



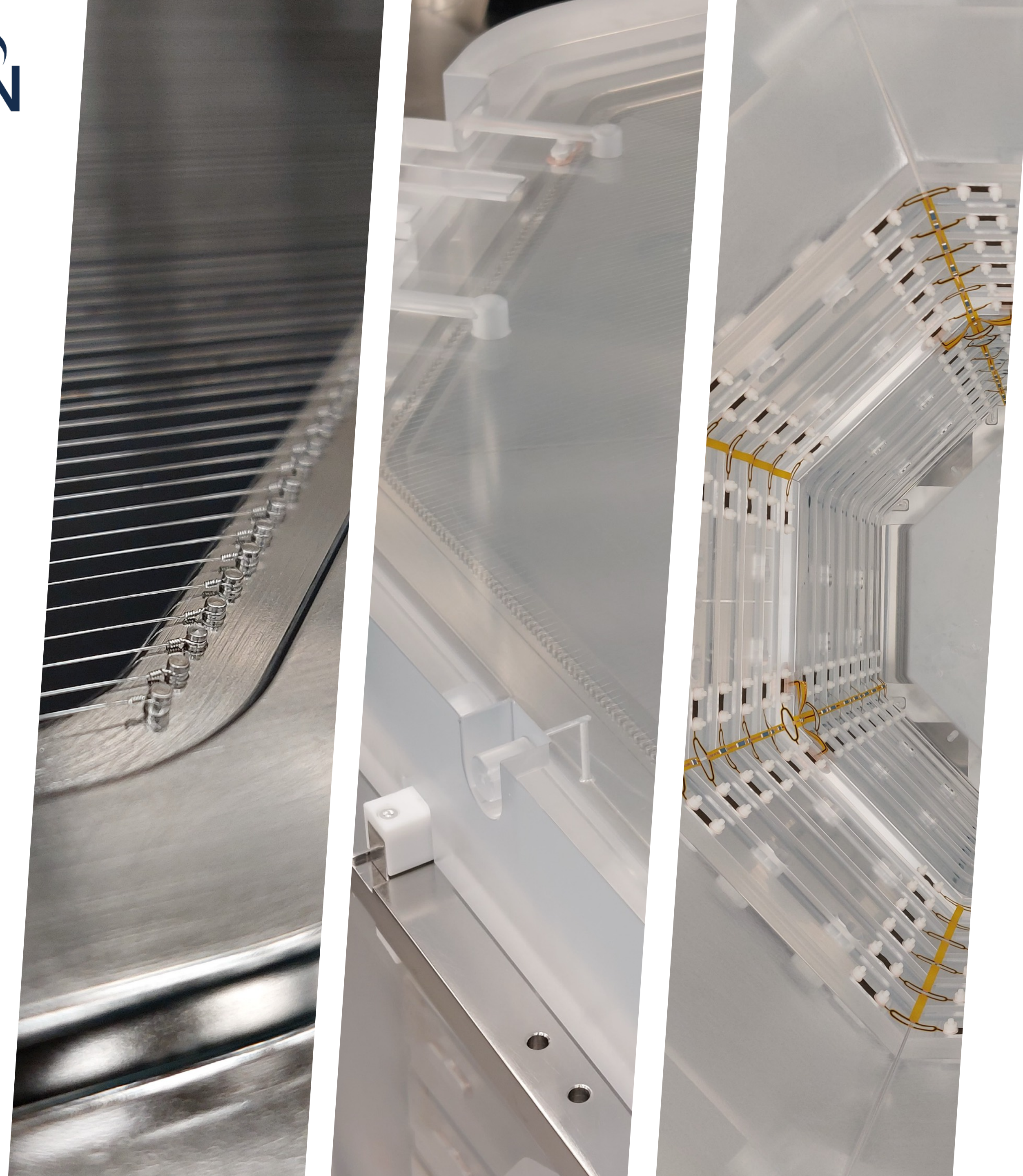
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A Tonne-scale Demonstrator for the DarkSide-20k Inner Detector

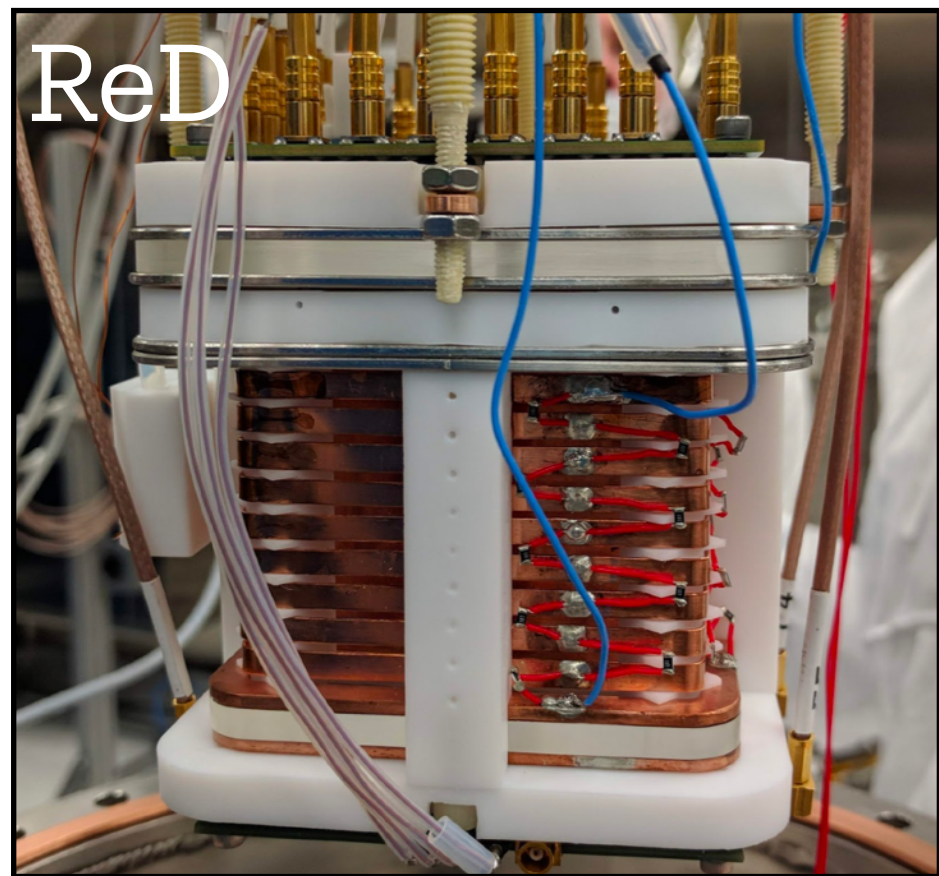
Assembly and Validation at
Laboratori Nazionali del Gran Sasso (LNGS)

Paolo Salomone
on behalf of the GADMC
LIDINE 21/10/25



The DarkSide Program

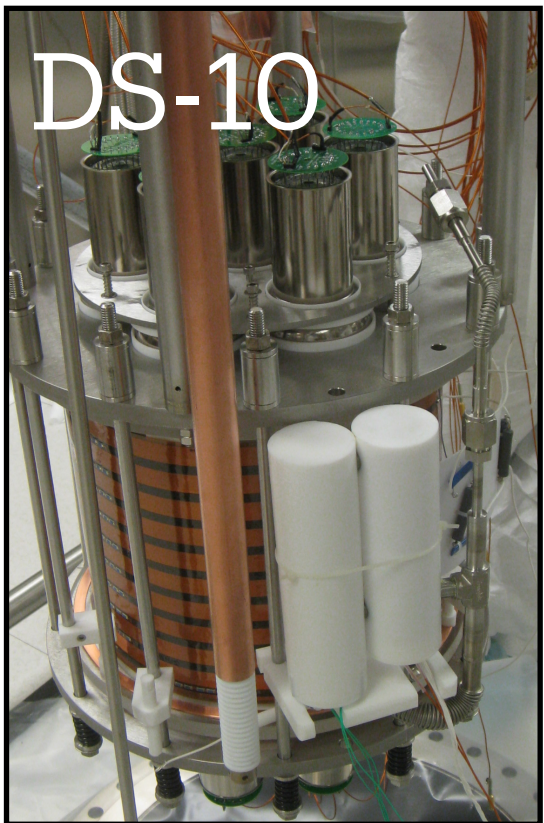
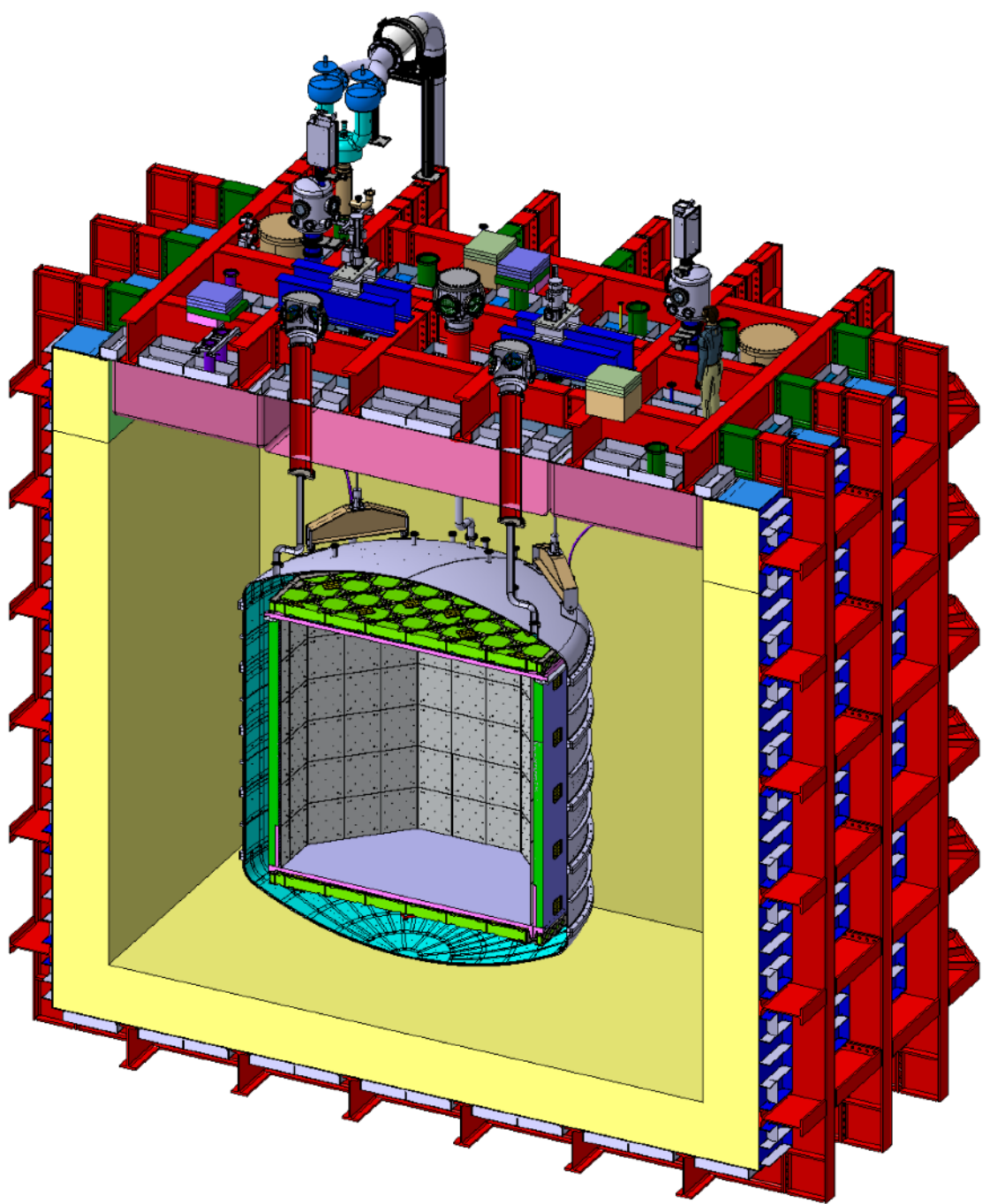
Towards Darkside-20k



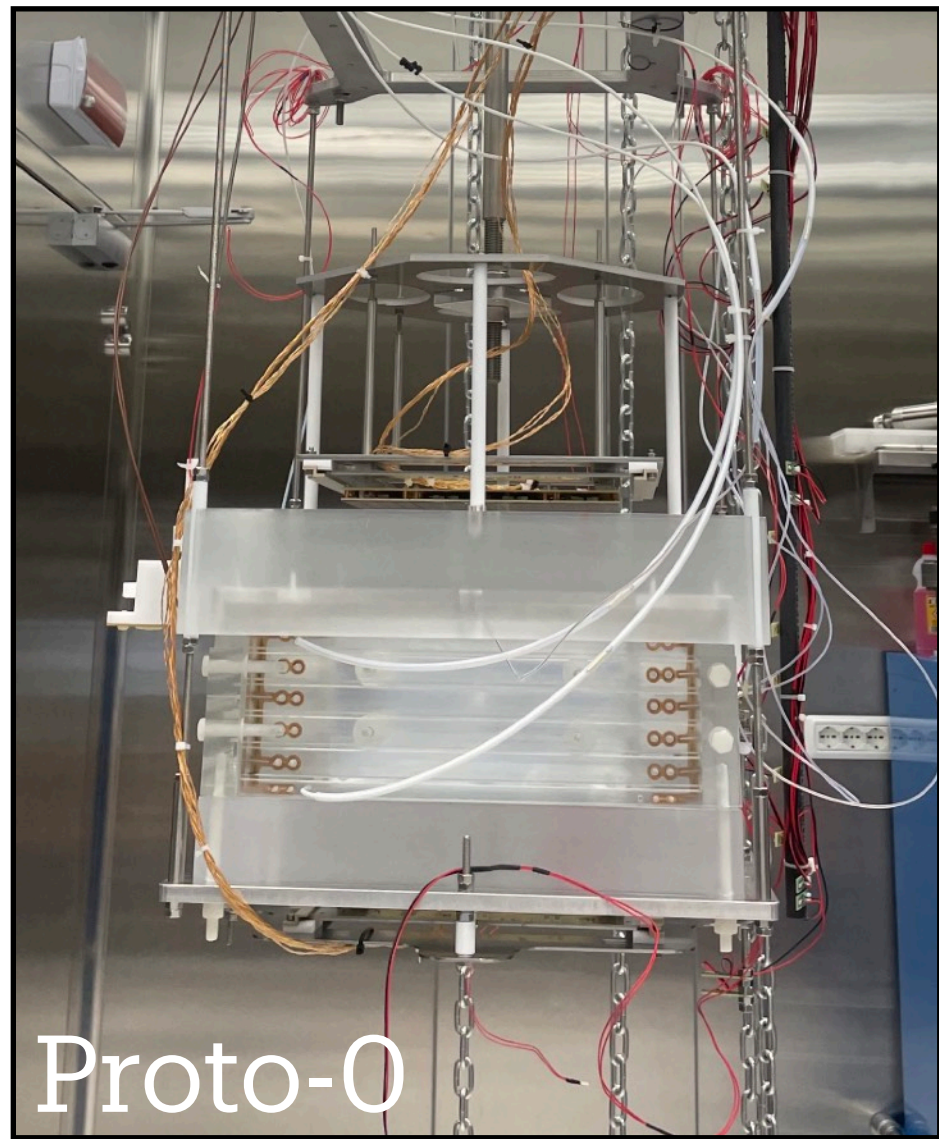
Present



Upcoming



Past



This Talk!

DarkSide-20k

The DarkSide Program

Towards Darkside-20k

Present

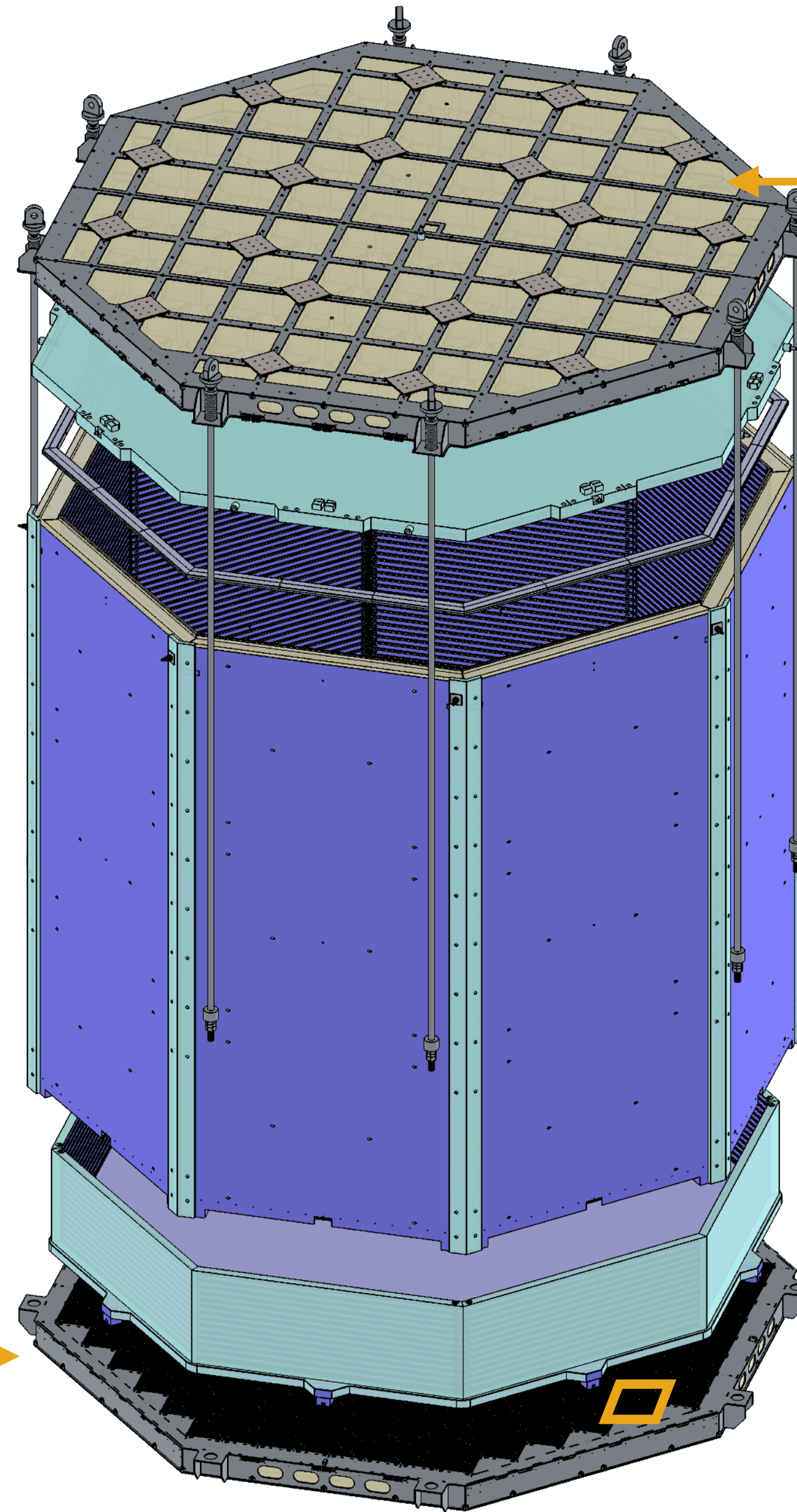


- **Apr '23 - Mar '24:** Cryogenic System Assembly and Benchmarking at LNGS
(JINST 20 (2025) 02, P02016)
- **Apr '24 - Dec '24:** Component machining, Dry-fit and shipment to LNGS
- **Jan '25 - May '25:** DS-Mockup Assembly, Commissioning and Testing at LNGS
(Paper in progress)

The DarkSide-20k Inner Detector

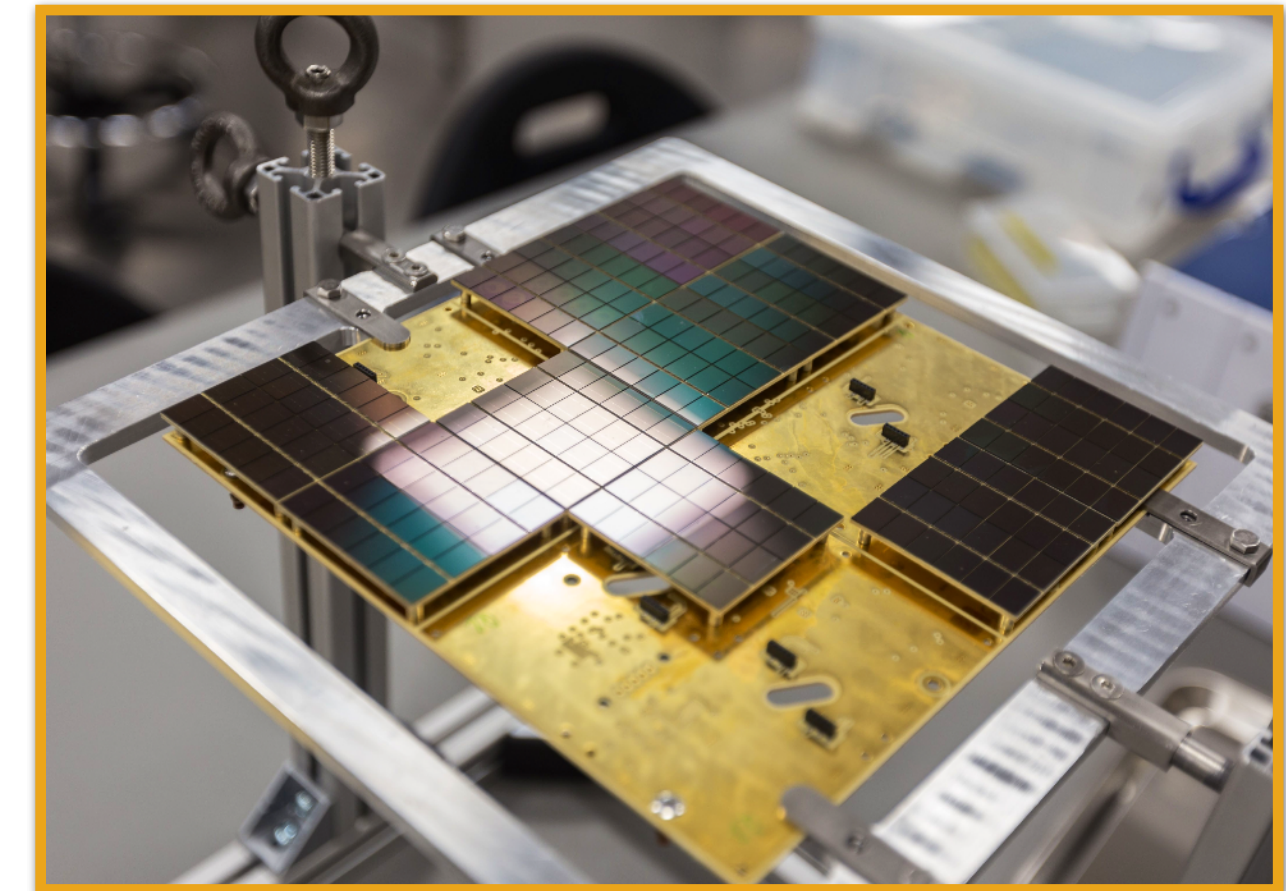
- Acrylic (PMMA) based TPC (~4m wide and tall)
 - High Radiopurity
 - Neutron moderation
- 20t of active pure-underground LAr
- Scintillation light shifted via TPB from 128nm to 420nm

Bottom Optical Plane:
*Octagonal SS beam structure
hosting ~10.5m² SiPMs array
for light readout*



Top Optical Plane:
*Octagonal SS beam structure
hosting ~10.5m² SiPMs array
for light readout*

