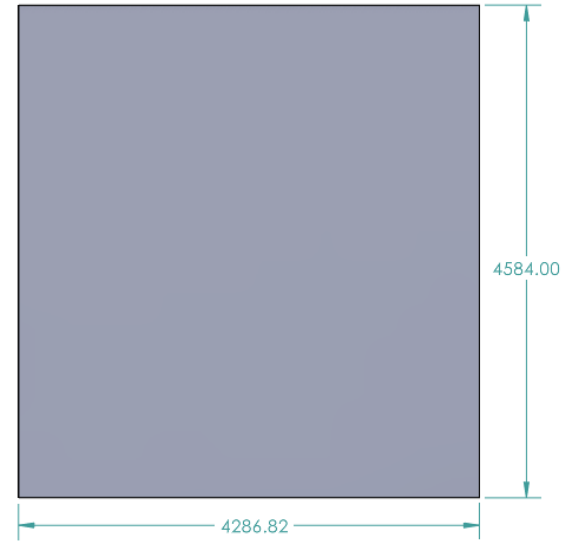
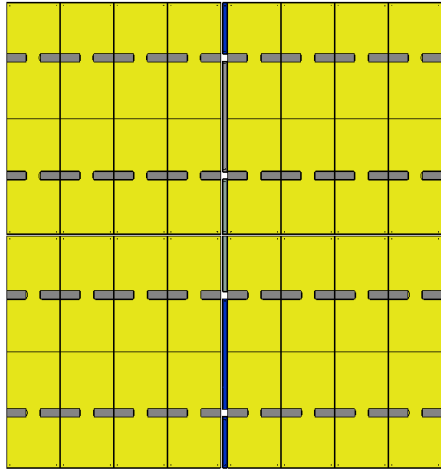
APA

# Model Simplification for CFD

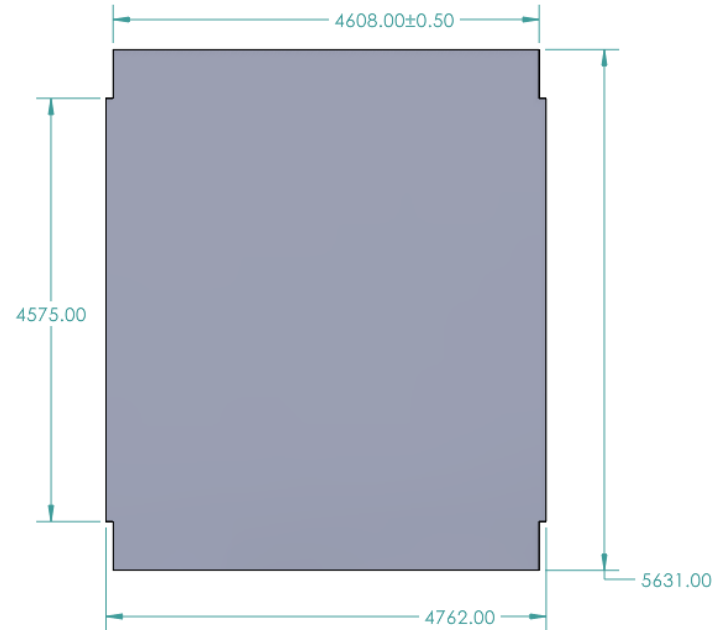
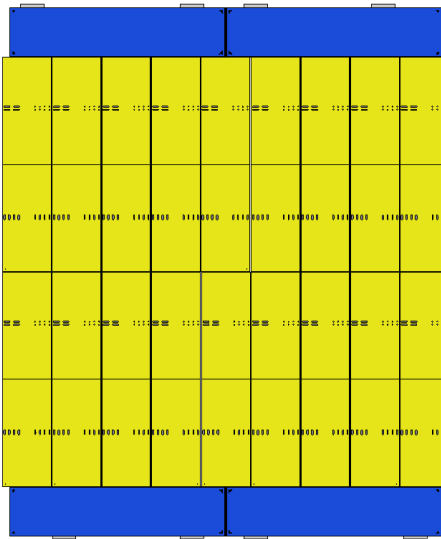