*SiPM-based Photo Detection
Unit Assembly at LNGS*



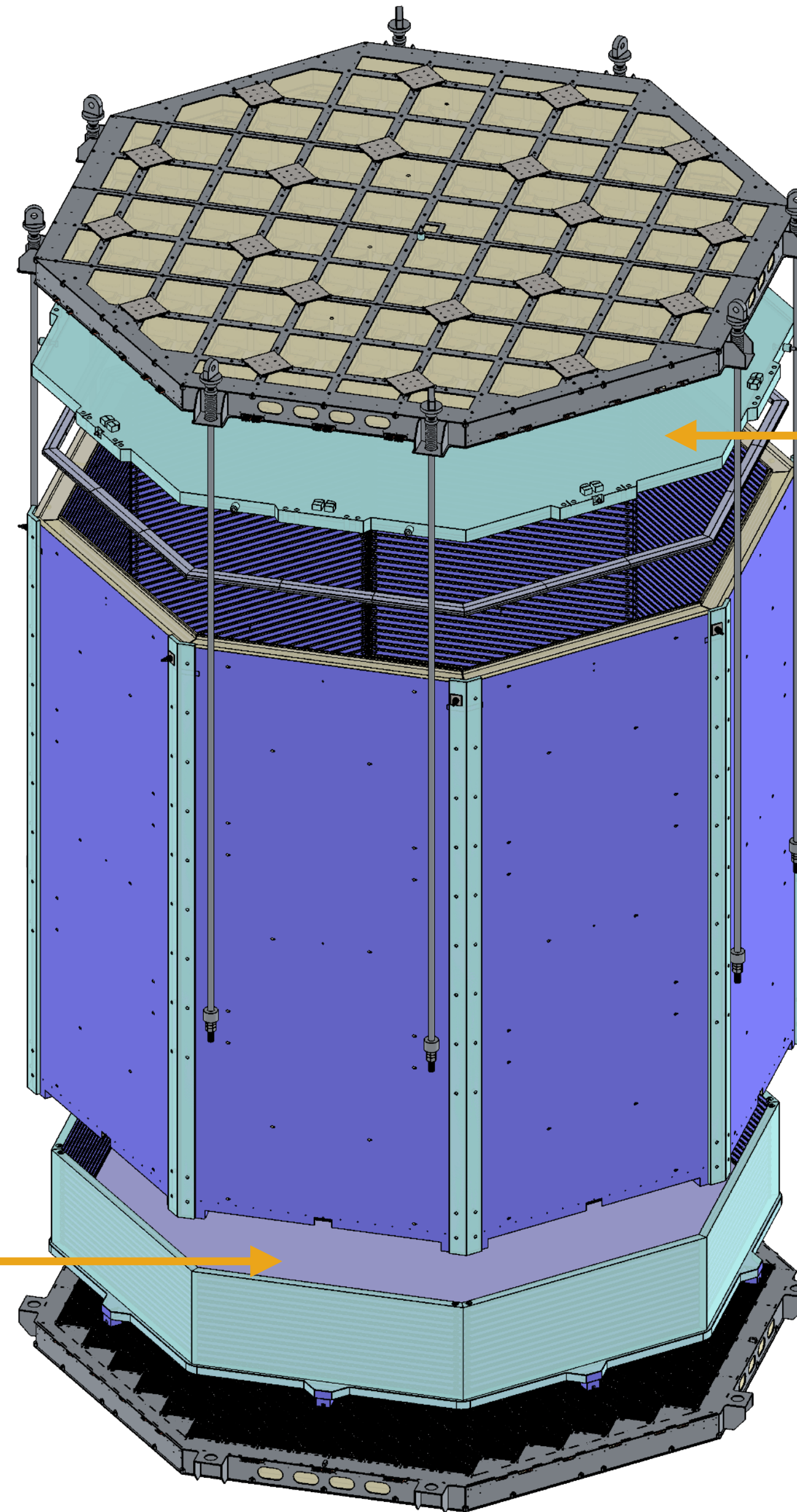
- PE Activities for DS-20k at NOA (D.Gahan)
- Characterization of DarkSide-20k Photo Detection Units (D.Rudik)

The DarkSide-20k Inner Detector

- Acrylic (PMMA) based TPC (~4m wide and tall)
 - High Radiopurity
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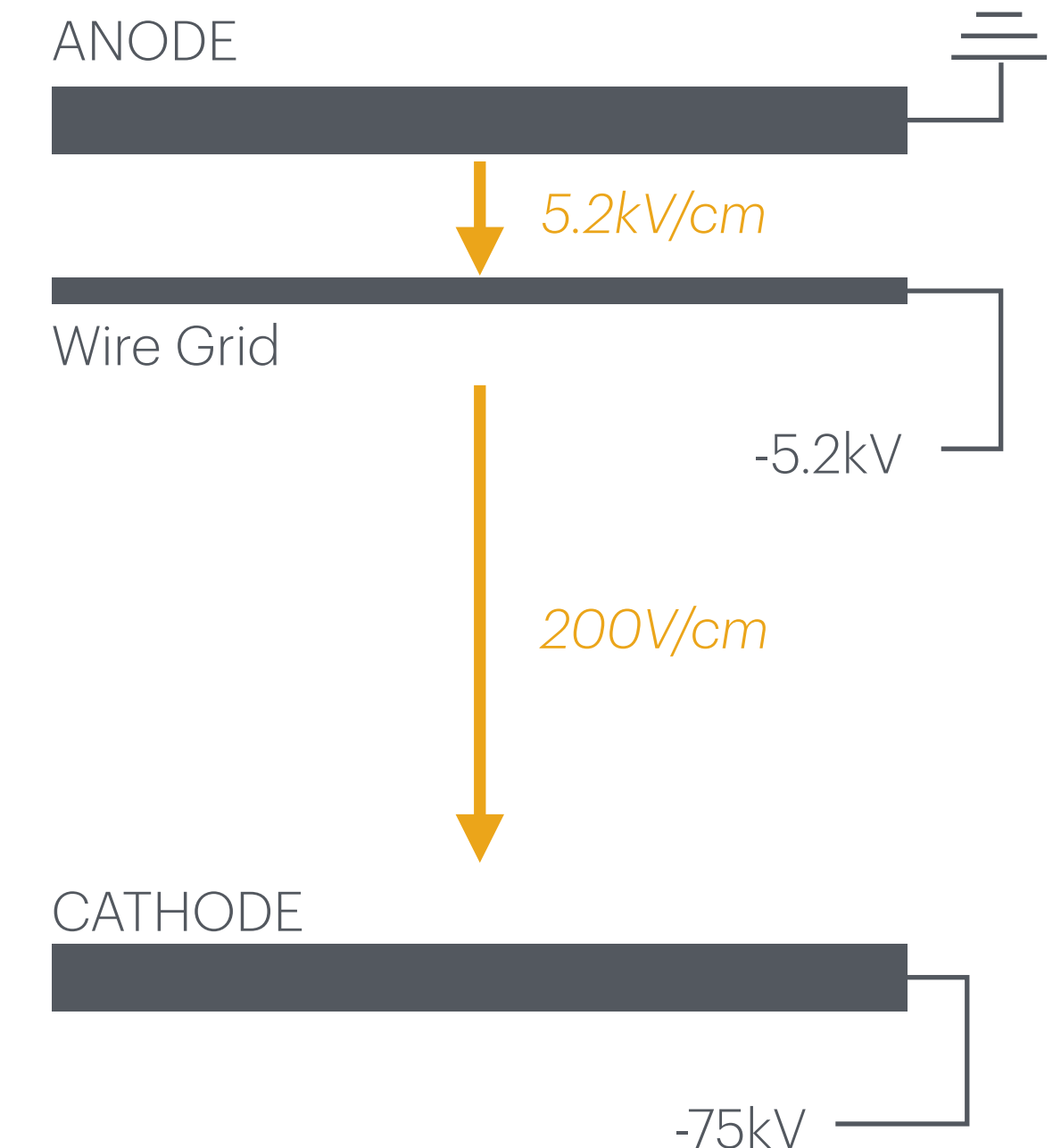
Cathode/Knee-wall:

Octagonal PMMA window coated with CleviosTM and wavelength shifter TPC layer. Design voltage set at -75kV



Anode:

Octagonal PMMA window featuring an inner diving bell for the gas pocket generation. Coated with CleviosTM and TPB

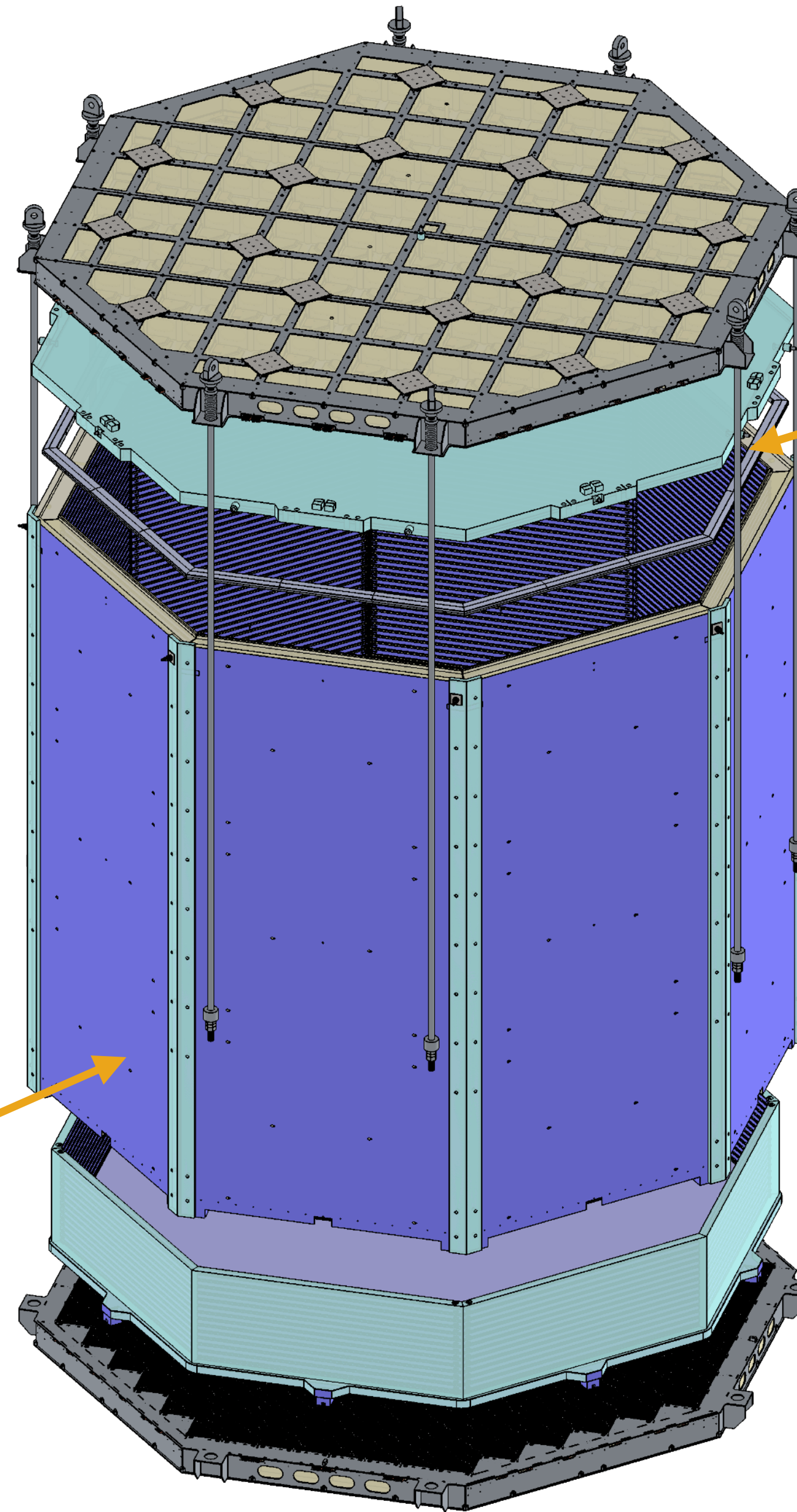


The DarkSide-20k Inner Detector

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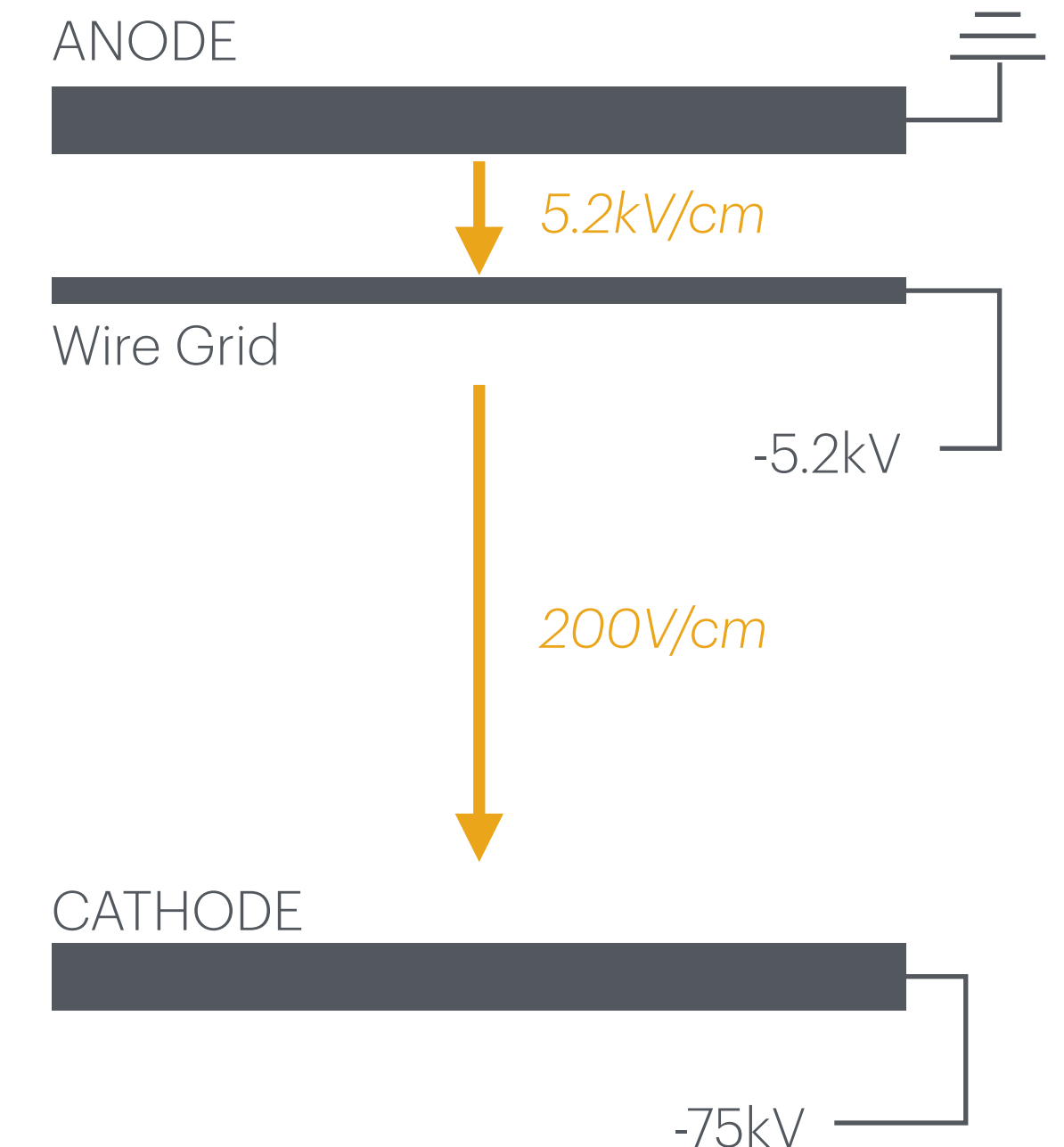
TPC Barrel:

Octagonal PMMA window comprised of **8 individual panels**, held by corner brackets. Define the TPC **field cage**



Wire Grid:

Octagonal SS frame featuring 1236 ss wires (235um thick). Design voltage is -5.2kV for extraction field generation (S2)

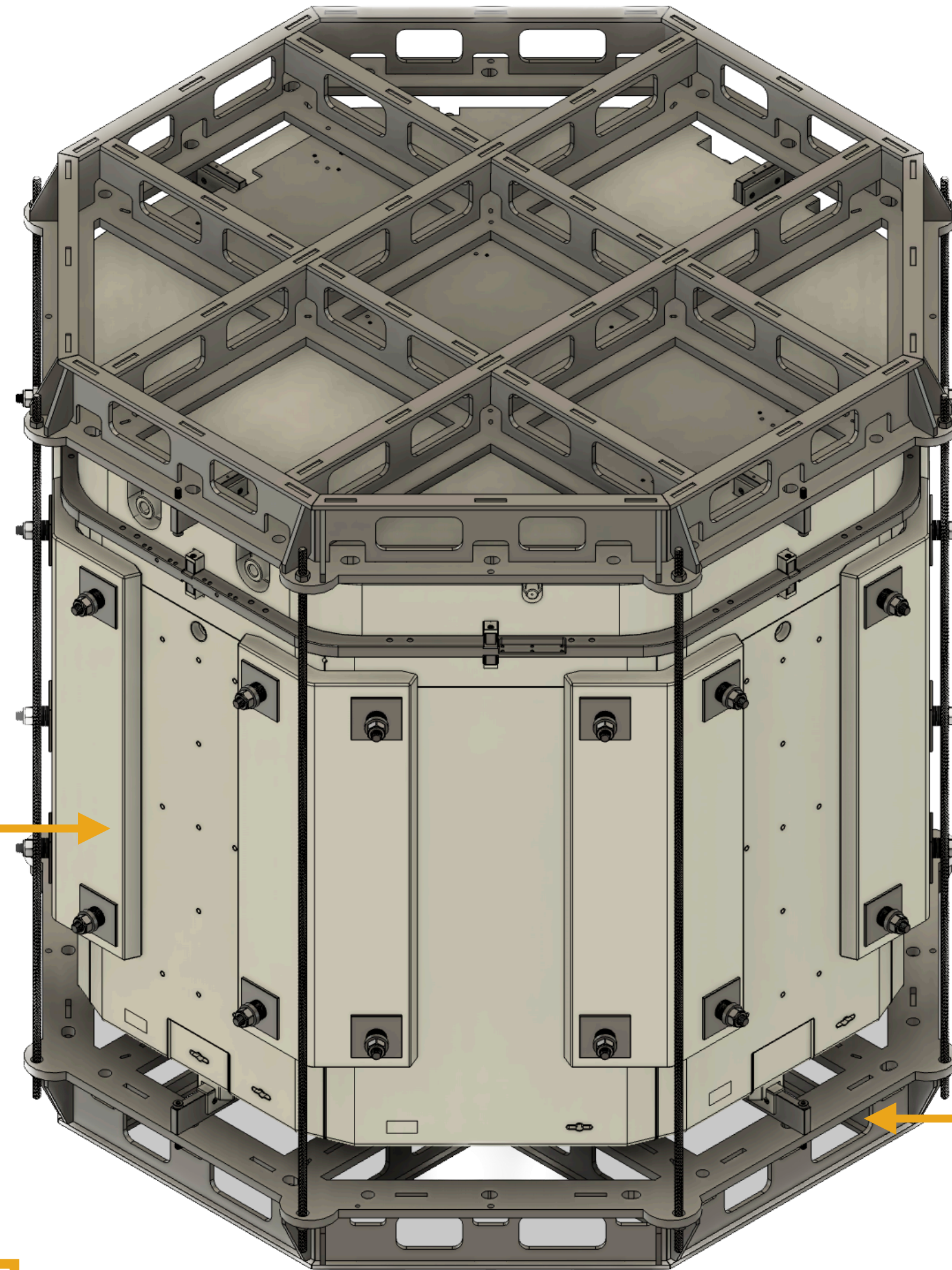


DS-Mockup TPC Design

- Scaled version of the Darkside-20k ID (80cm wide and 60cm tall)
- Total LAr mass of 760 kg
- Drift length: 560 mm

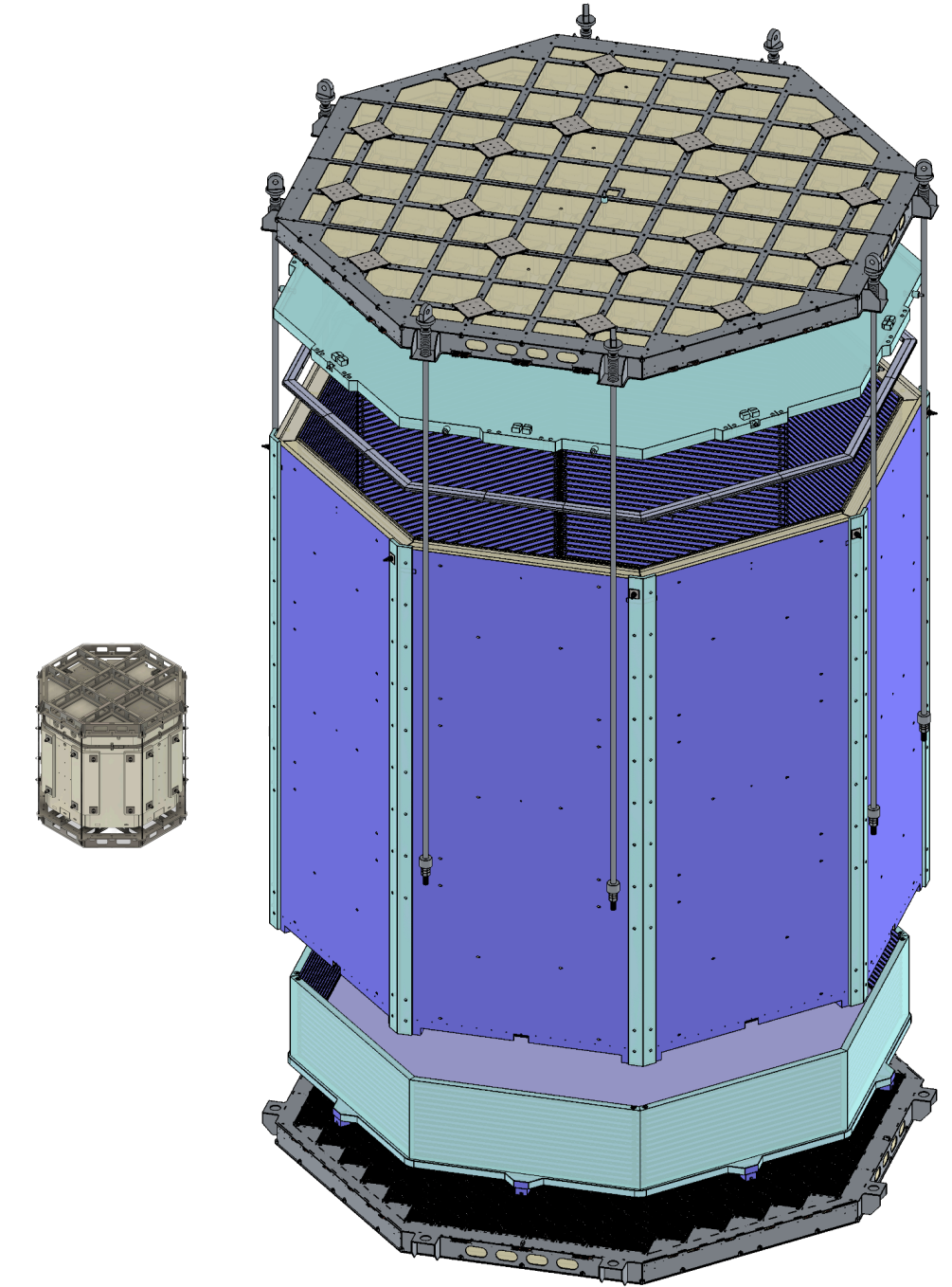
TPC:

Octagonal PMMA one tonne DarkSide-20k ID demonstrator



Same panel thickness as DS-20k!

To Scale



Darkside-20k TPC

SS Cage:

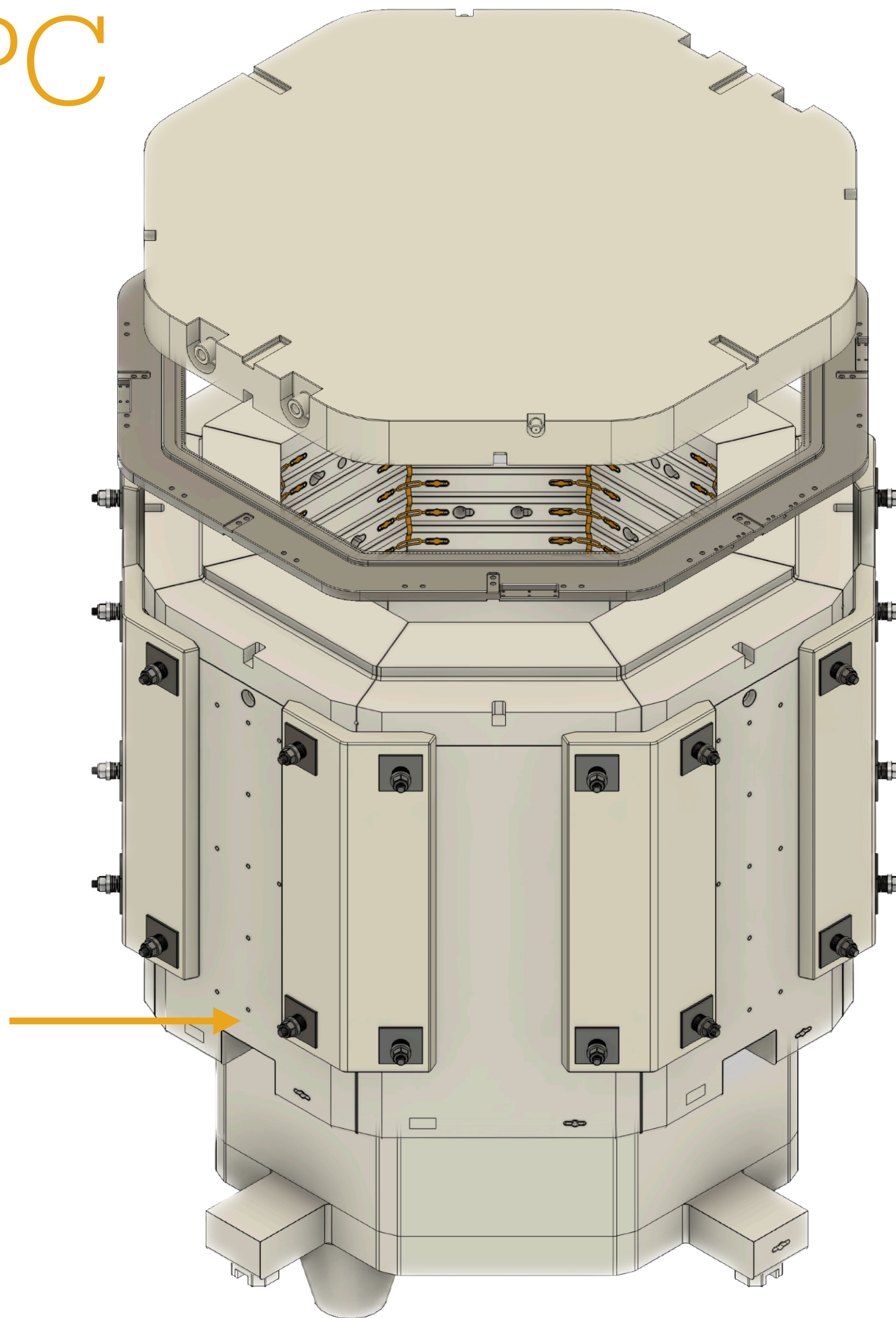
Support structure made of two SS octagonal planes (TOP-BOP) and 8 SS rods.

DS-Mockup TPC Design

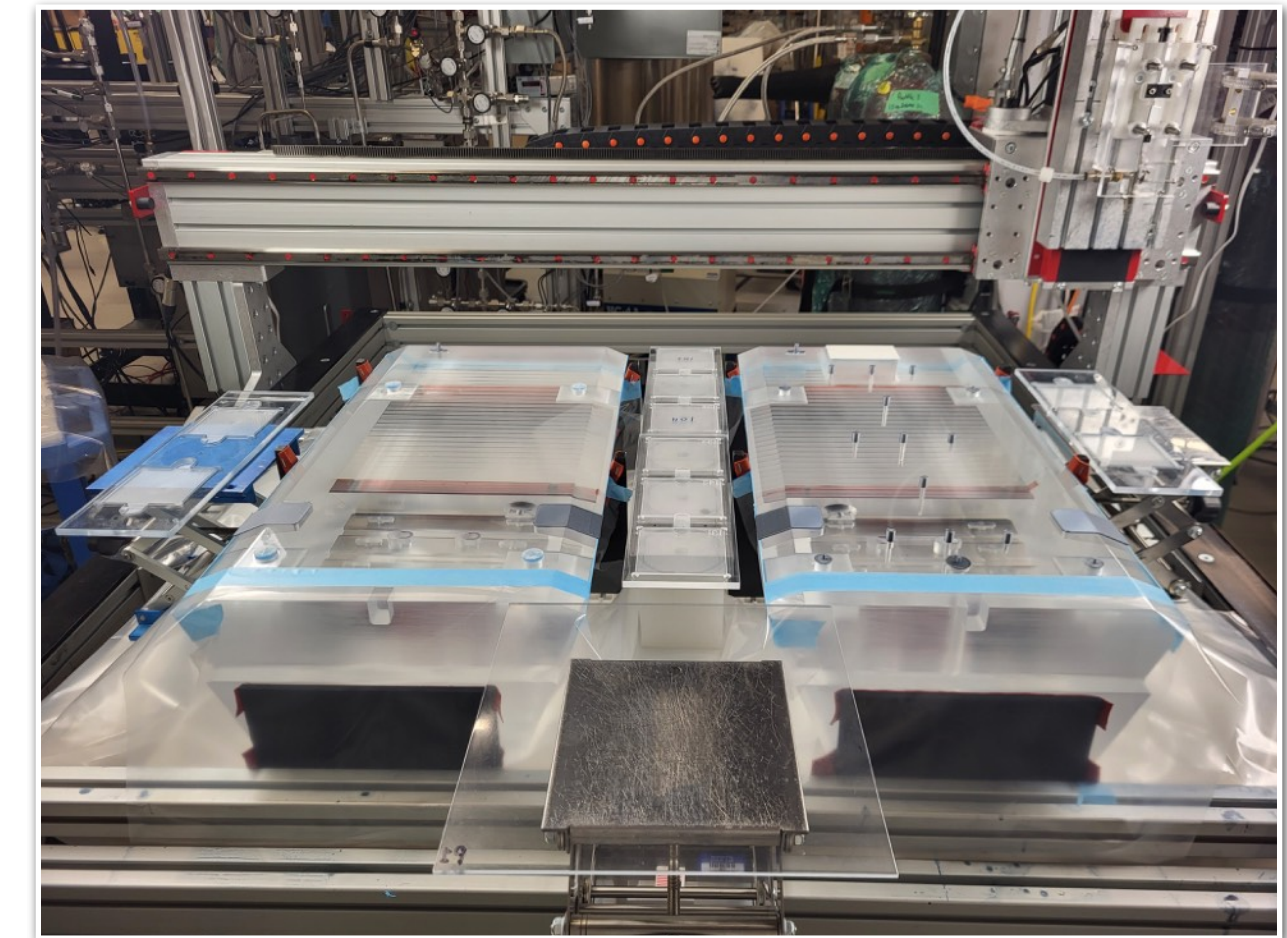
- PMMA components machined at UofA (CA)
- Dry-Fit at UofA
- Clevios™ coating at Carleton University

TPC Barrel:

Octagonal PMMA barrel comprised of **8 individual panels**, held by corner brackets. Define the TPC **field cage**



TPC barrel assembly after machining UofA

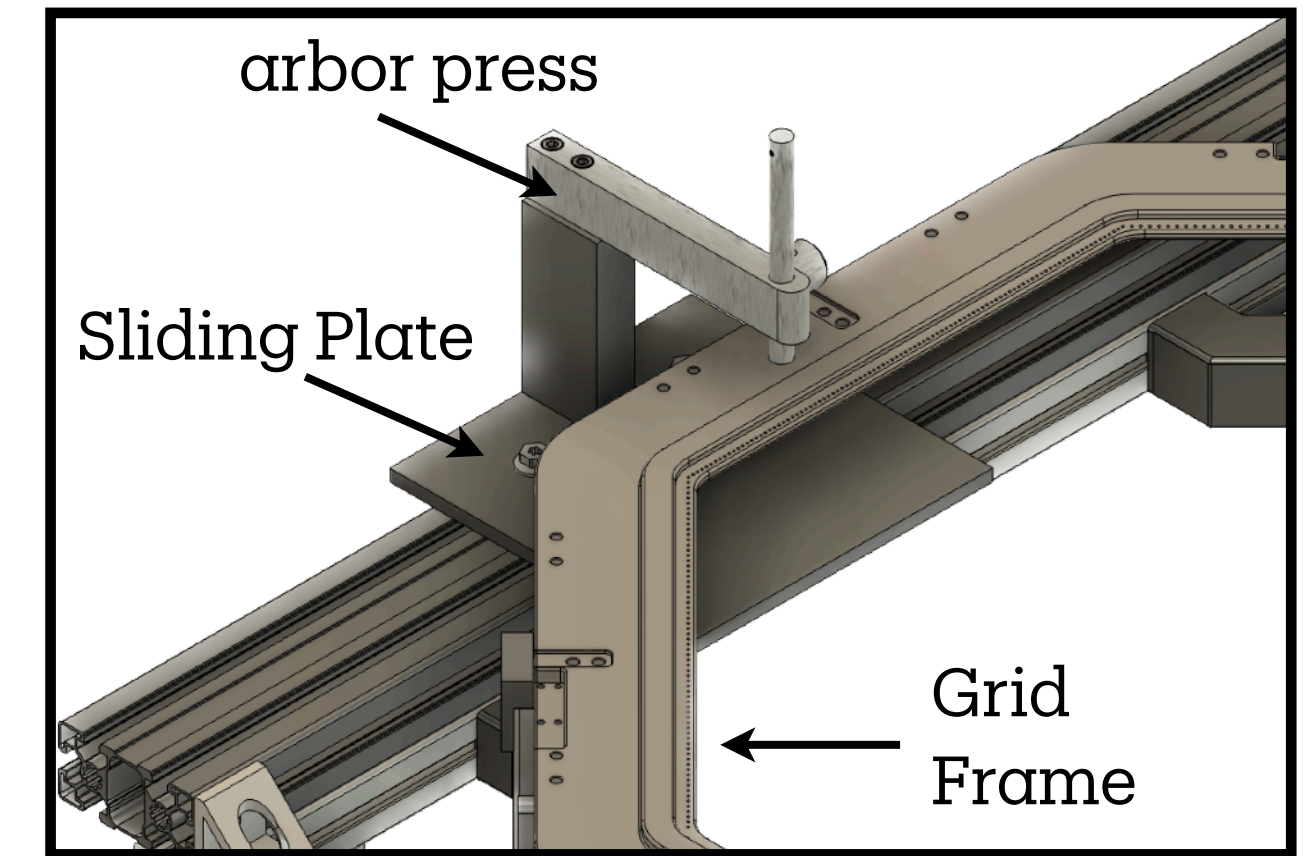
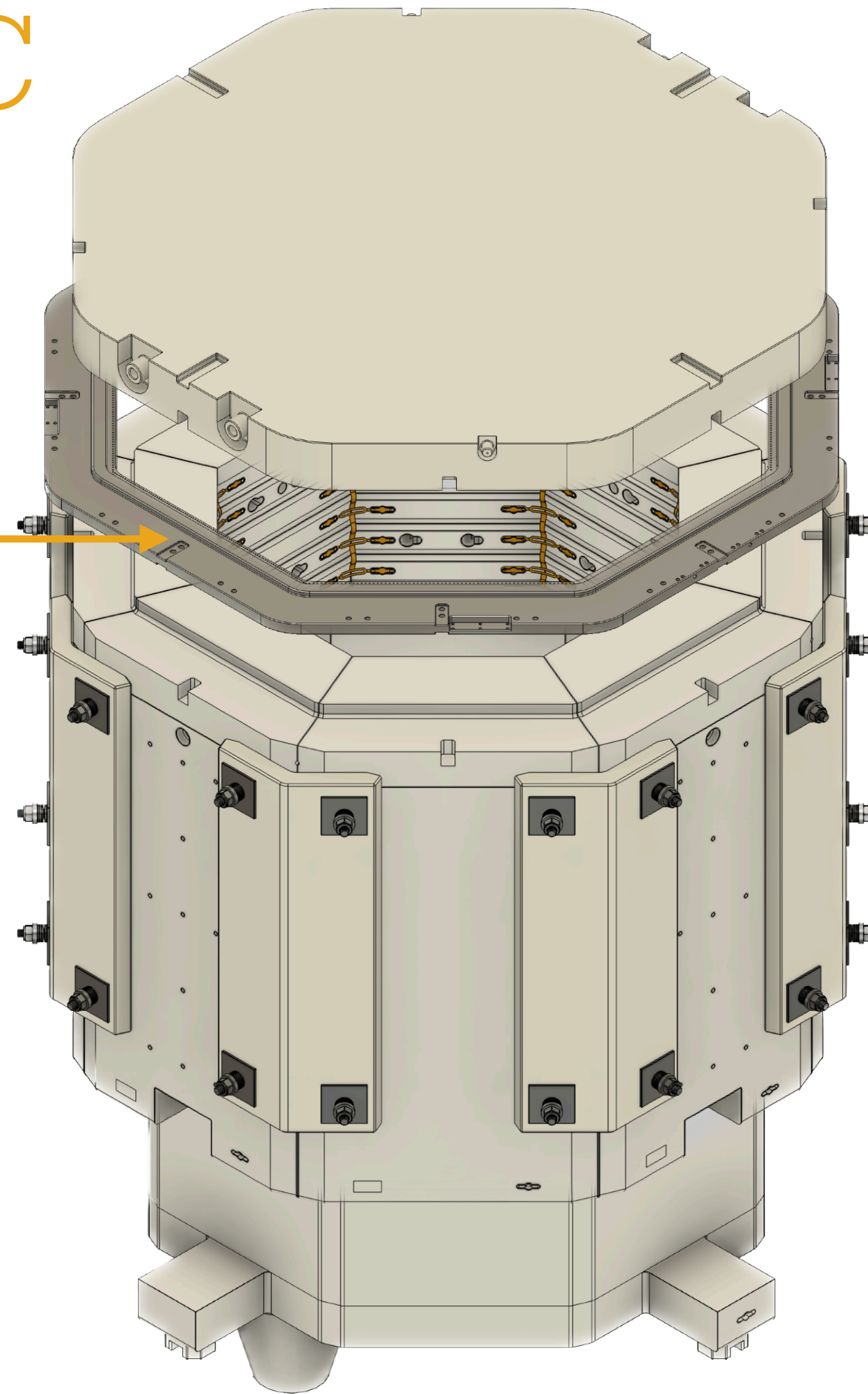


Barrel panels Clevios™ coating at Carleton U

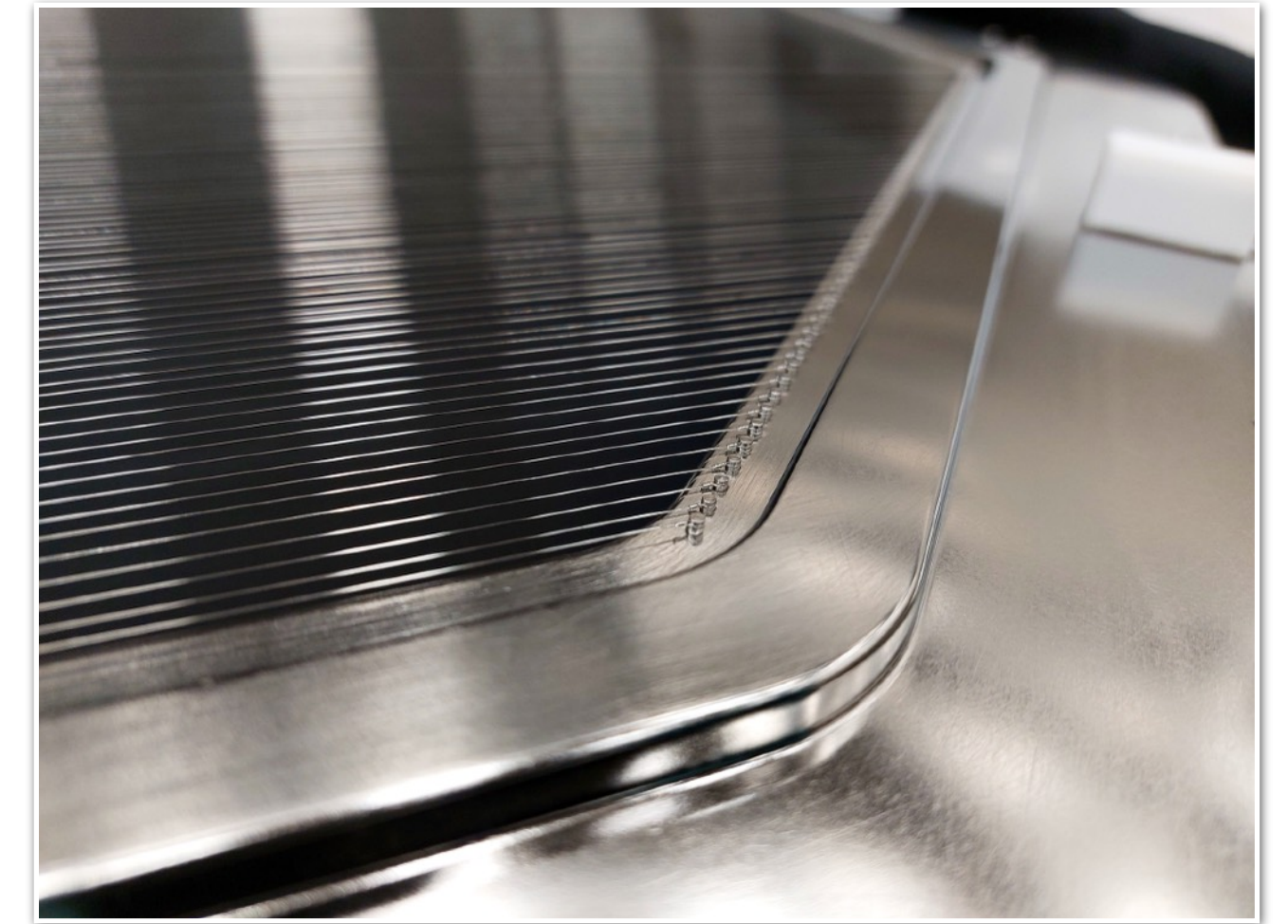
DS-Mockup TPC Design

Wire Grid:

Octagonal SS frame with 231 wires (200um diameter). Inserted with arbor presses

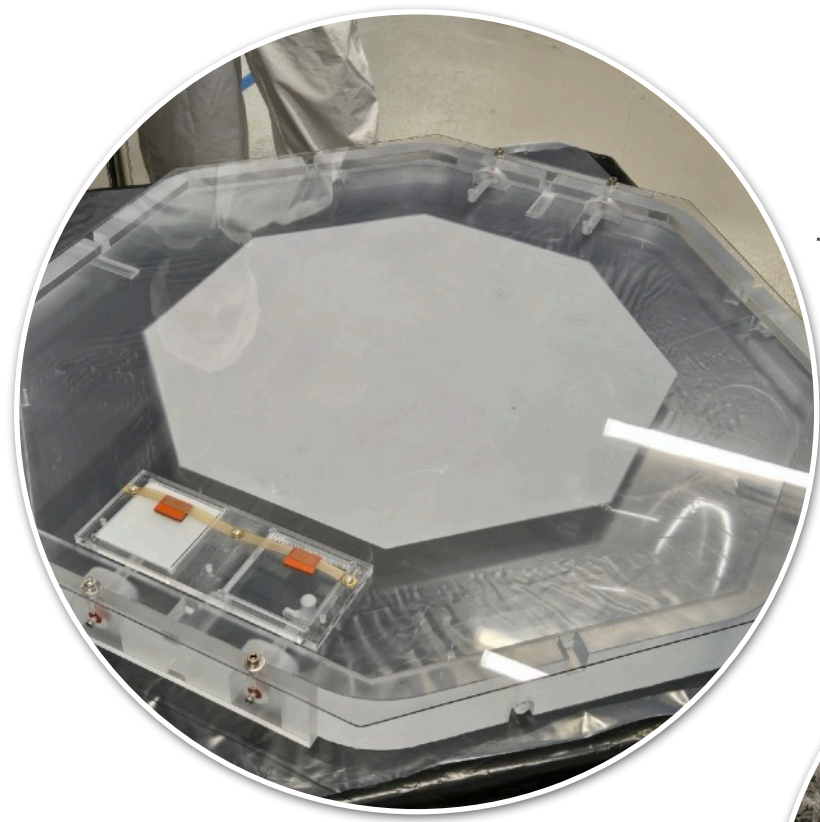


Wire insertion diagram



Completed Wire Frame

DS-Mockup TPC Design

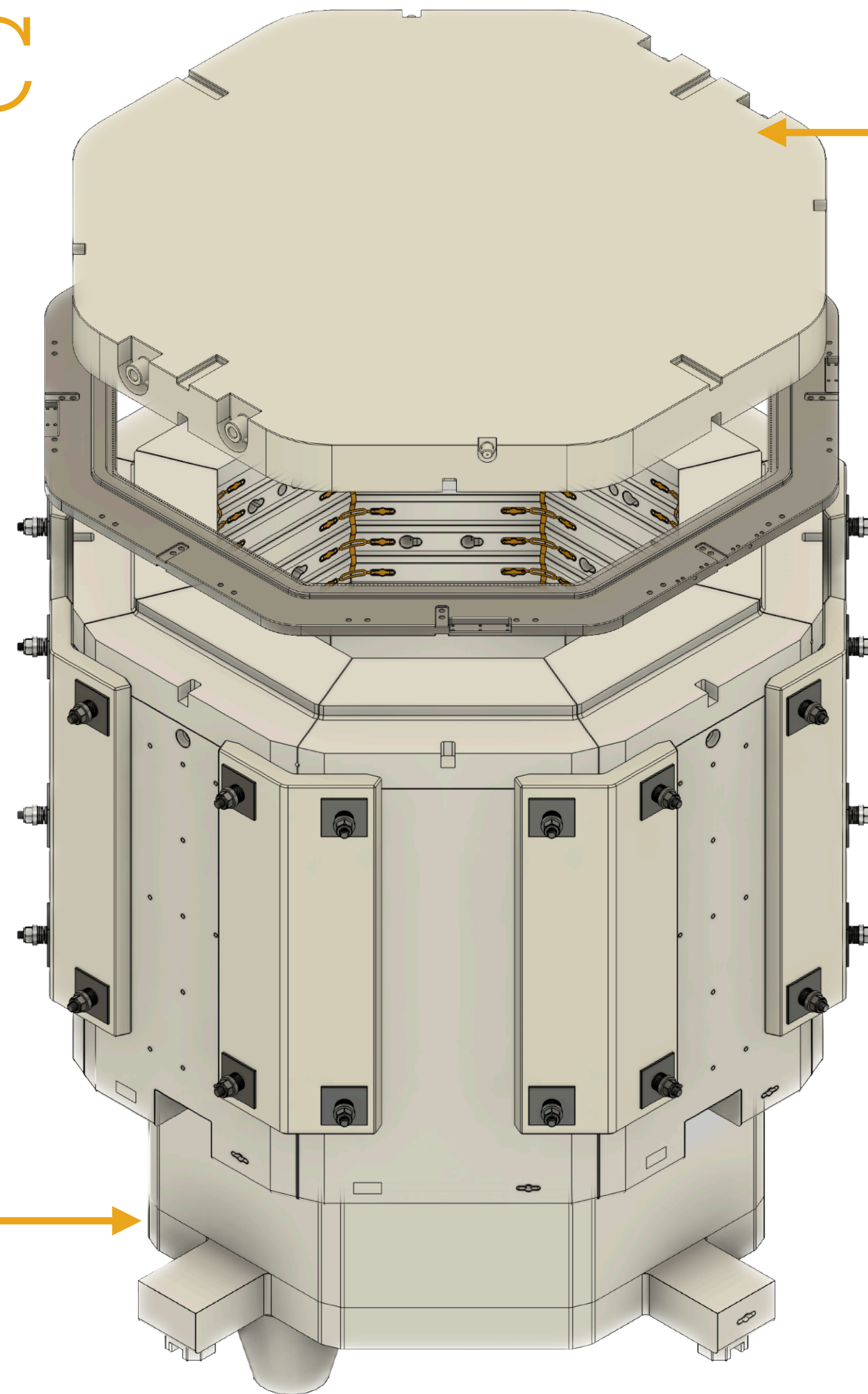


Anode coating at Carleton U.