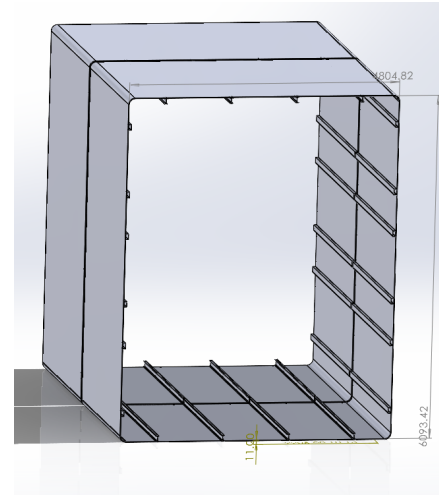
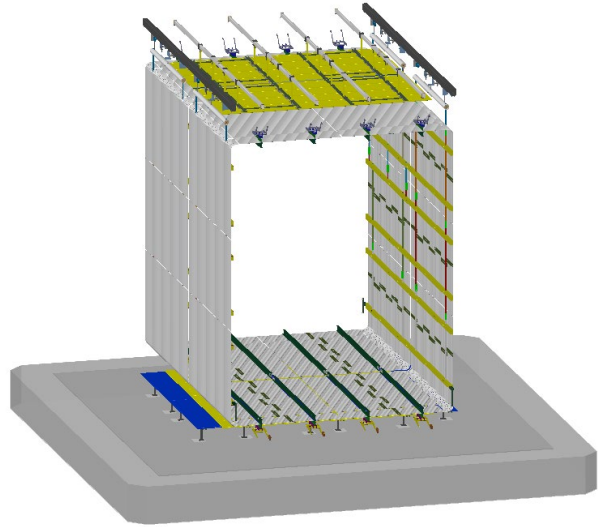
Bottom Ground Plane



Top Ground Plane

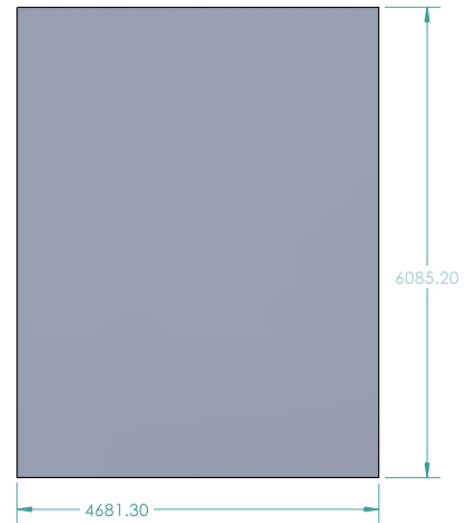
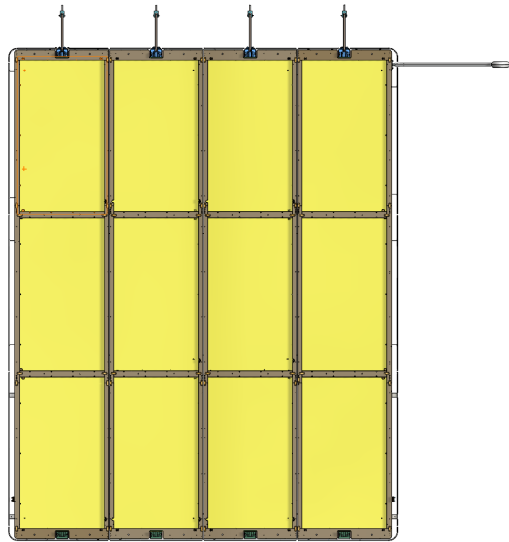