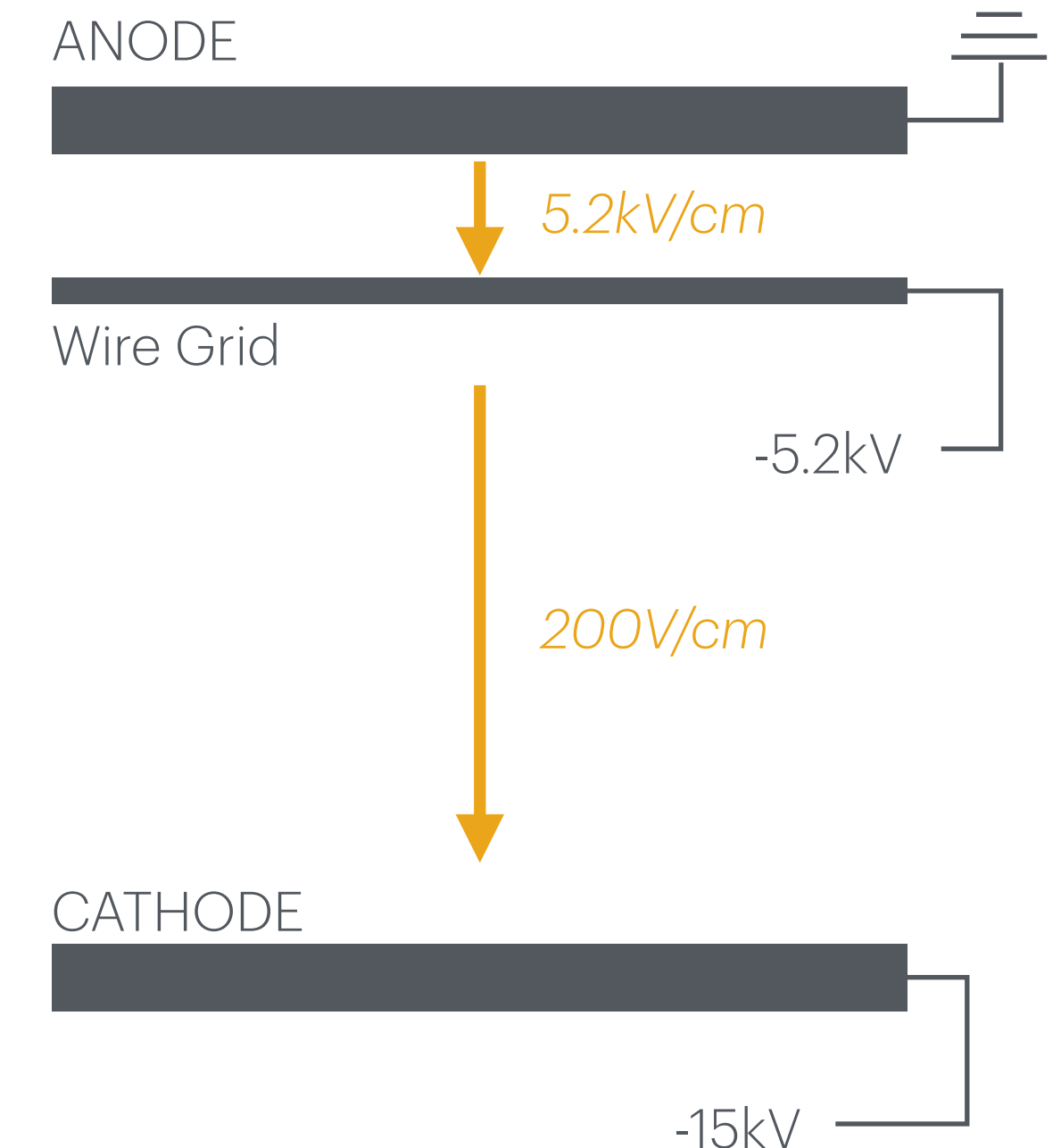
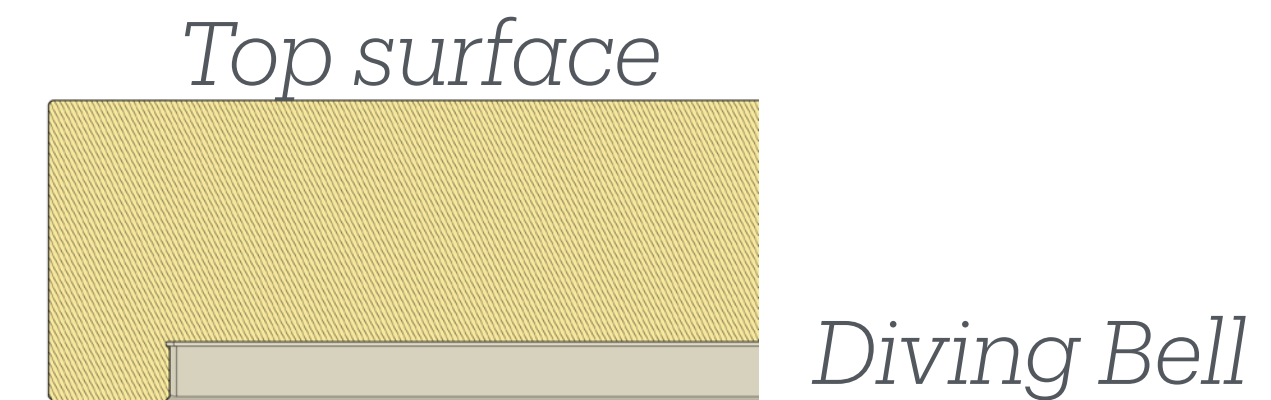


Cathode machining at UofA

Cathode & Knee-wall:
PMMA window defining the negative electrode and bottom side of the field cage

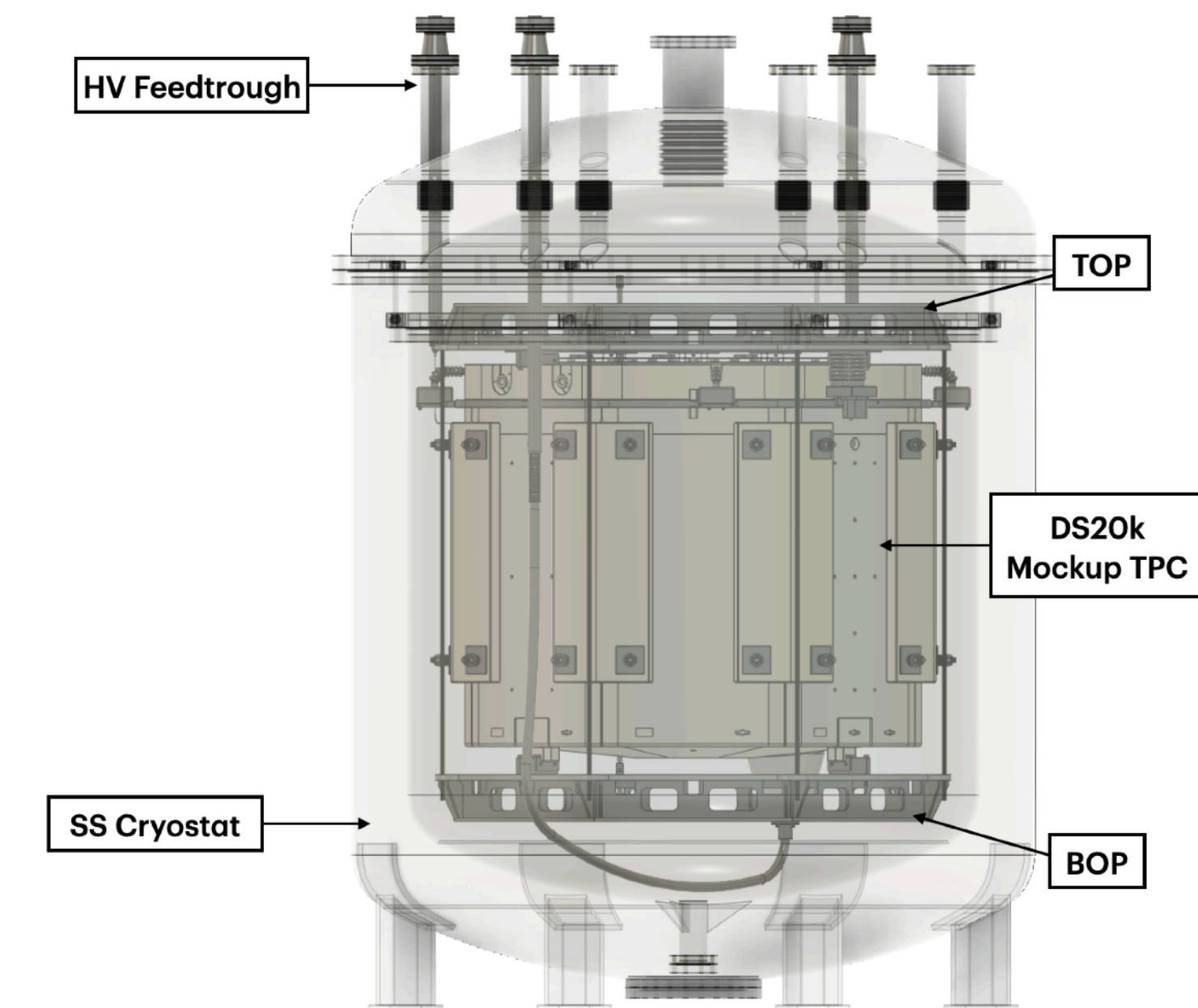
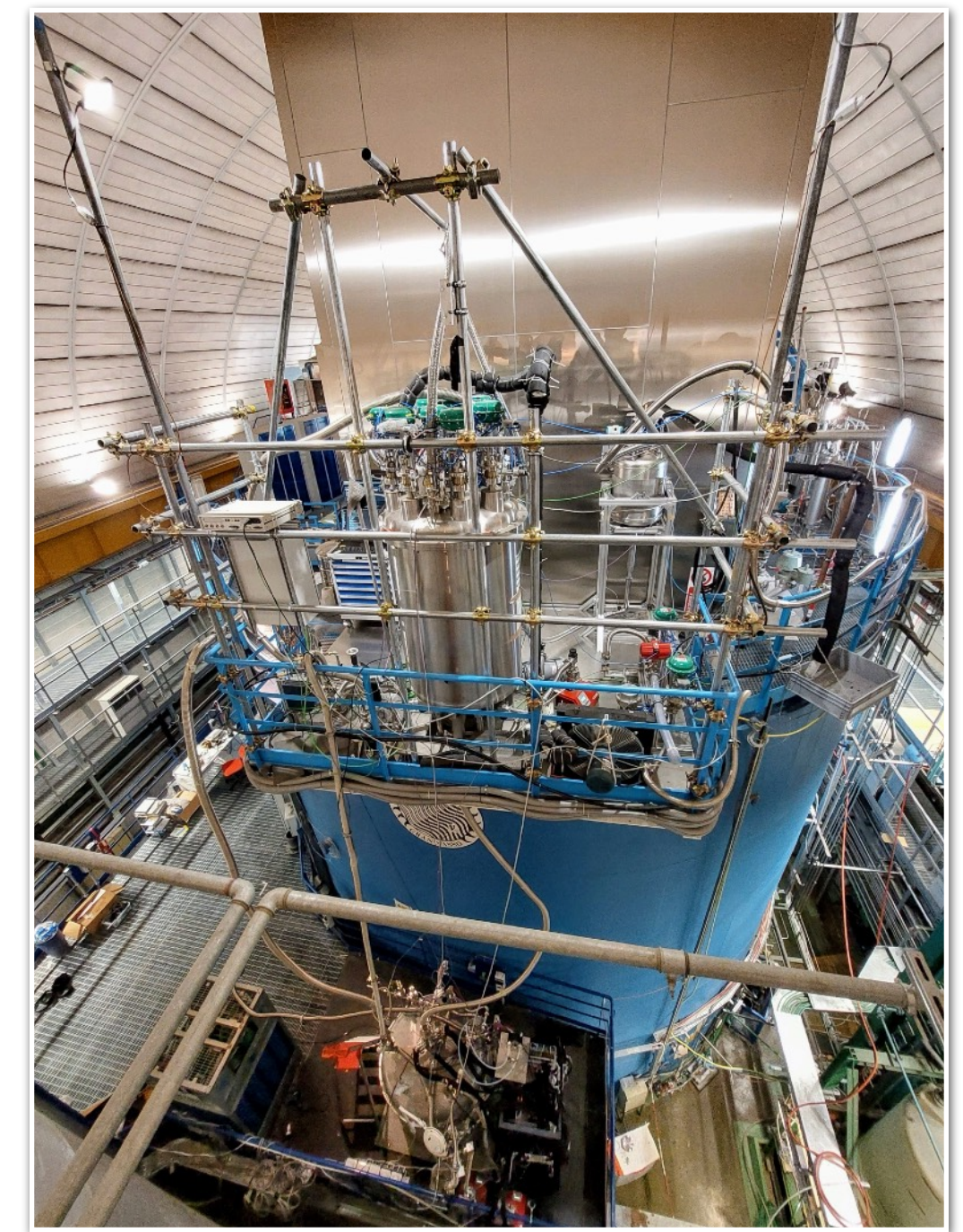


Anode:
Octagonal ~6cm thick PMMA window - define Gas Pocket volume and gnd electrode



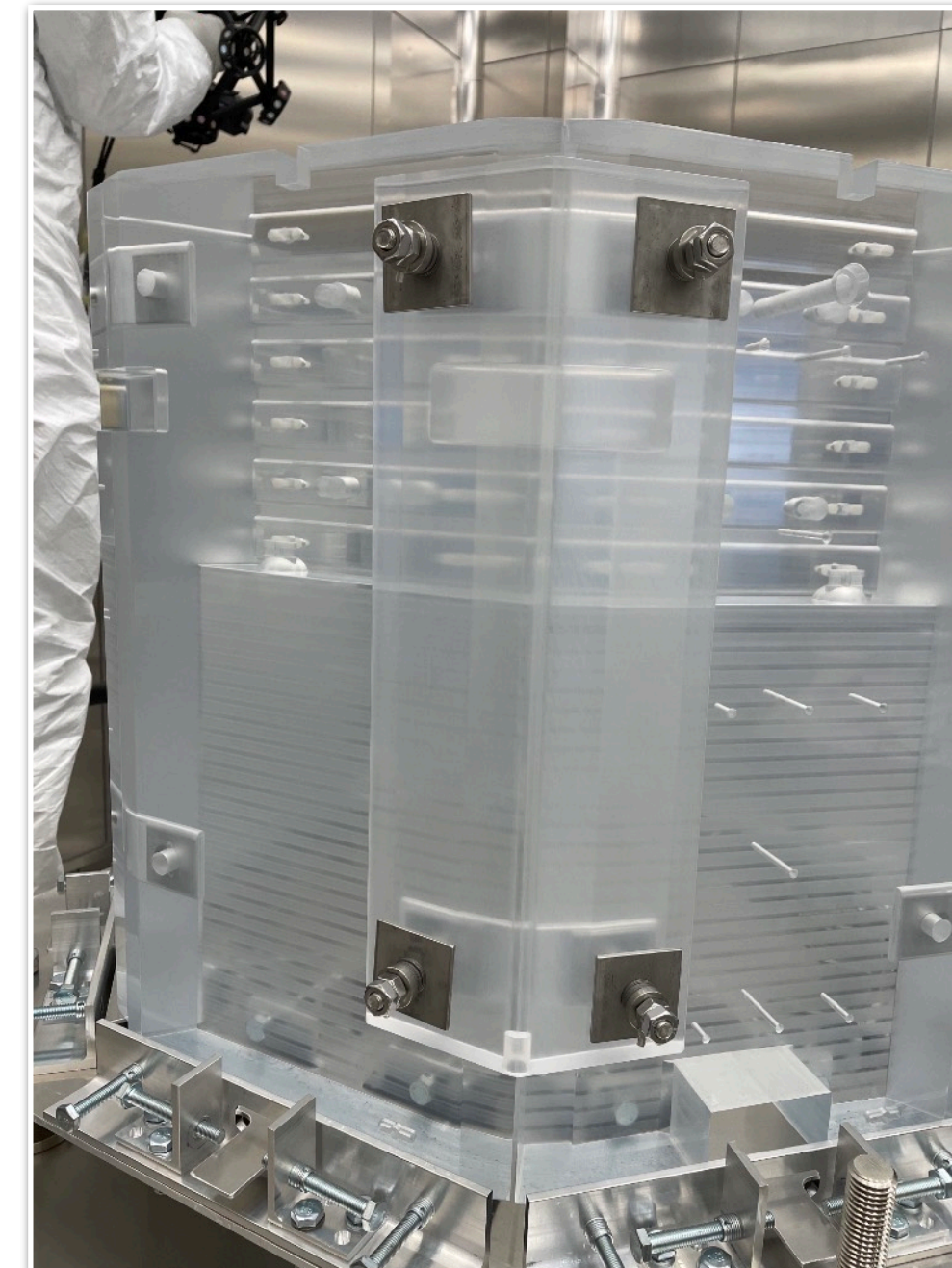
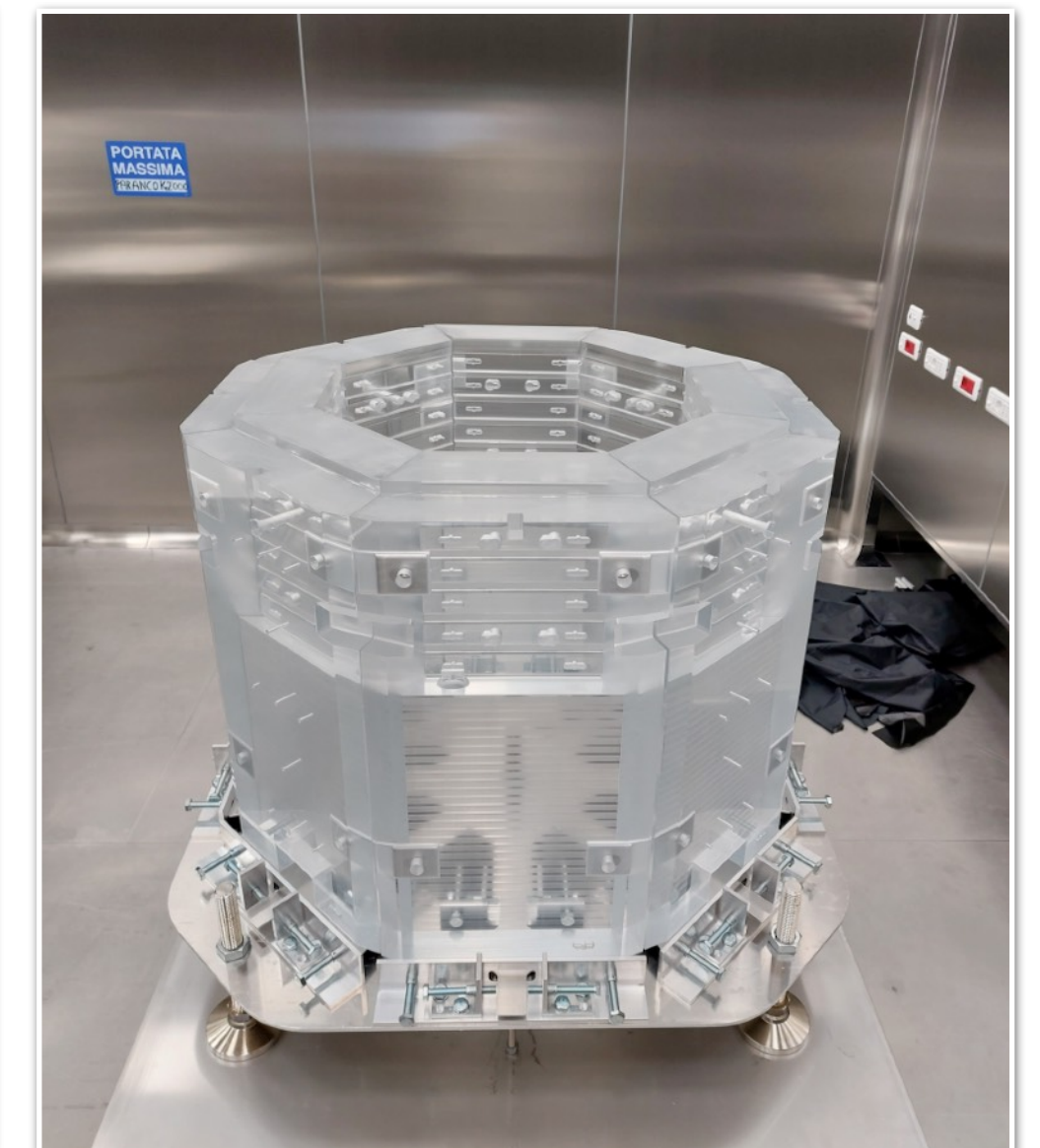
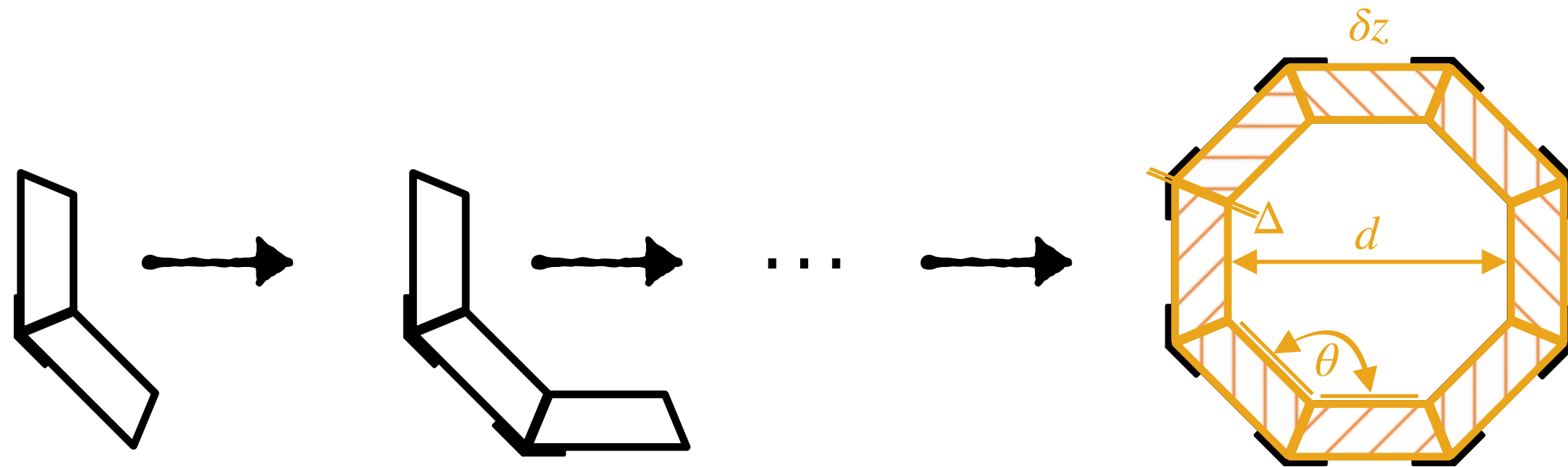
DS-Mockup: Goals

1. Integration exercise at the tonne-scale level with DS-20k UAr cryogenic system at LNGS.
2. Assembly the PMMA barrel ensuring flatness of the top surface to within $\sim 100\ \mu\text{m}$ (preserve S2 uniformity).
3. Perform a safe and reliable thermal cycling of the PMMA TPC.
4. Ensure High-voltage (HV) delivery up to and beyond the nominal cathode voltage of $V_C \sim -75\ \text{kV}$.
5. Validate **CleviosTM** coatings in LAr.
6. Measure the power requirements for gas pocket generation and extrapolate to DS-20k.



TPC Barrel Assembly

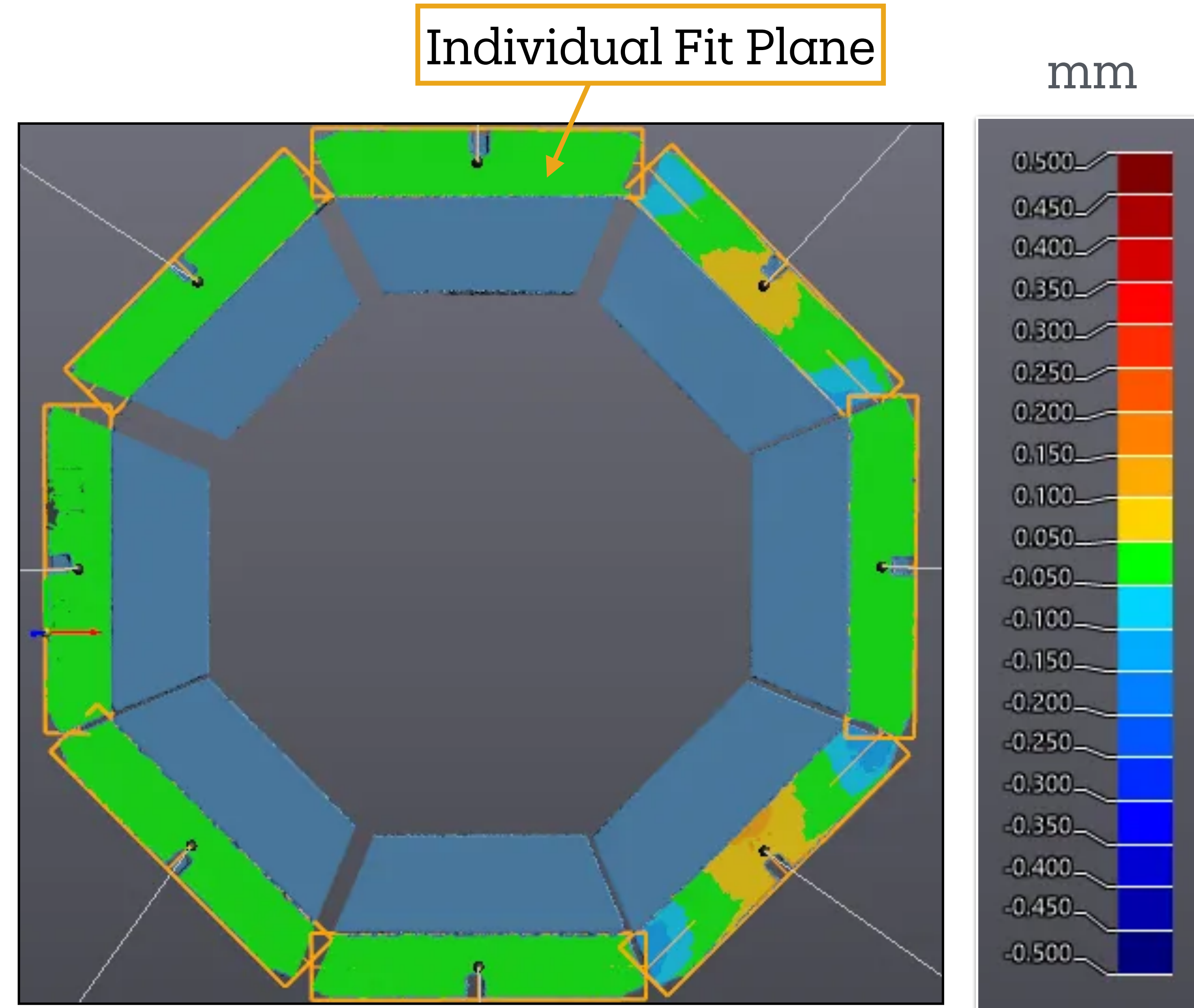
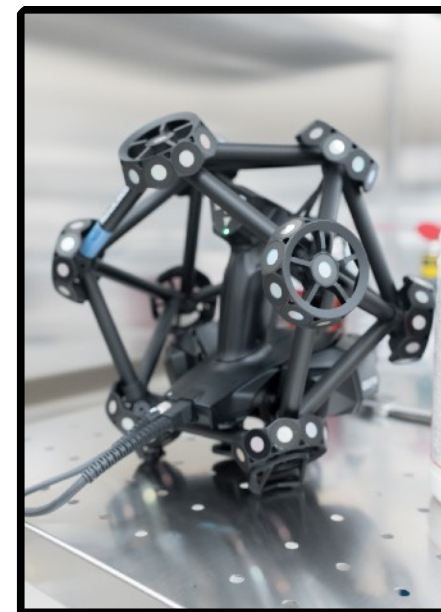
- Assembly and installation at **LNGS** (ISO-6 CR)
- MetraScan 3D Laser scanner for assessing the planarity (*25 μ m resolution*) - *same device for DS-20k*
- Assembly goals:
 - Gaps between panels to be kept at $\Delta \leq 2 \text{ mm}$
 - Octagonality θ and panel spacing d to fit with knee-wall
 - $\delta z \approx 100 \mu\text{m}$ flatness of the barrel top surface (S2 uniformity)



TPC Barrel Assembly

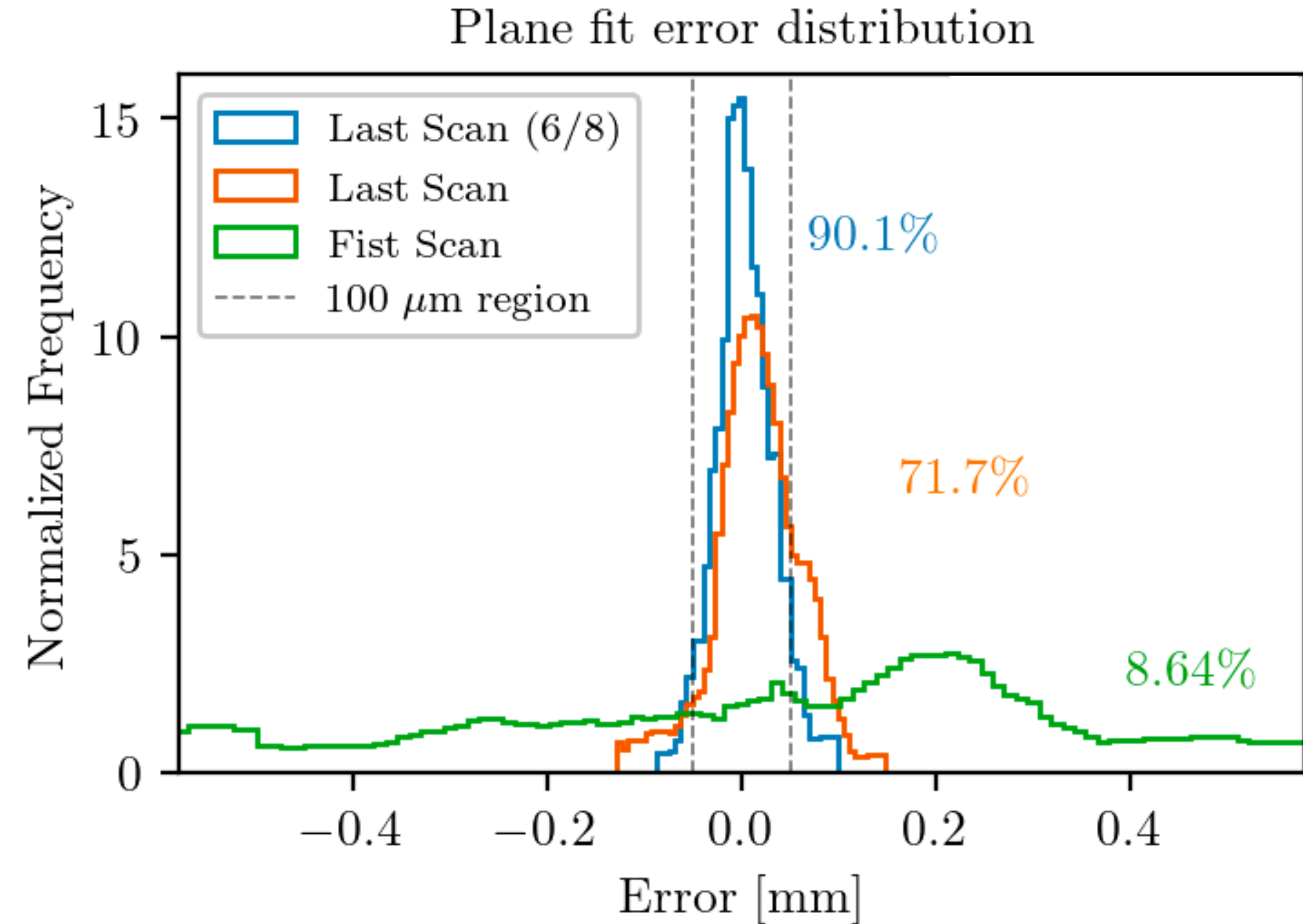
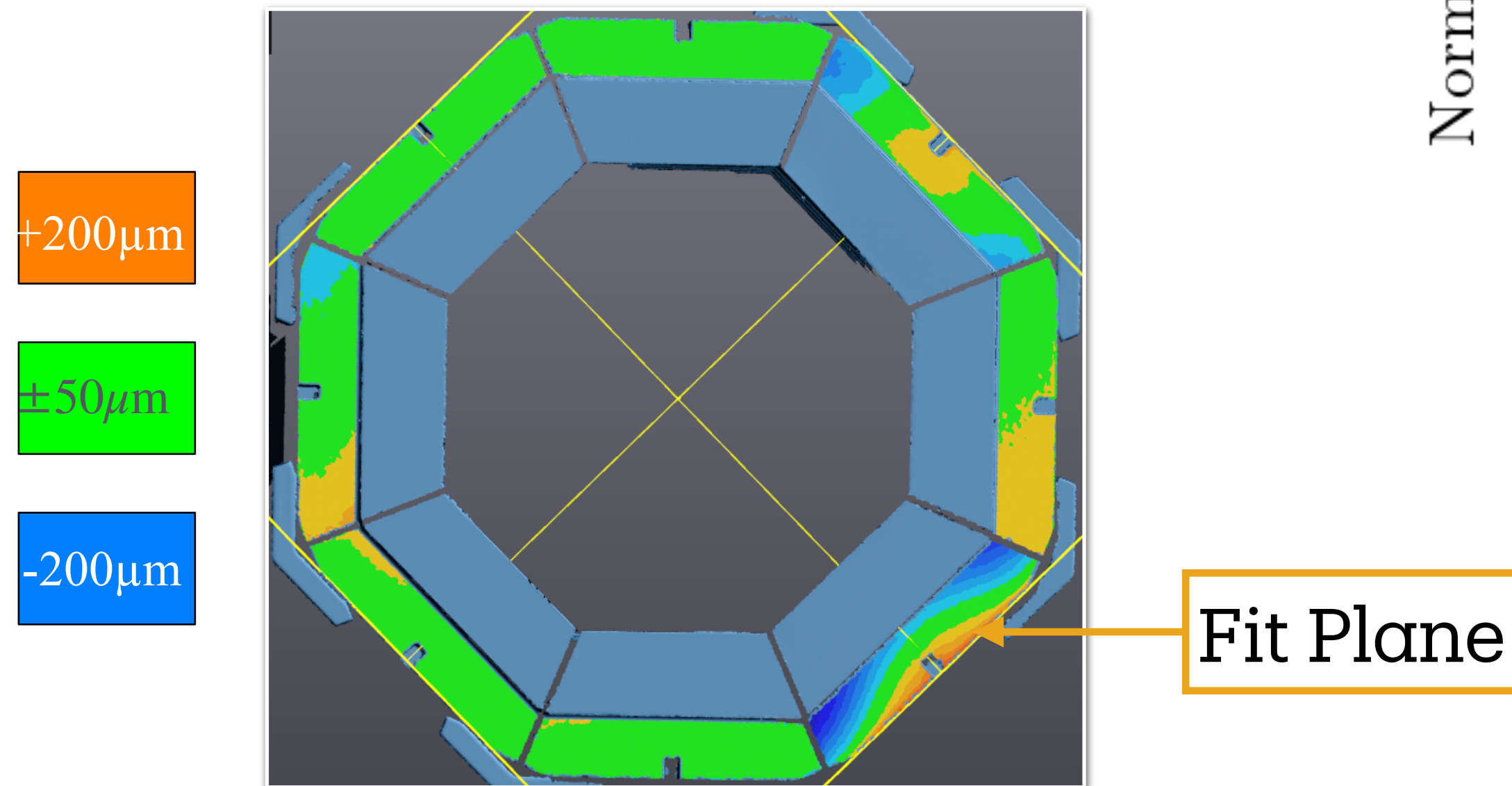
- 6/8 within (100um intrinsic flatness)
- 2/8 panels found to be deformed
- Underwent a uncontrolled thermal cycle during the baking process:
- Asymmetric bending and curvature along all axes
- Difficulty in lateral mating with adjacent ones

MetraScan 3D Laser scanner



TPC Barrel Assembly

- Planarity within $\delta z \approx 100 \mu\text{m}$ achieved for the regular panels at 90% level
- Barrel lifting had no impact on the flatness of the barrel
- Gaps within specs for Resistor Chain installation



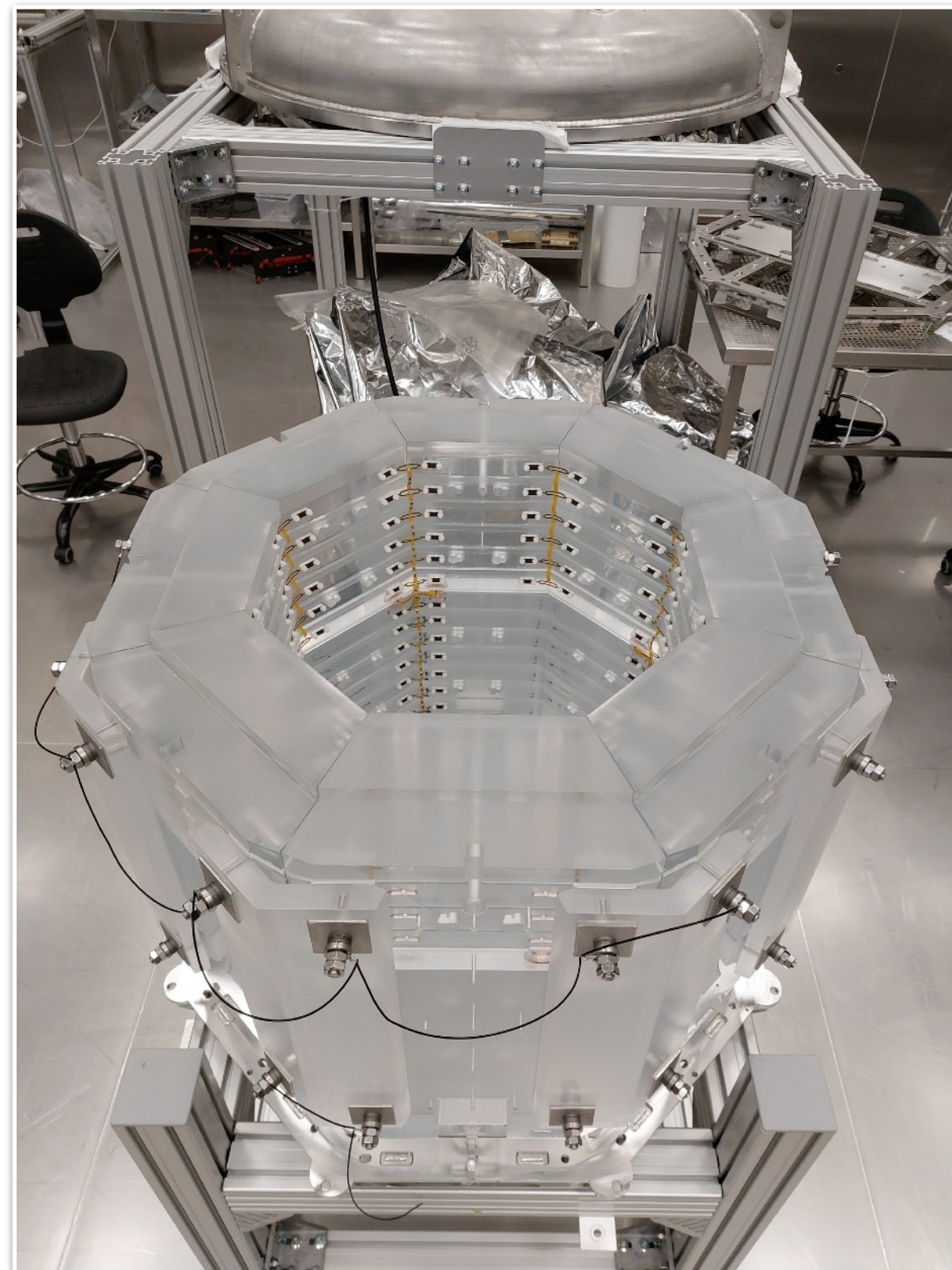
TPC Assembly

Finalization

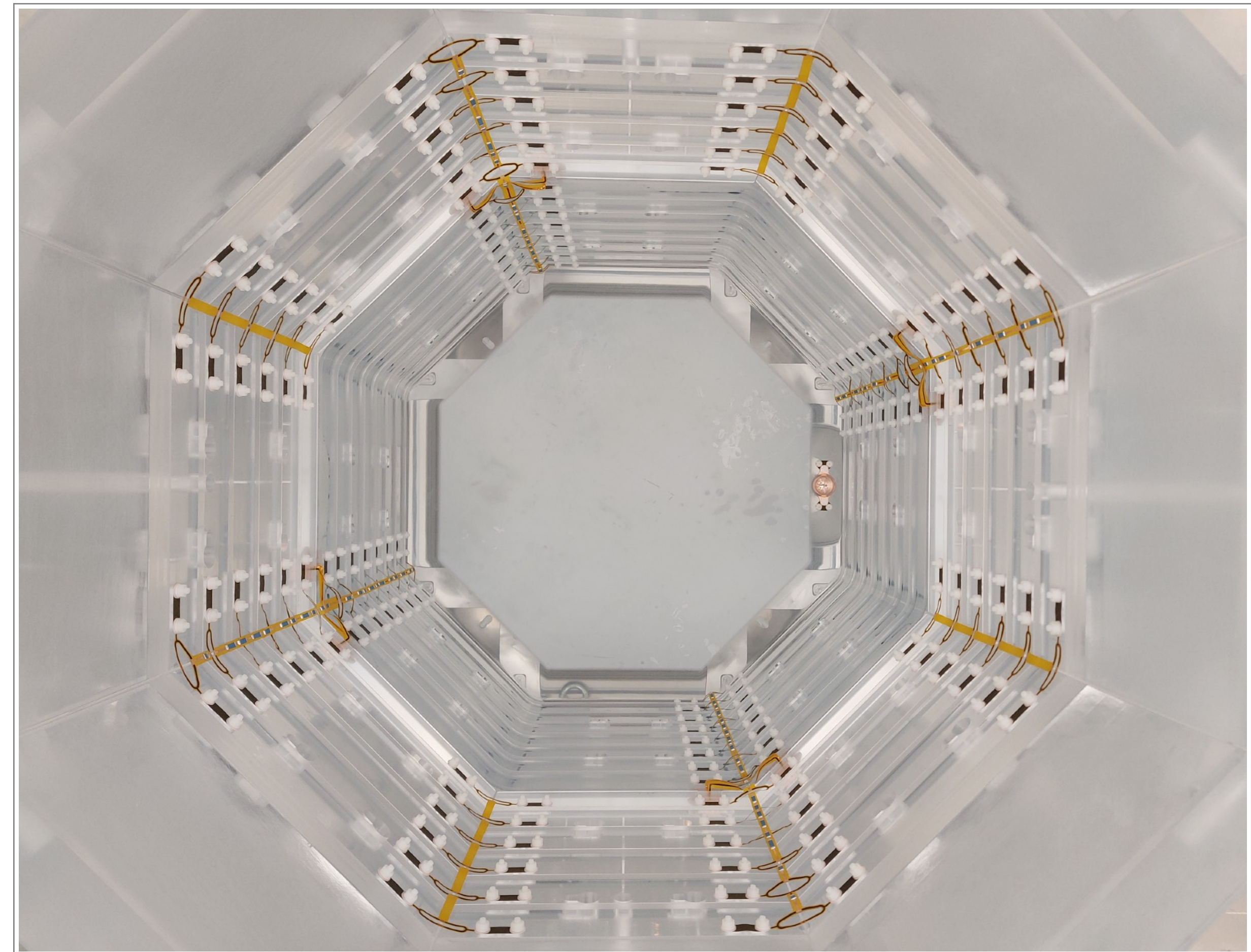
Cathode and Knee-wall



Barrel on Cathode

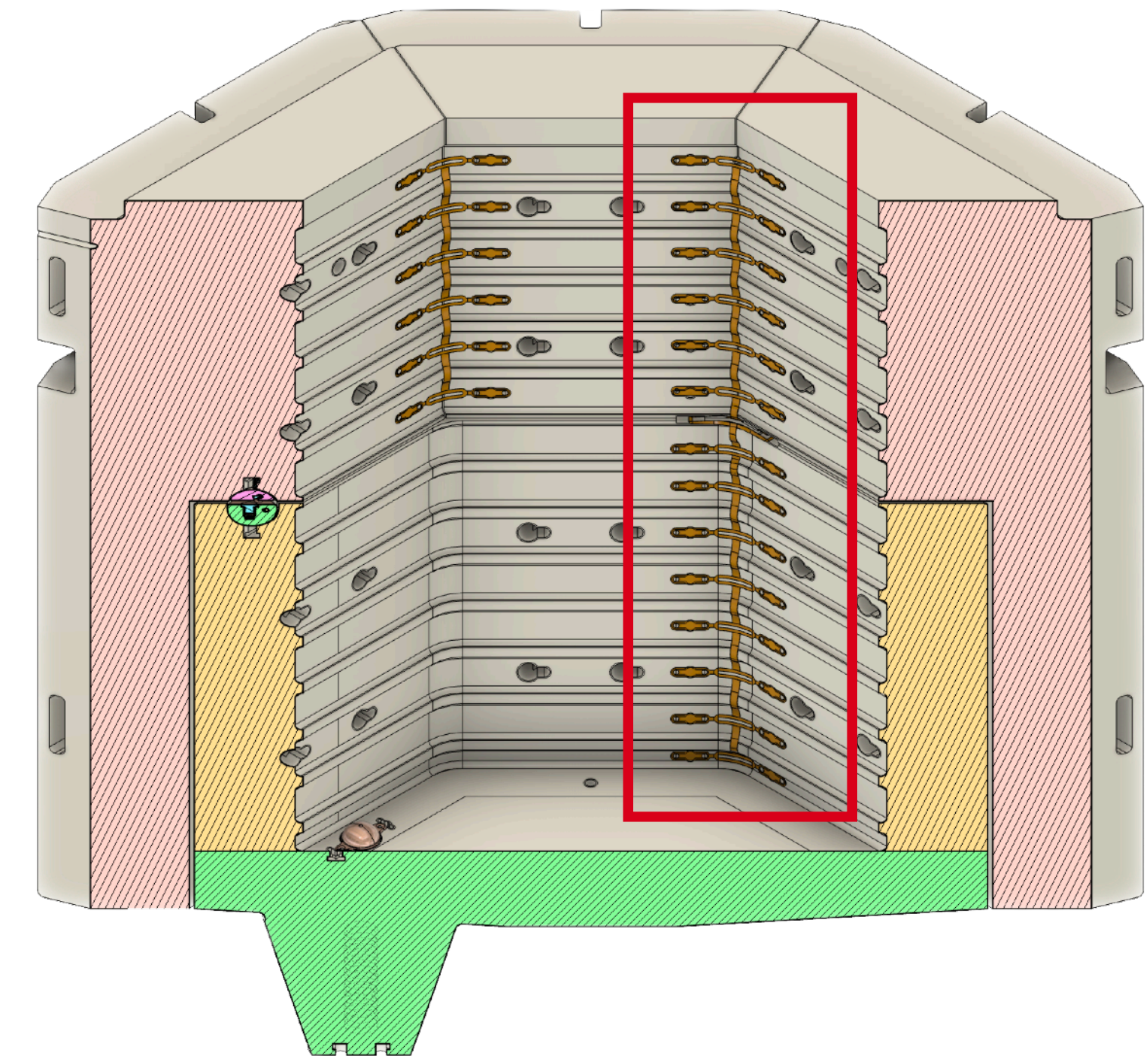
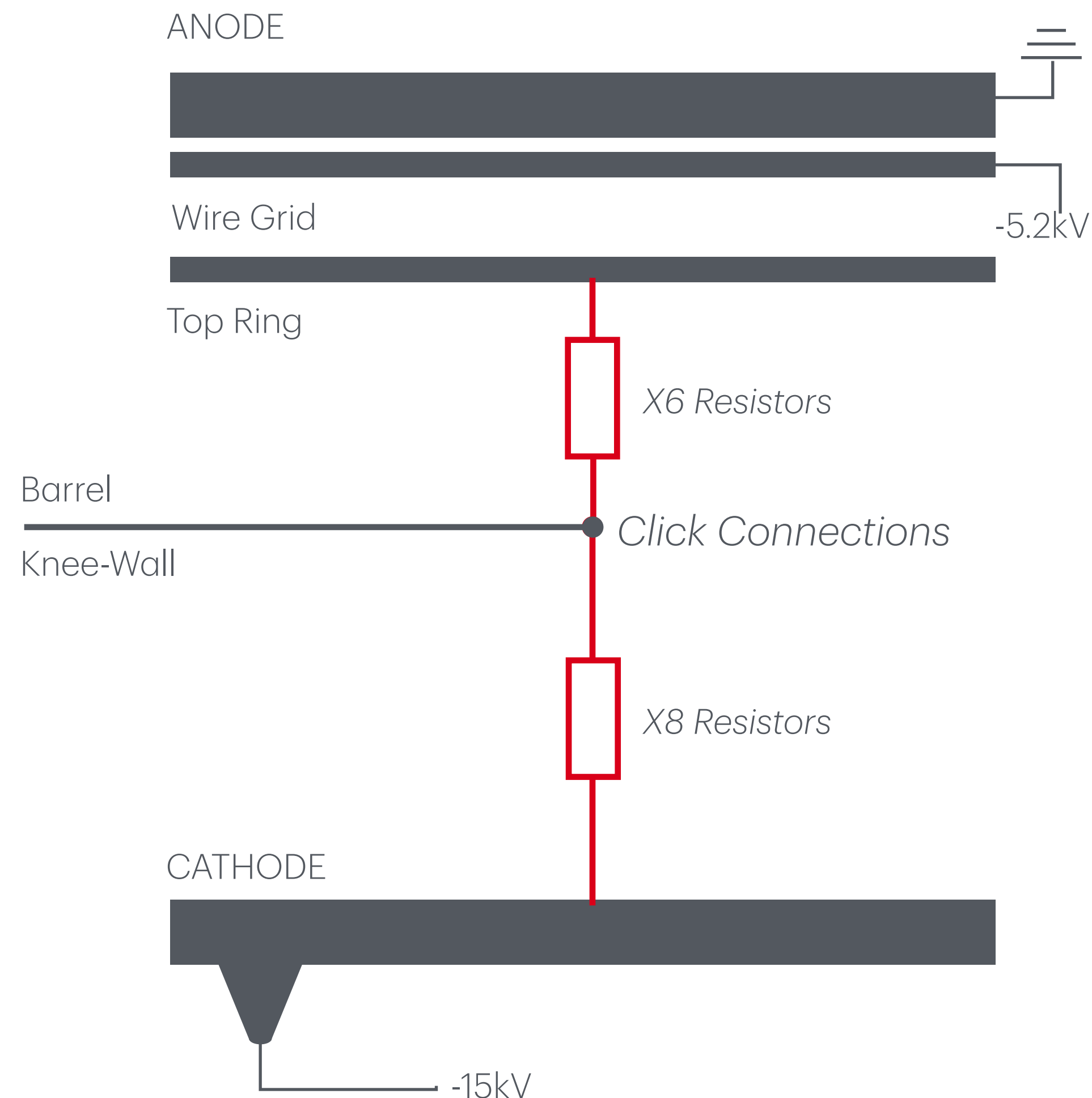