## Field Cage

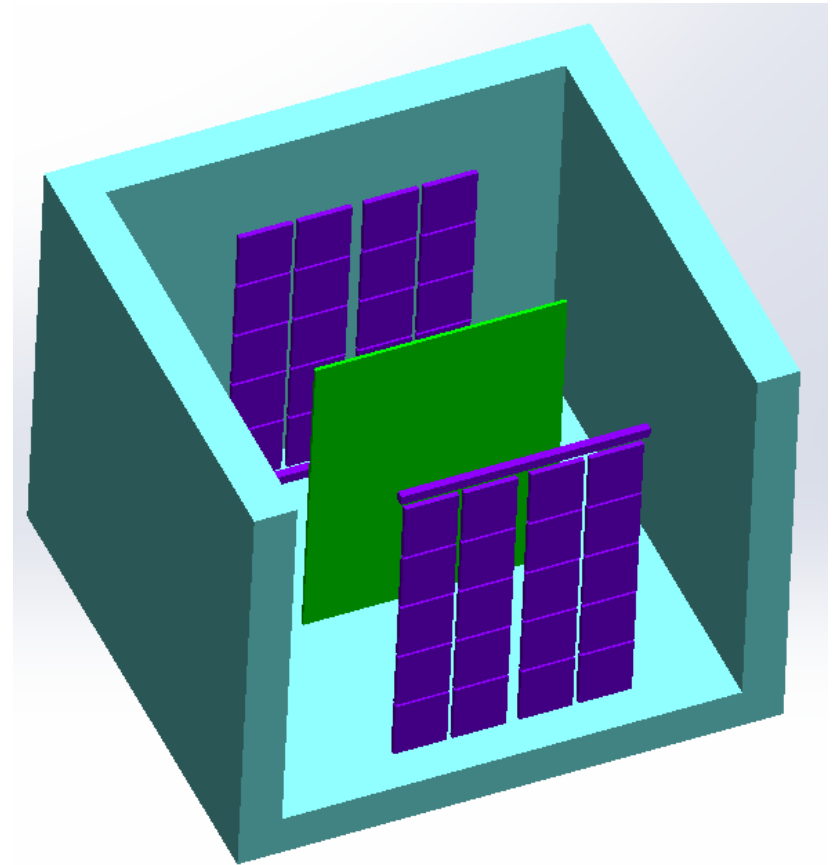
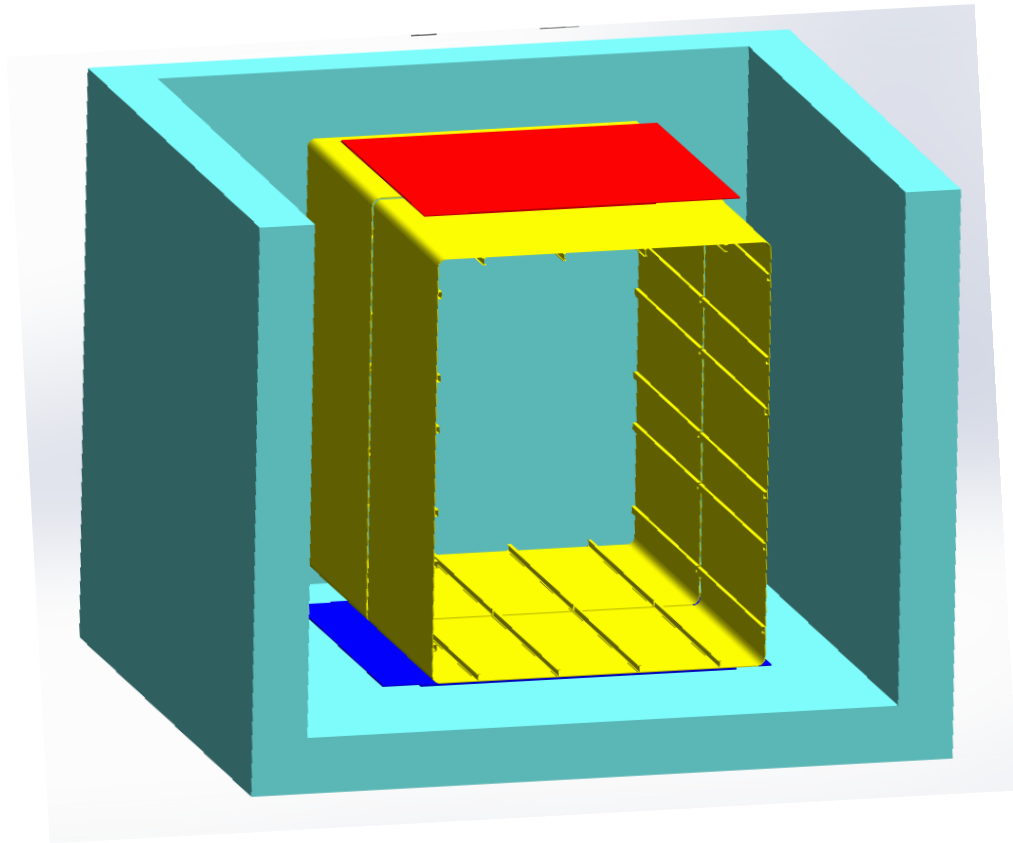