Barrel on Cathode - Inside view



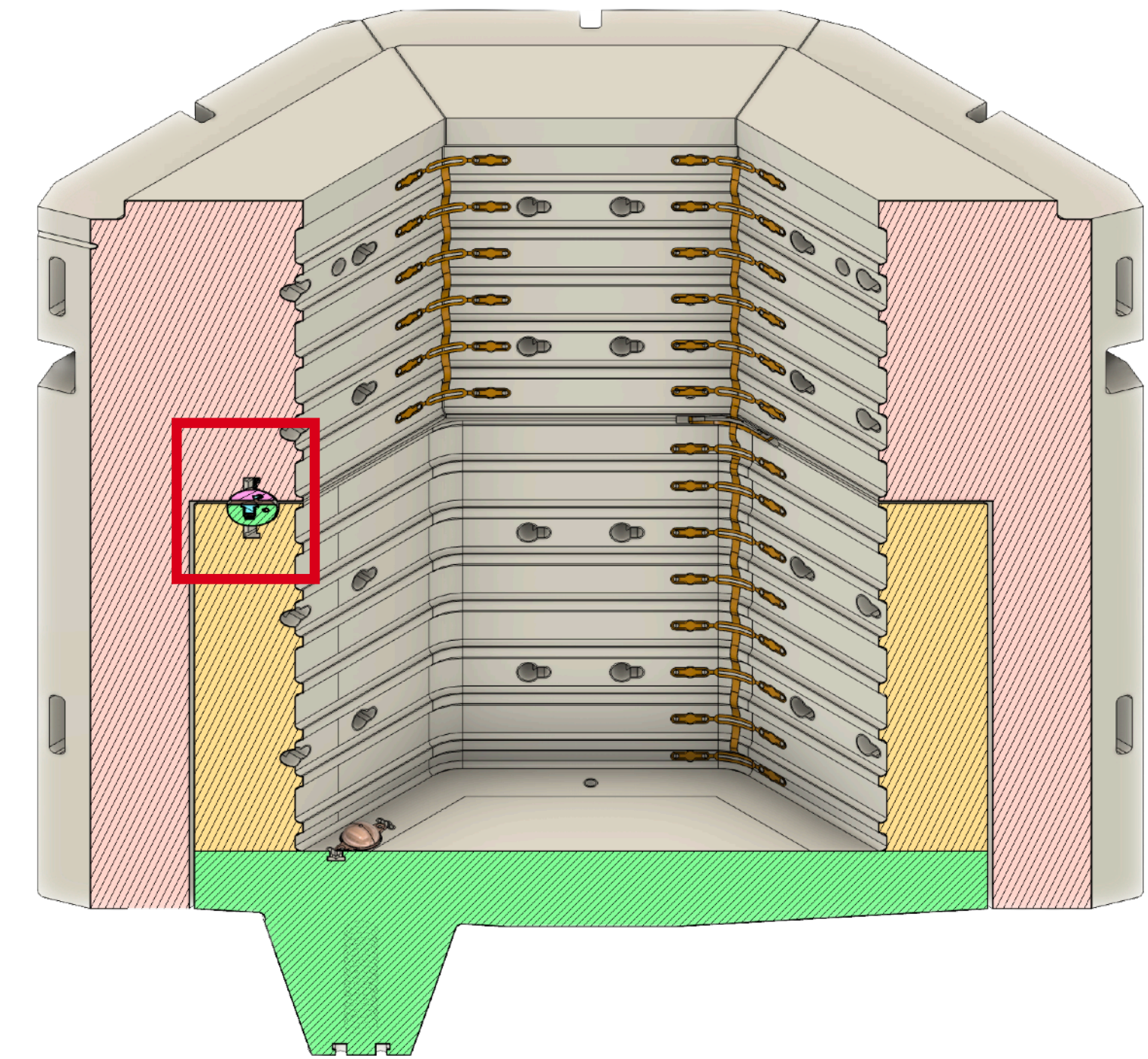
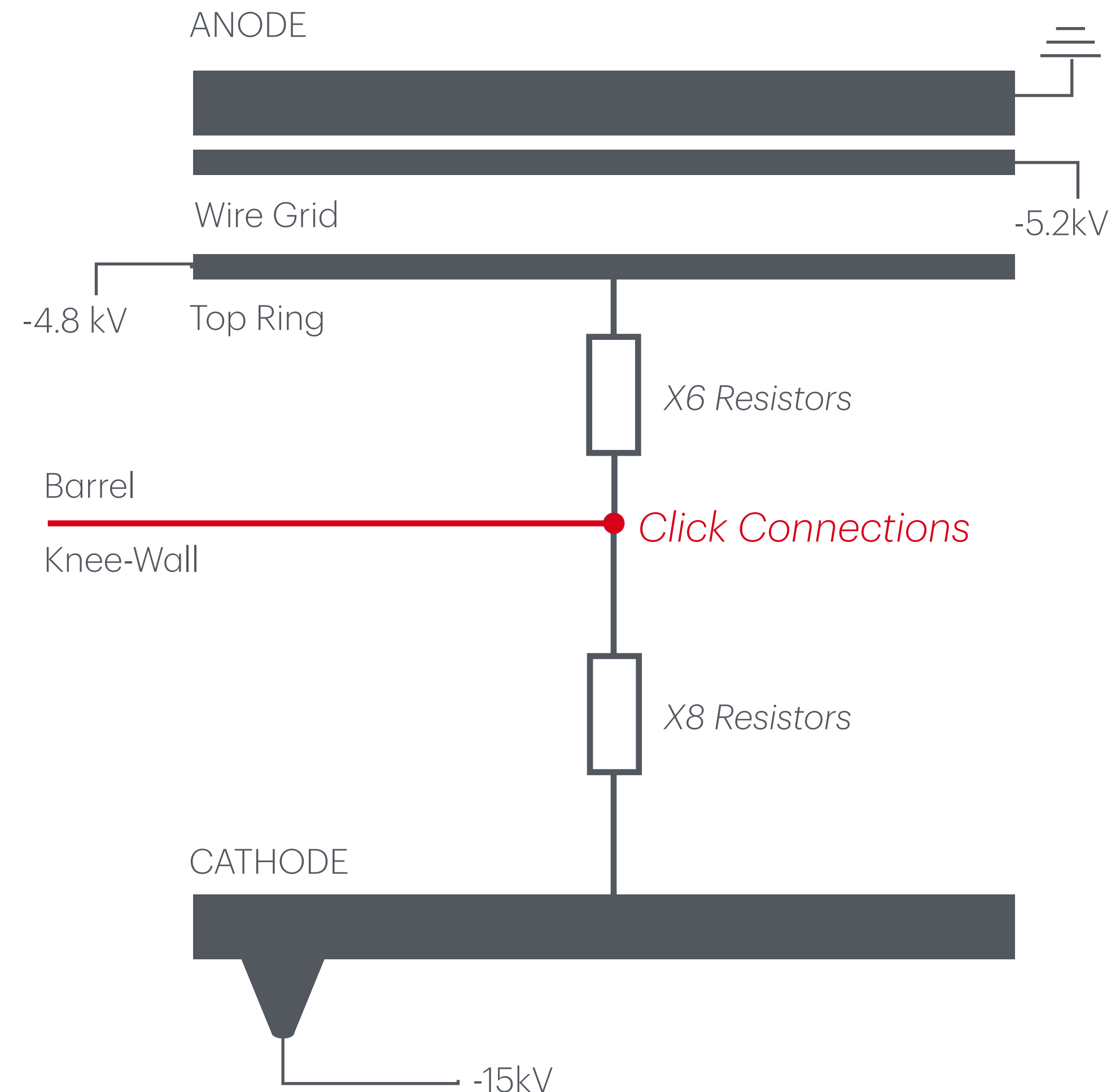
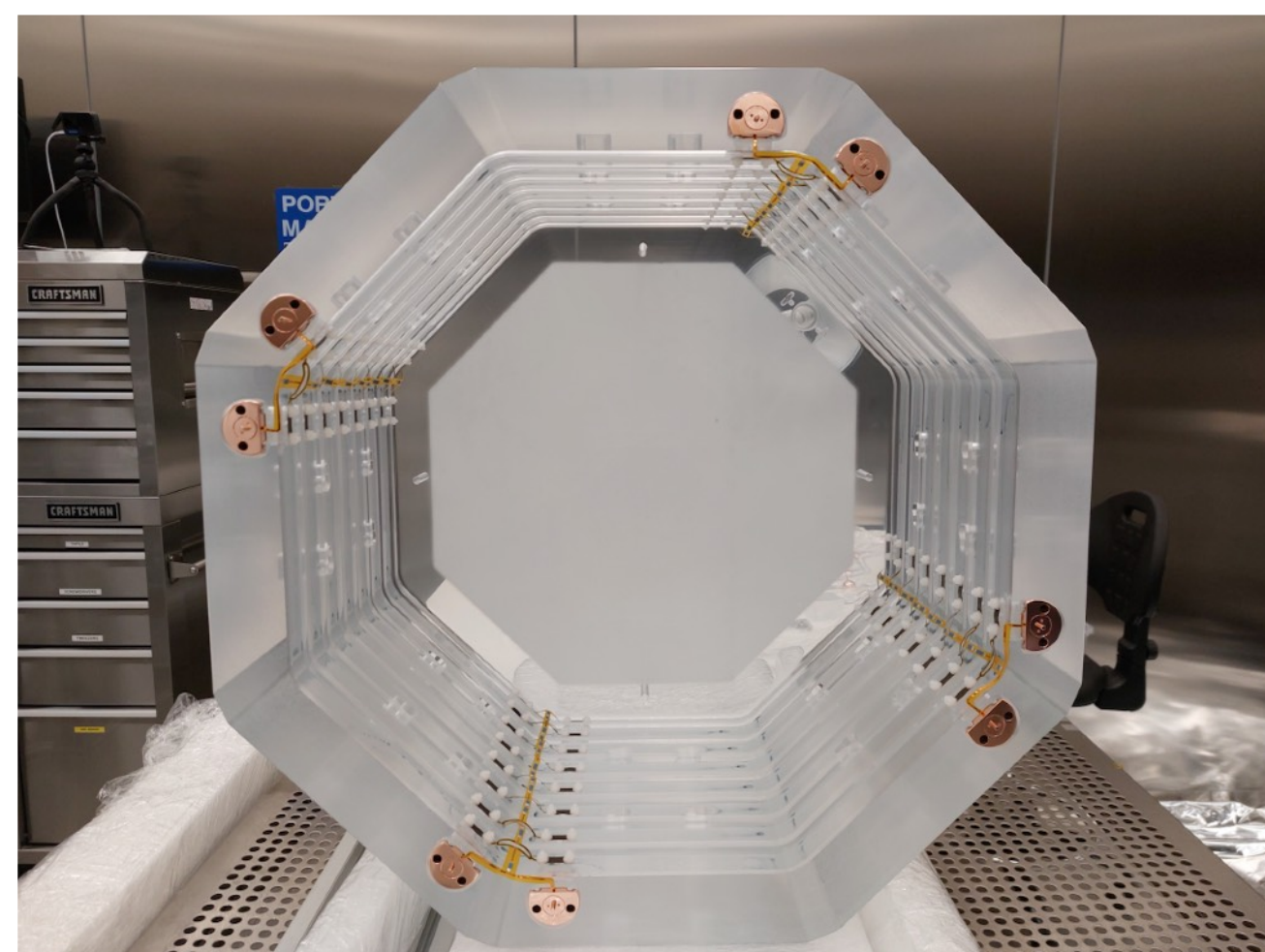
High Voltage Distribution

- Resistive chains (x4) made of Kapton and Cu ensure the proper voltage drop at each field cage ring (x12 $2\text{G}\Omega$ resistors, x2 $1\text{G}\Omega$ resistor)
- Additional x4 chains for continuity



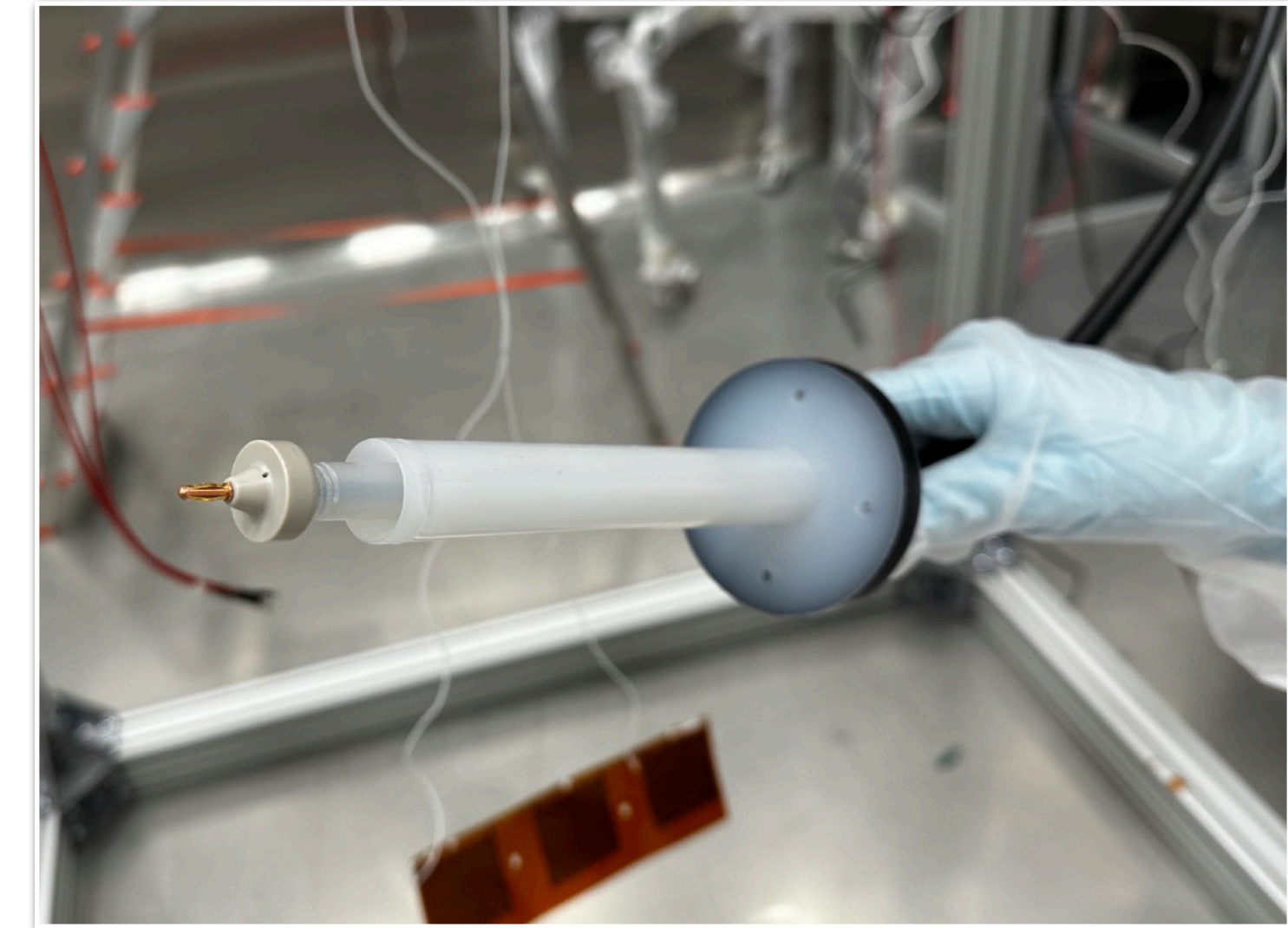
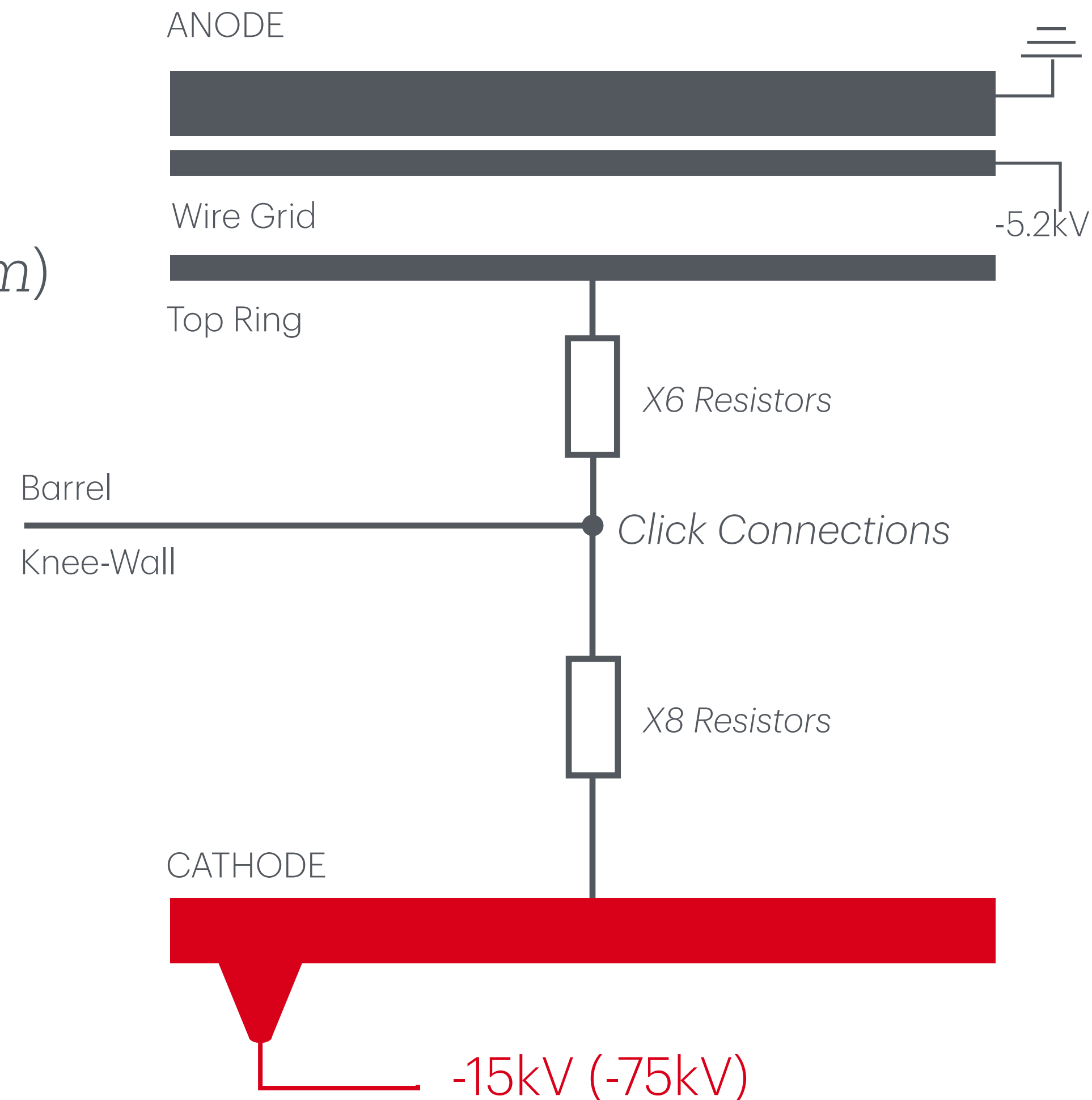
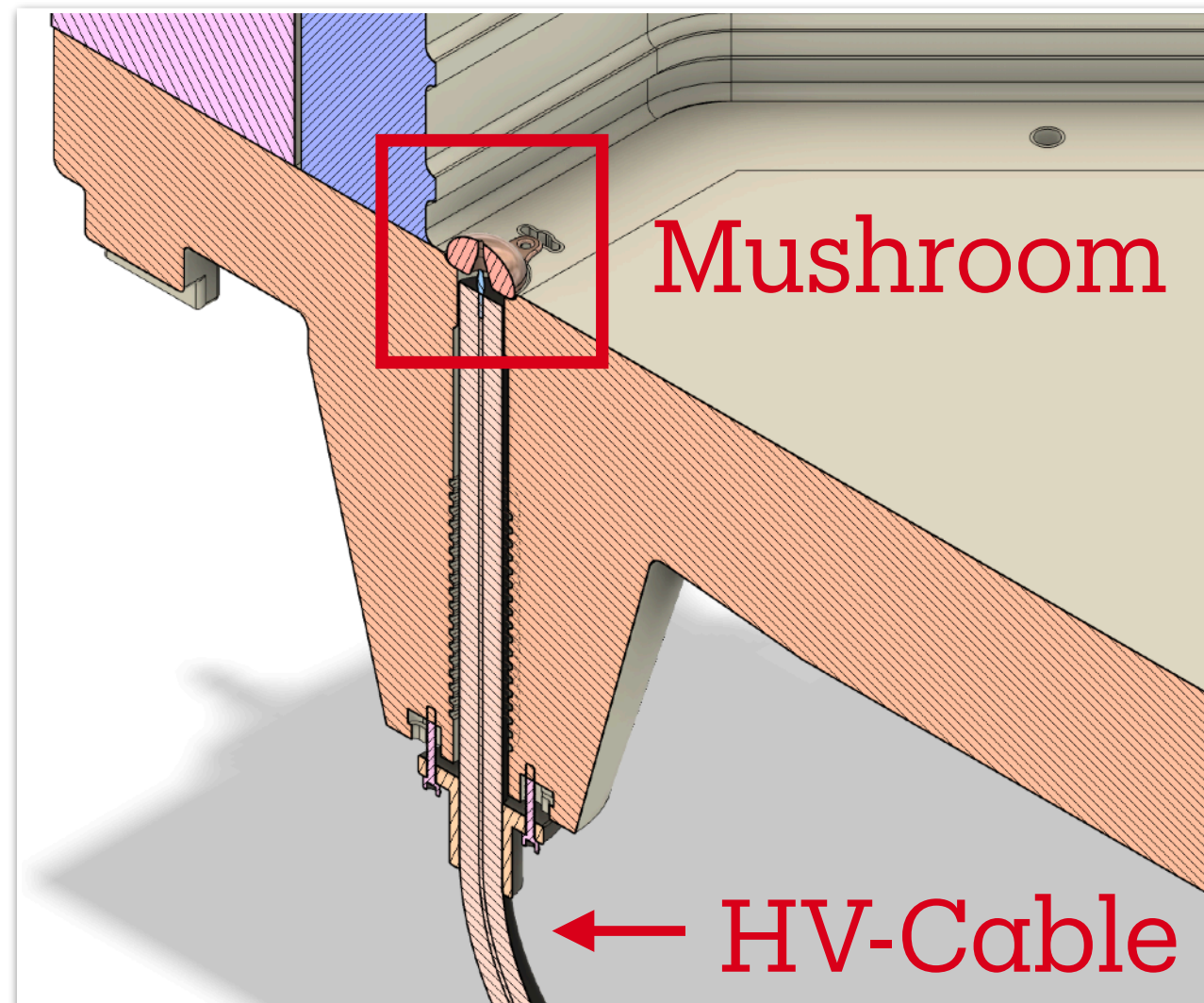
High Voltage Distribution