Thickness: 11.11mm

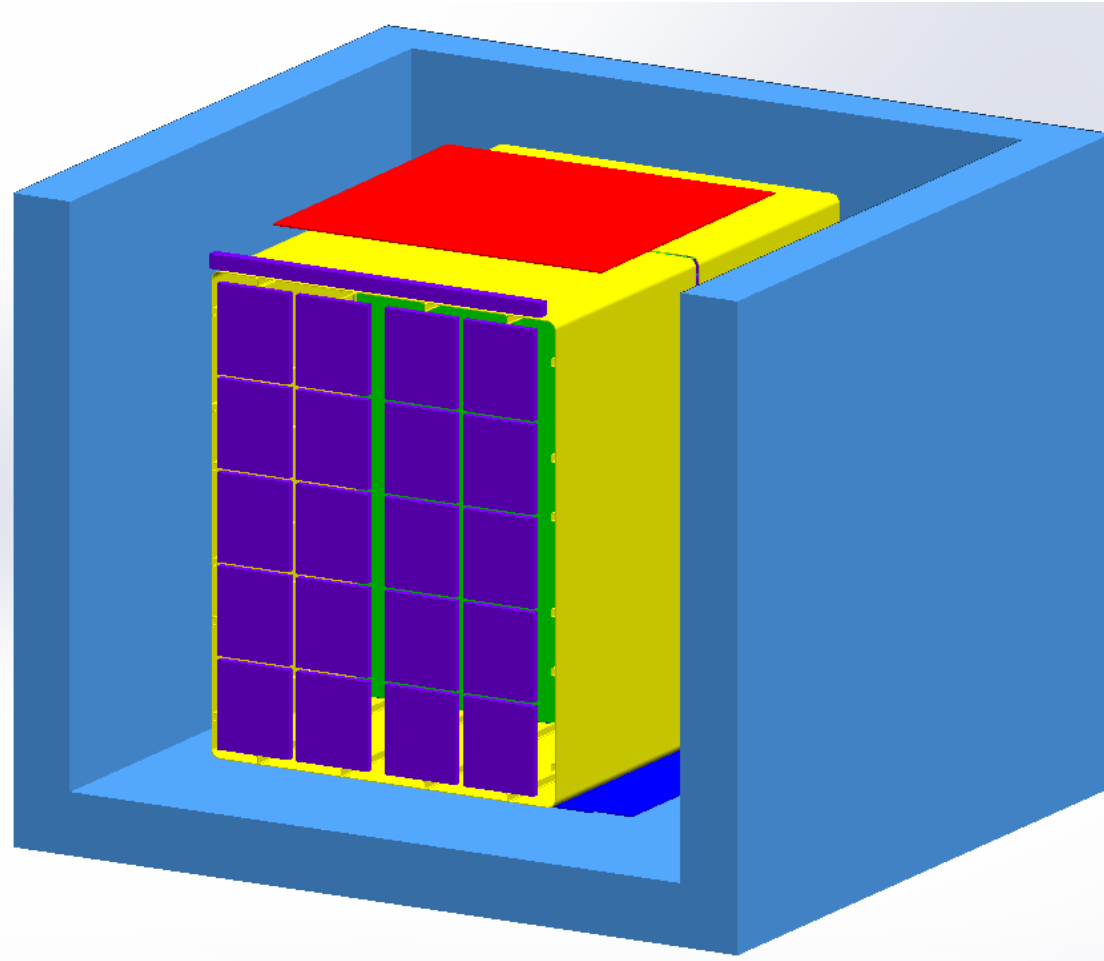
## Cathode Plane Assembly



Thickness: 69.85mm



# Simplified Assembly inside Insulation



# Next Steps

- Setting up CFD simulation with new geometry and boundary conditions from PD-1
- Changes in design for validation.
- Update information on new purity monitors and temperature sensors

# Thank You

- <https://docs.dunescience.org/>
- <https://edms.cern.ch/ui/#!/master/navigator/project?P:1097874761:100632891:subDocs>
- <https://edms.cern.ch/project/CERN-0000209067>
- PROTO DUNE SP: Plans of Experiment – Tingjun Yang(Fermilab)
- PROTO DUNE II – Eric James FS Integration Meeting