- Connection between knee-wall and cathode ensured via Cu shell components called **click connections**
- Different and safer design for DS-20k



High Voltage Distribution

- **Cathode HV** connection via:
 - Custom cable
 - Cu connection on the PMMA window (*mushroom*)



- High-Voltage Performance Testing in LAr of the PMMA Cathode Connection for the DarkSide-20k Experiment - **L. Luzzi**



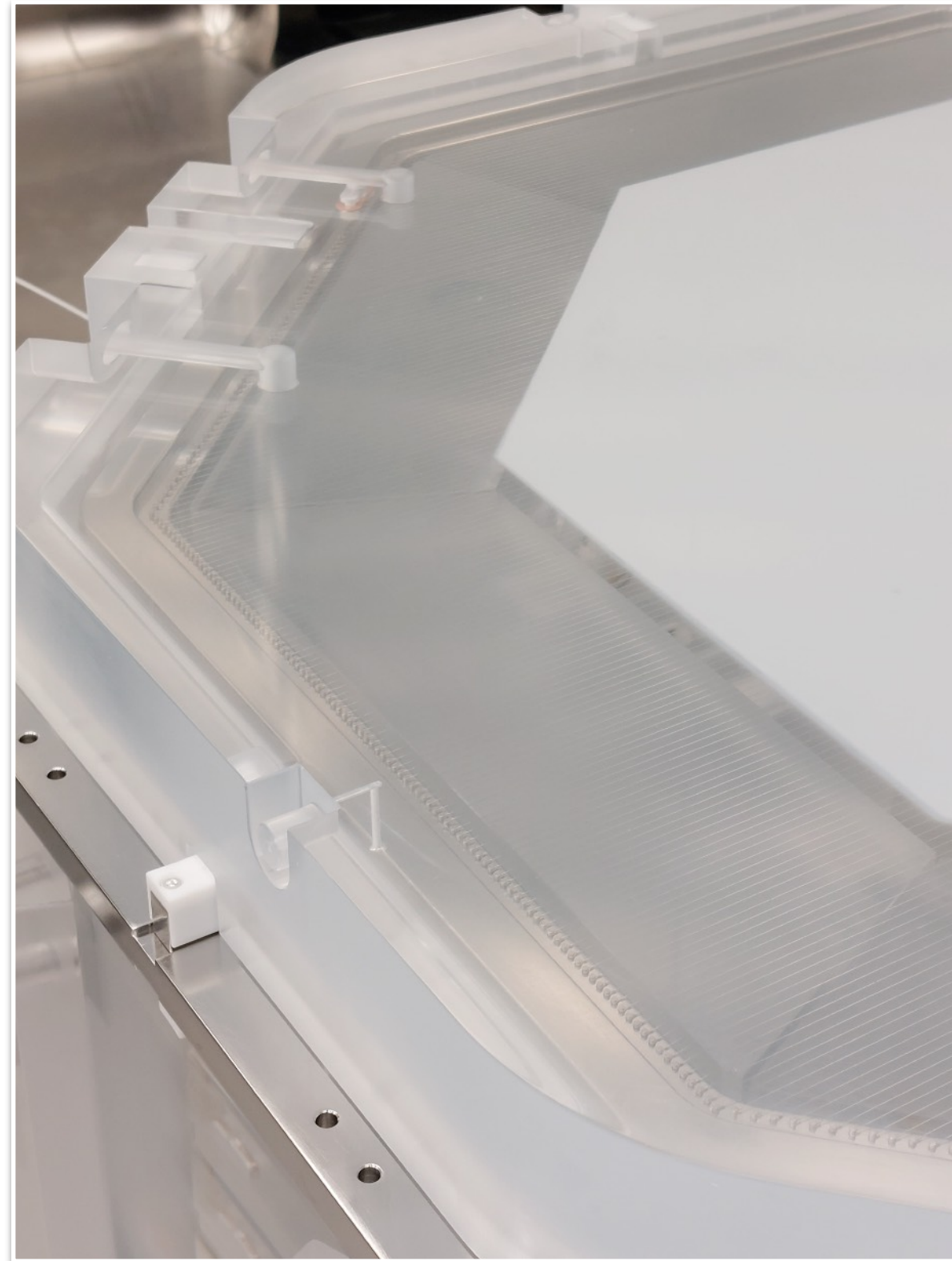
TPC Assembly

Finalization

Wire Grid on Barrel



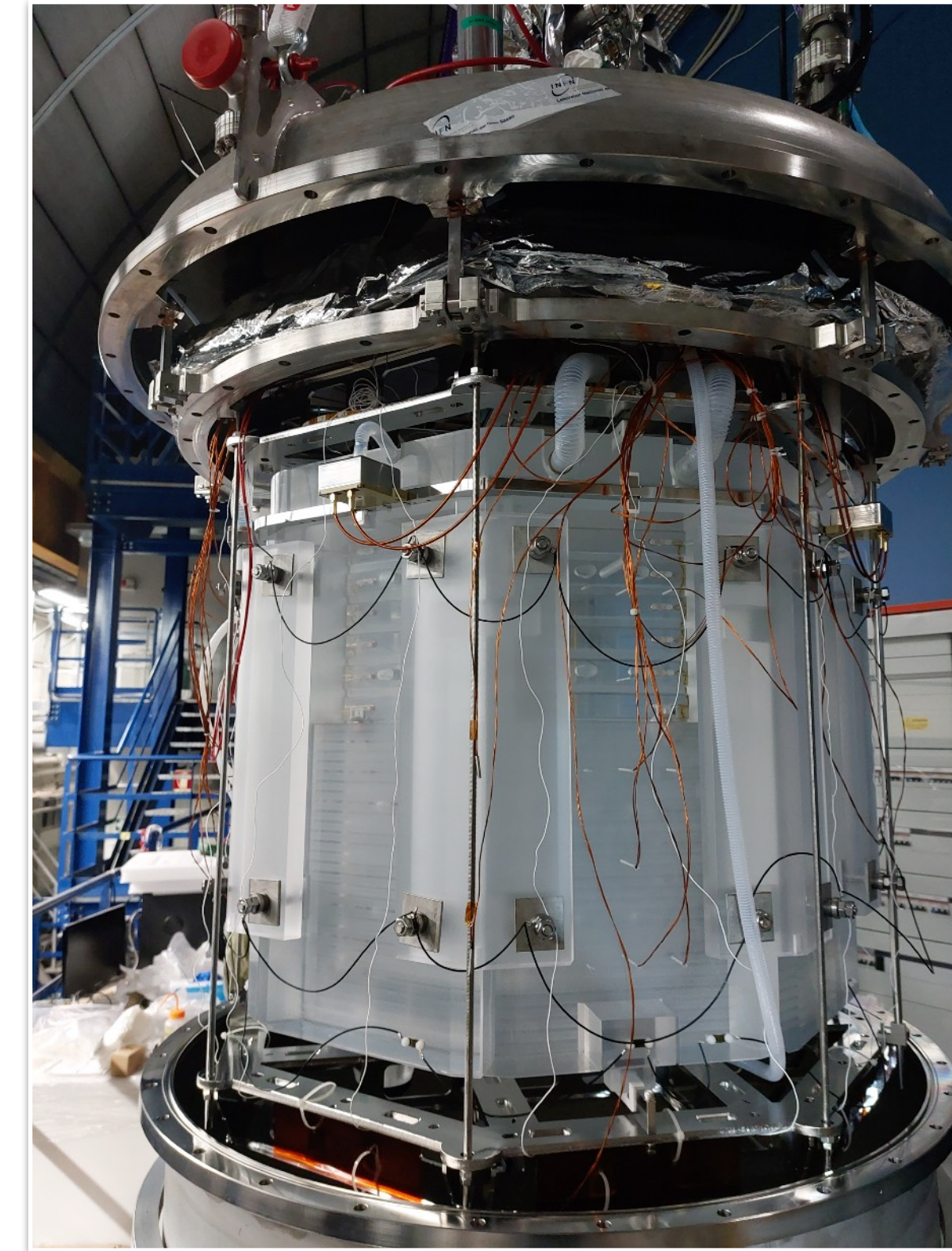
Anode on Grid



Cryostat dome connection

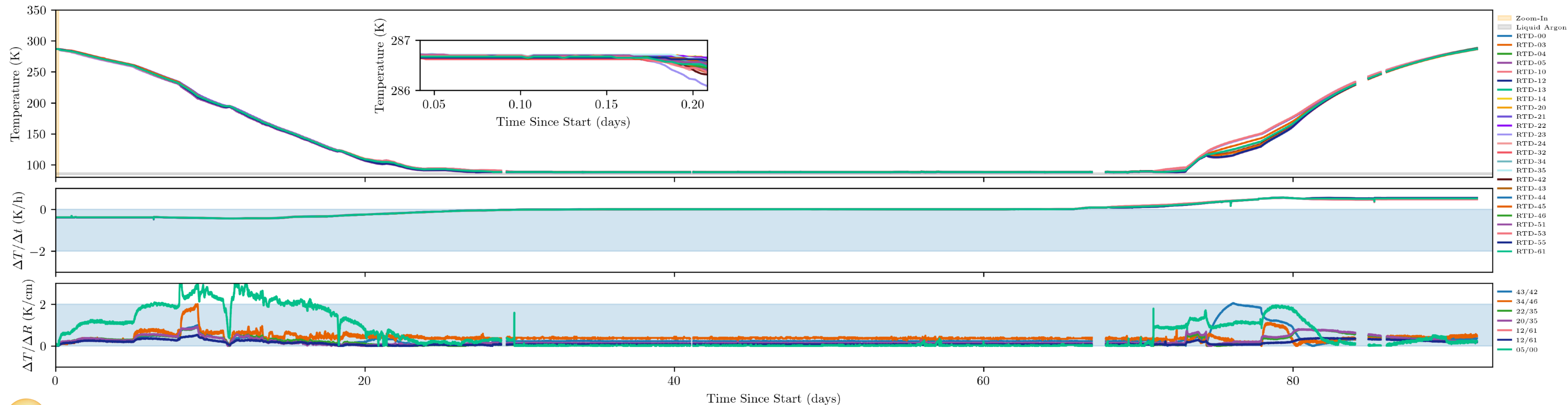
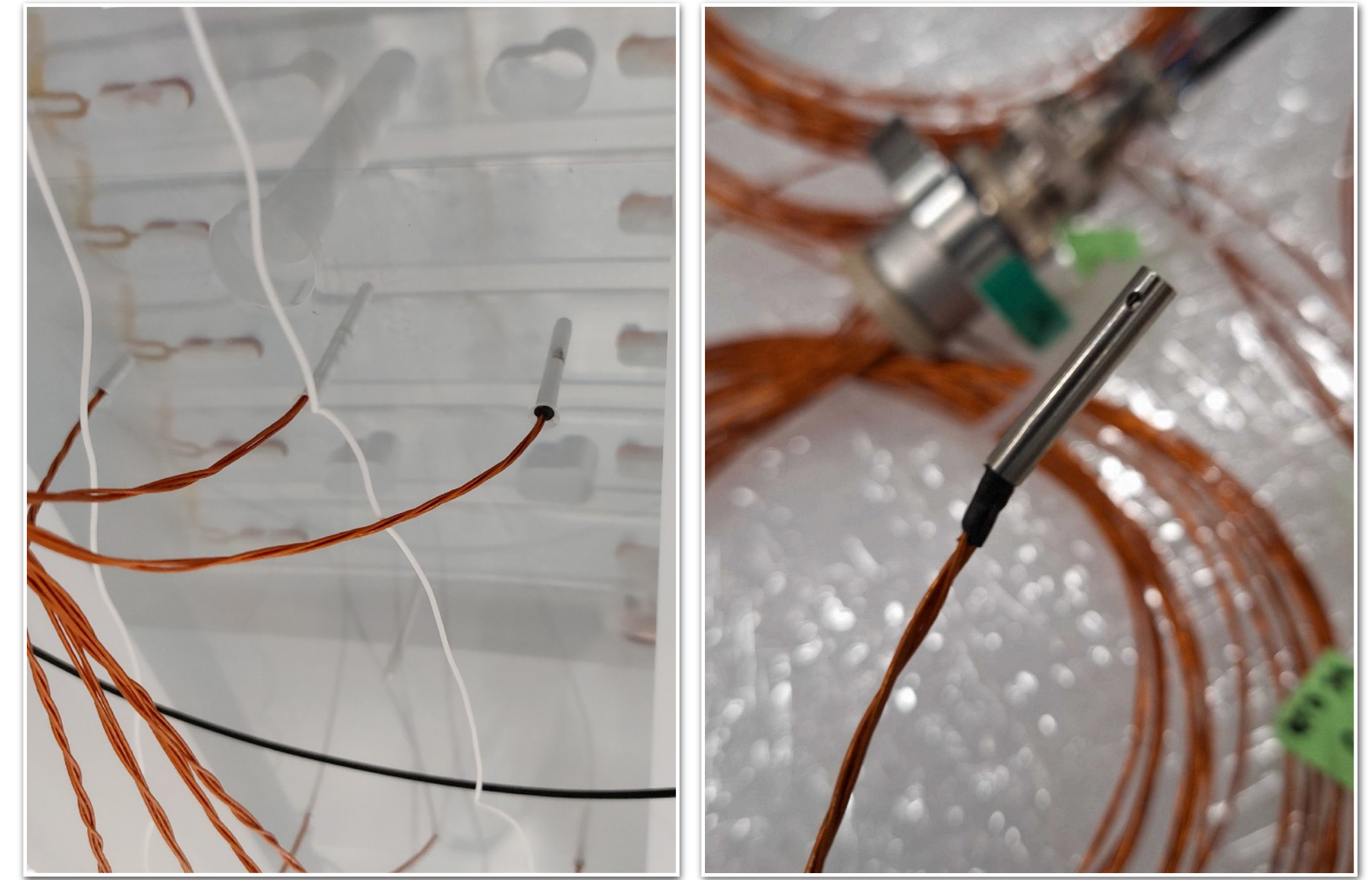


Test Cryostat insertion



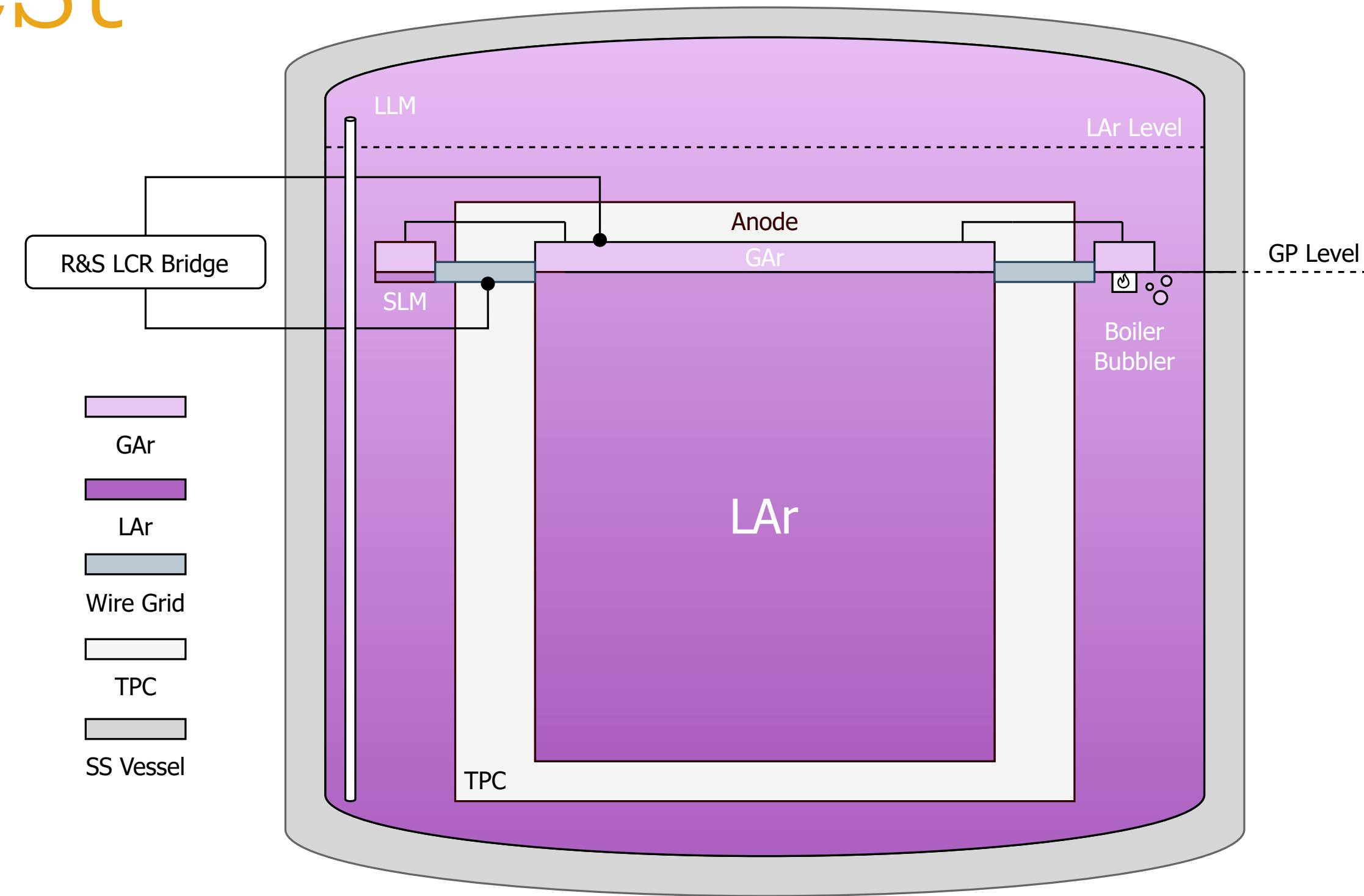
TPC Cool-down

- Slow cool-down in argon to limit and minimize the thermal stress due to temporal and spatial gradients.
- Thermal simulations indicate that a $\sim 0.5 \text{ K/h}$ is needed to stay below $\sim 2 \text{ K/cm}$.
- Measured temperature inside the PMMA panels.



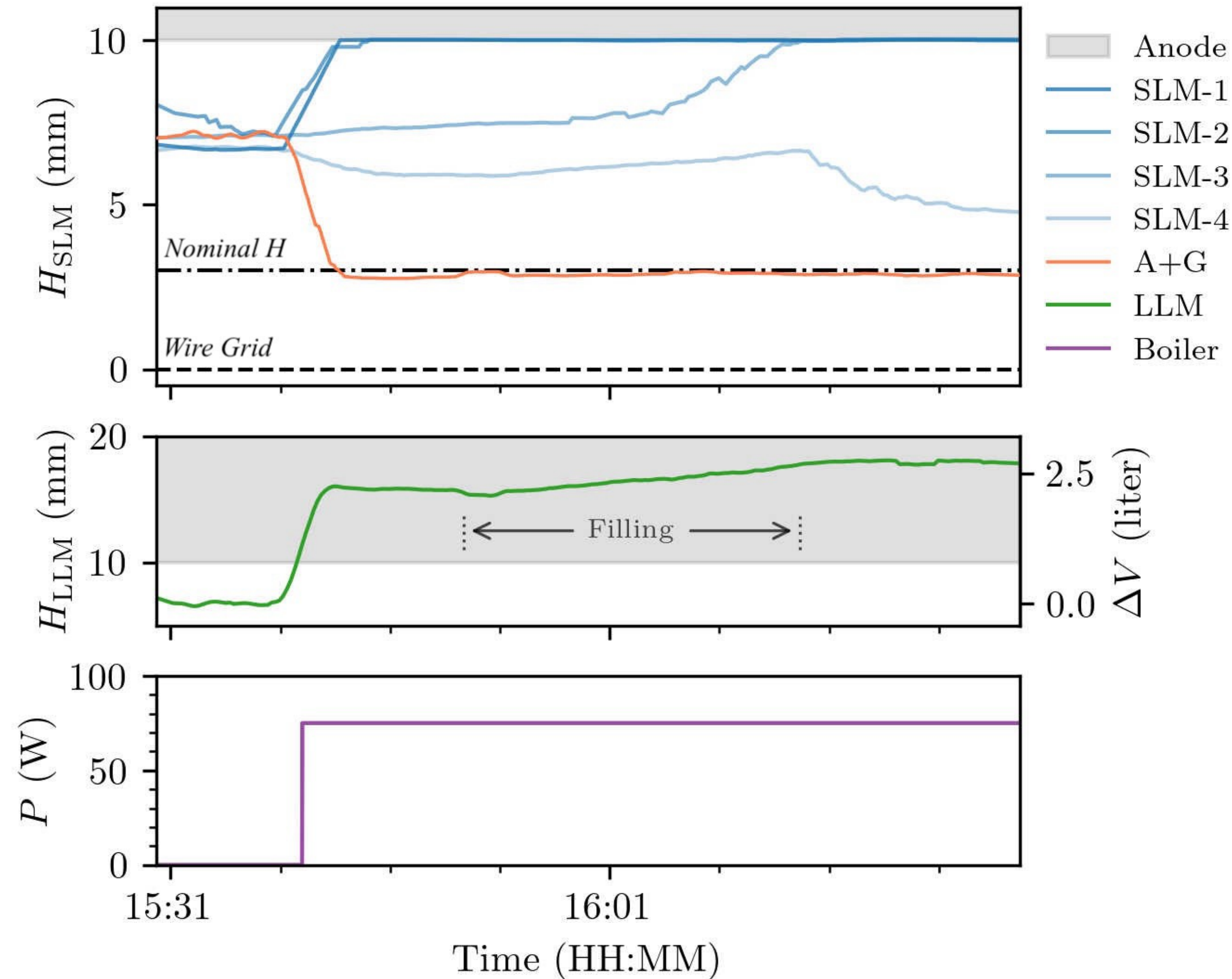
Gas Pocket Formation Test

- Generation of gas pocket in the **Bubbler/Boiler** via
 - LAr vaporization via a 10Ω resistor
 - GAr direct feed from an external bottle
- Liquid level measurement via
 - **SLM**: capacitive sensors (x4) mirror diving bell liquid level
 - **LLM**: capacitive sensor that measure the LAr level outside TPC
 - **R&S LCR Bridge**: anode-wire grid capacitance



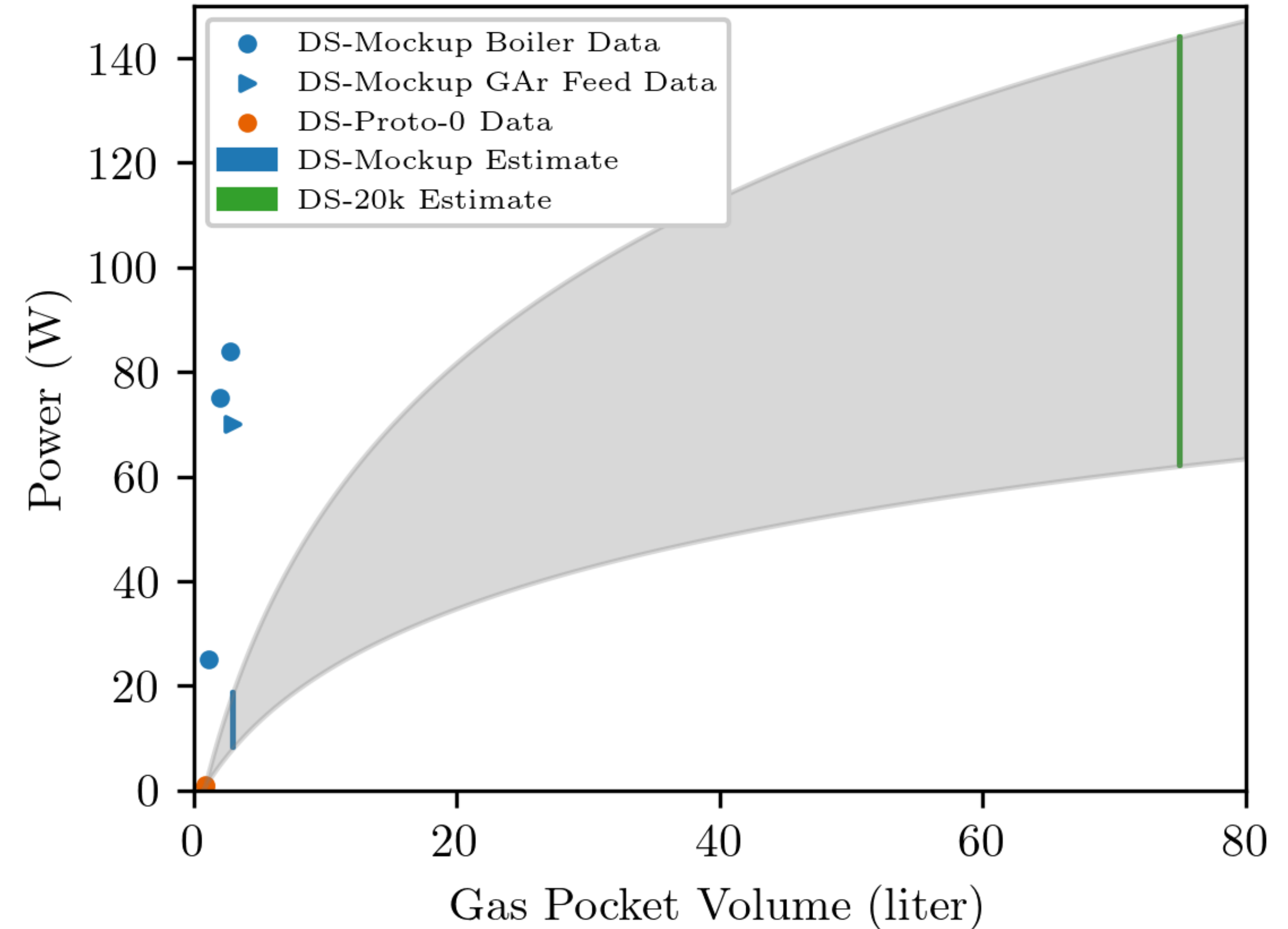
Gas Pocket Formation Test

- Multiple attempts in different configurations were performed
- Gas bubble was created but:
 - SLM failed to measure the liquid displacement.
 - Power to generate and maintain the gas pocket is multiple times higher than expected



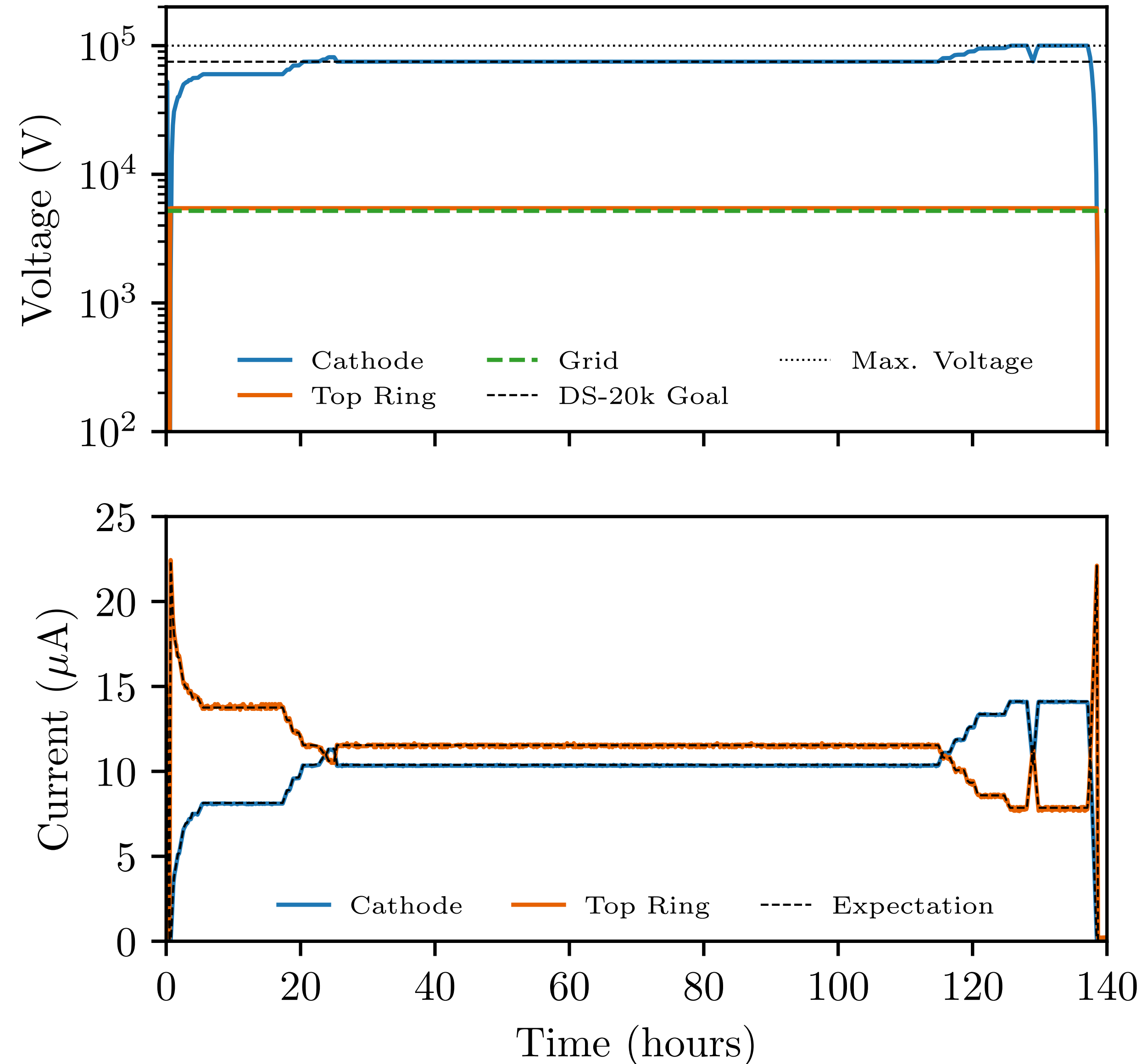
Gas Pocket Formation Test

- Possible explanation:
 - Imperfect seal between PTFE connections and PMMA
- Leaks made the measurement difficult:
 - Standalone gas pocket test using DS-20k-like fittings for sealing is underway (PMMA press-fit)



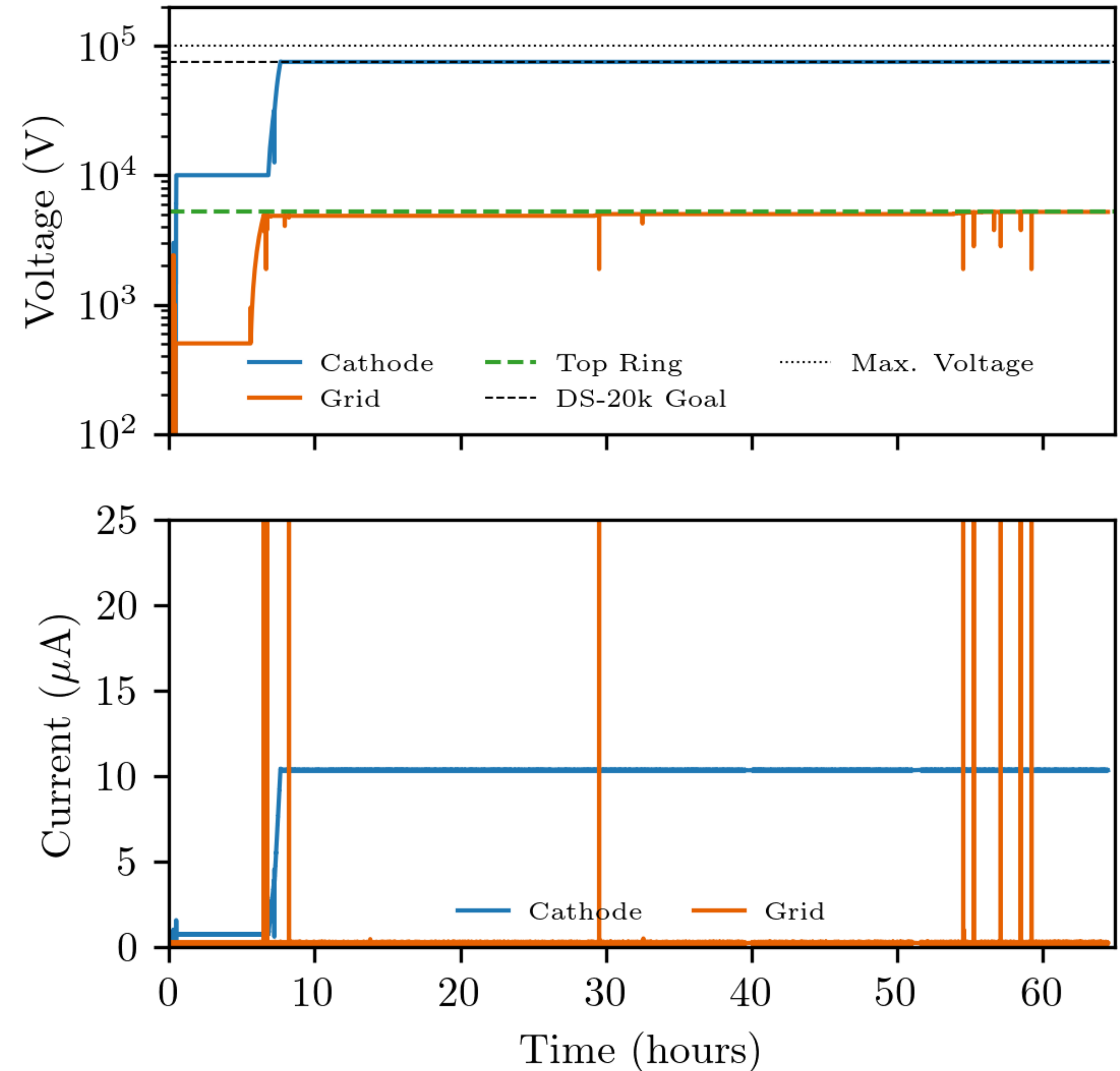
High Voltage Test - Single Phase

- Successful automated high voltage ramp up of **100 V/10 s** performed.
- The current draw from both cathode and top ring power supplies match the model.
- Successfully delivered up to **−100 kV** to the cathode (stress test).
- Additional test with Ar purity control and increased long term stability are underway.



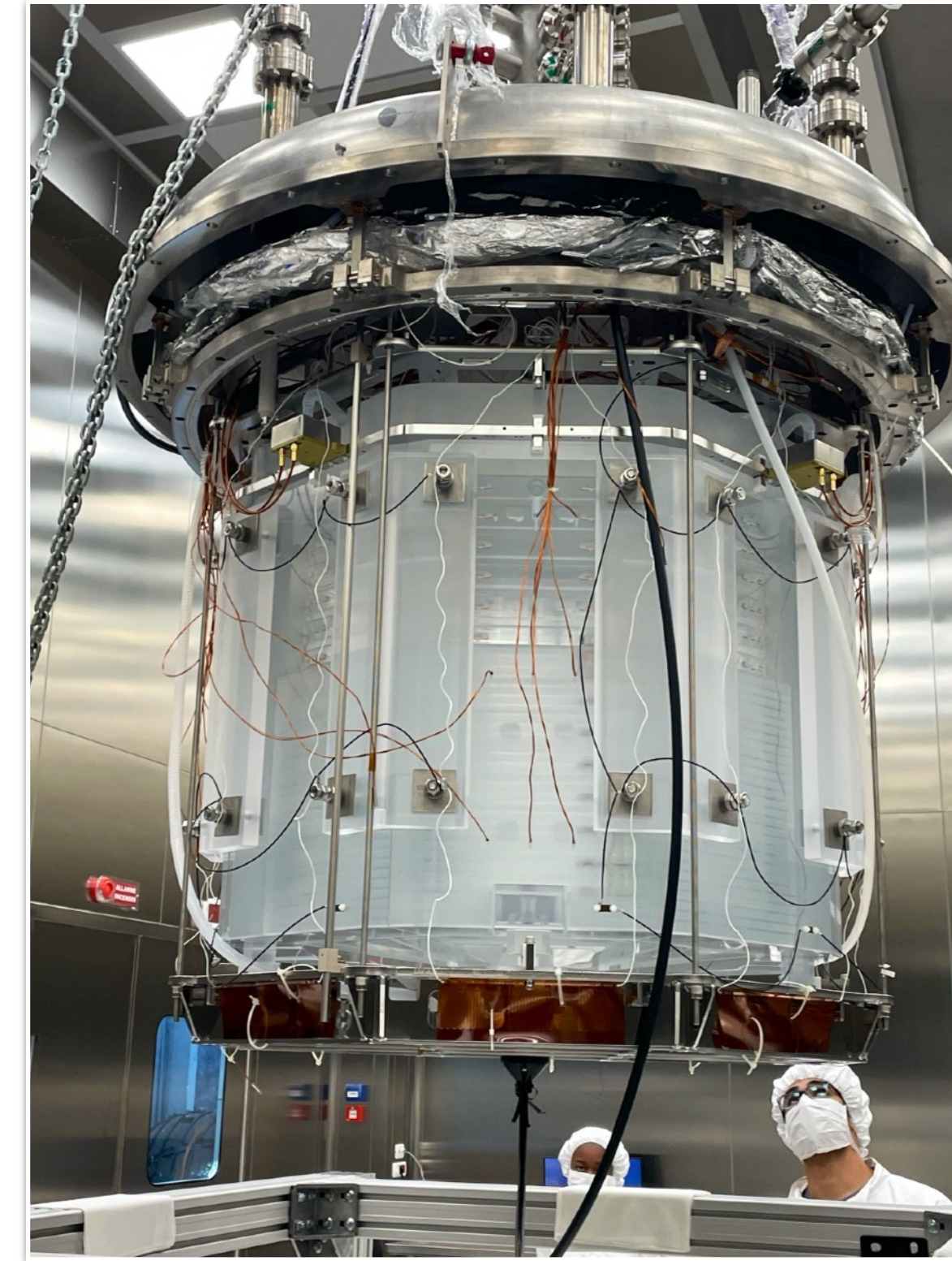
High Voltage Test - Dual Phase

- HV test performed with a gas pocket.
- Instabilities were observed in the grid HV
- Likely due to:
 - Gas pocket instability (leaks)
 - Slightly out-of-spec tension of a few grid wires (different design for DS-20k will prevent this with a spring loaded mechanism)
- HV recovers quickly after ~10s



Post-Run Inspection

- Custom HV cable undamaged after thermal cycling and HV operations
- Clevios coatings are intact and resistivity consistent with previous measurement
- Leak hypothesis “confirmed” through tests with compressed air on the SLMs connections.
- PMMA remained undamaged, implying that a proper cool-down procedure was performed.



DS-Mockup TPC campaigning summary

- **Major outcome:** Successfully built, assembled, and ran a tonne-scale octagonal PMMA TPC
- Performed a reliable and safe thermal cycling of PMMA TPC.
- Barrel Alignment: flatness within 100um is achievable and the procedure scalable for DS-20k
- Gas Pocket: higher than expected generation power
- High Voltage: DS-20k Cathode nominal voltage achieved (-75kV)



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Thanks!



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LIDINE 21/10/25

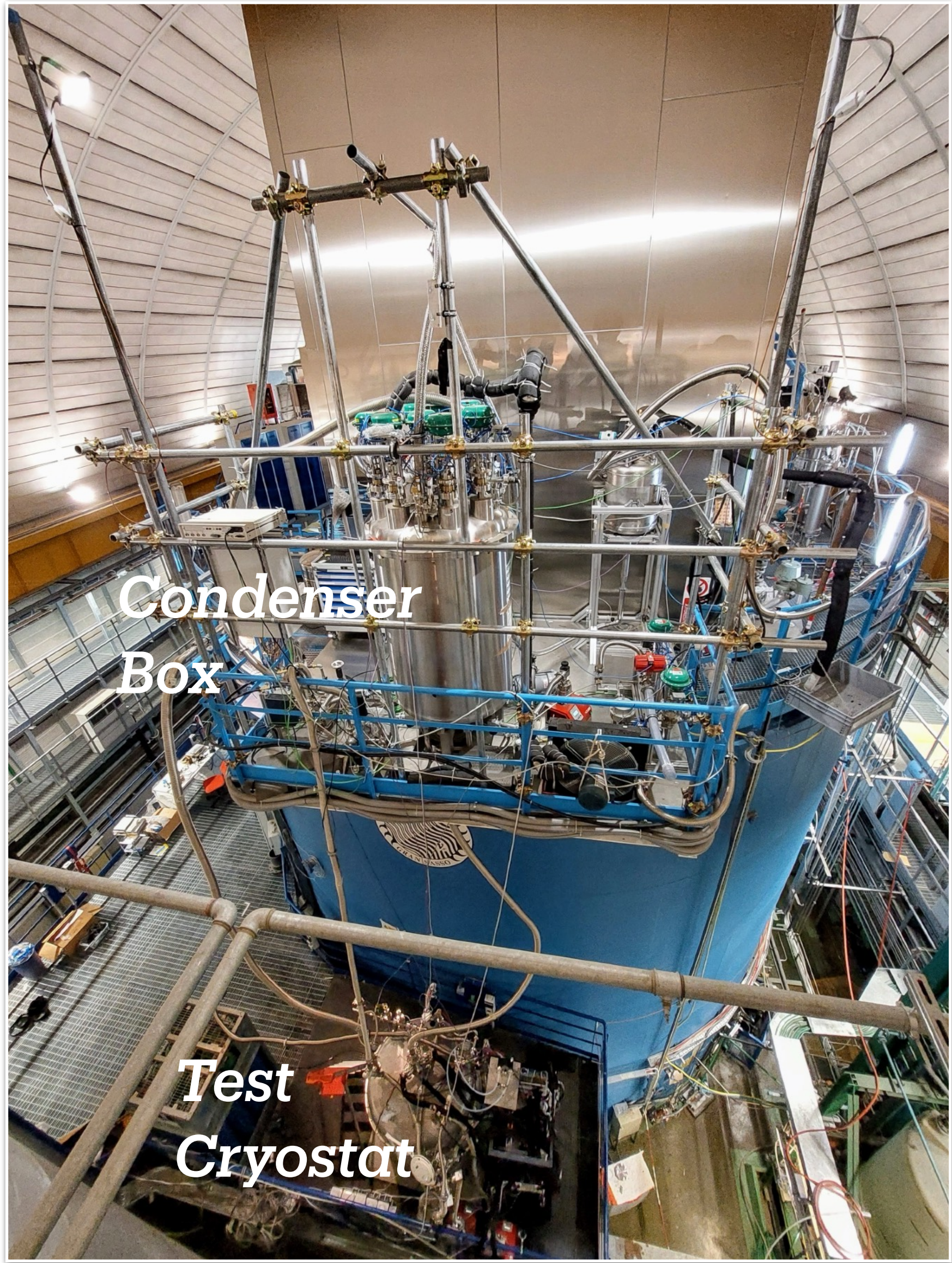


Backup



Paolo Salomone
for the GADMC
LIDINE 21/10/25

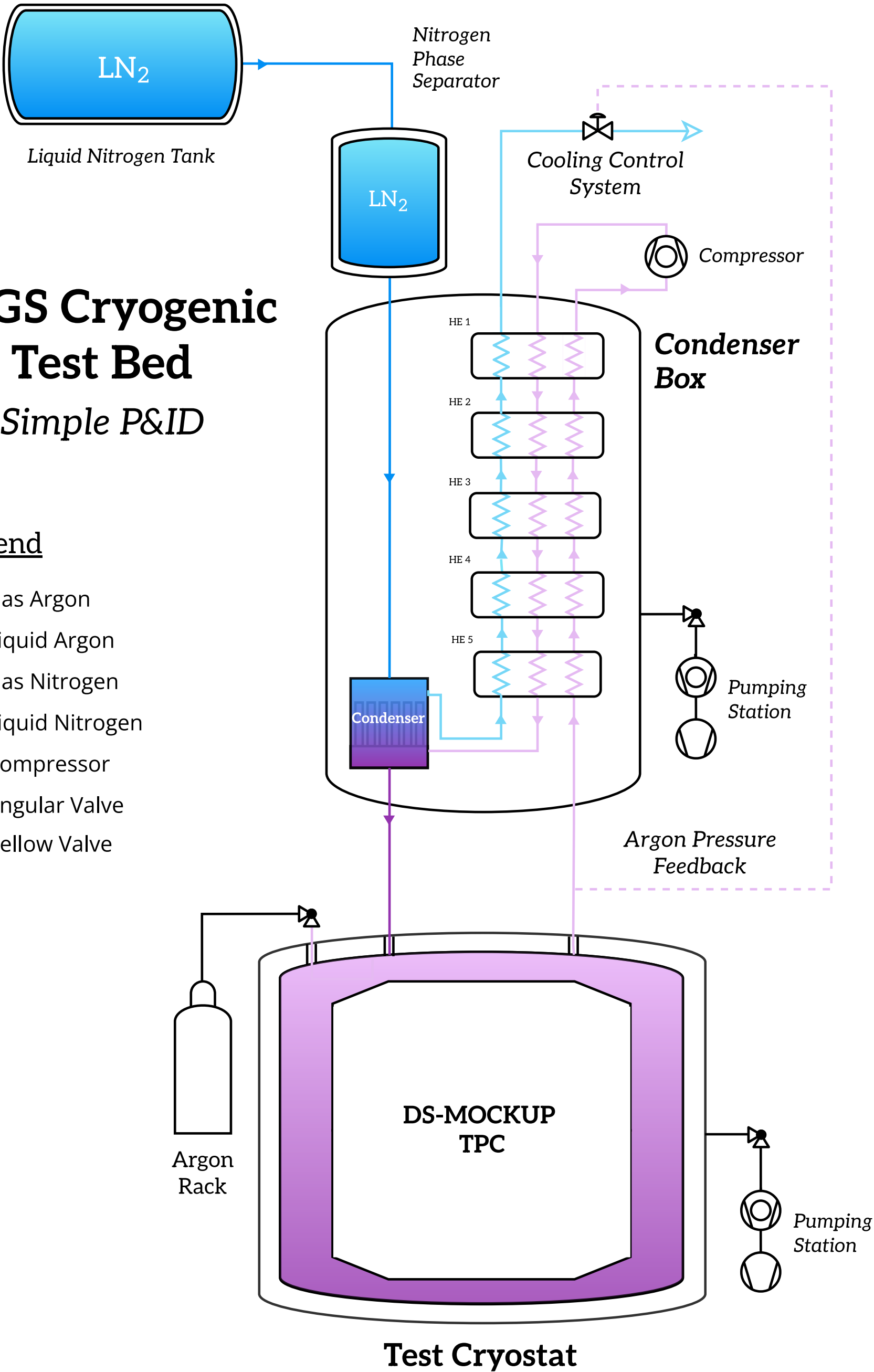
LNGS Test Bed



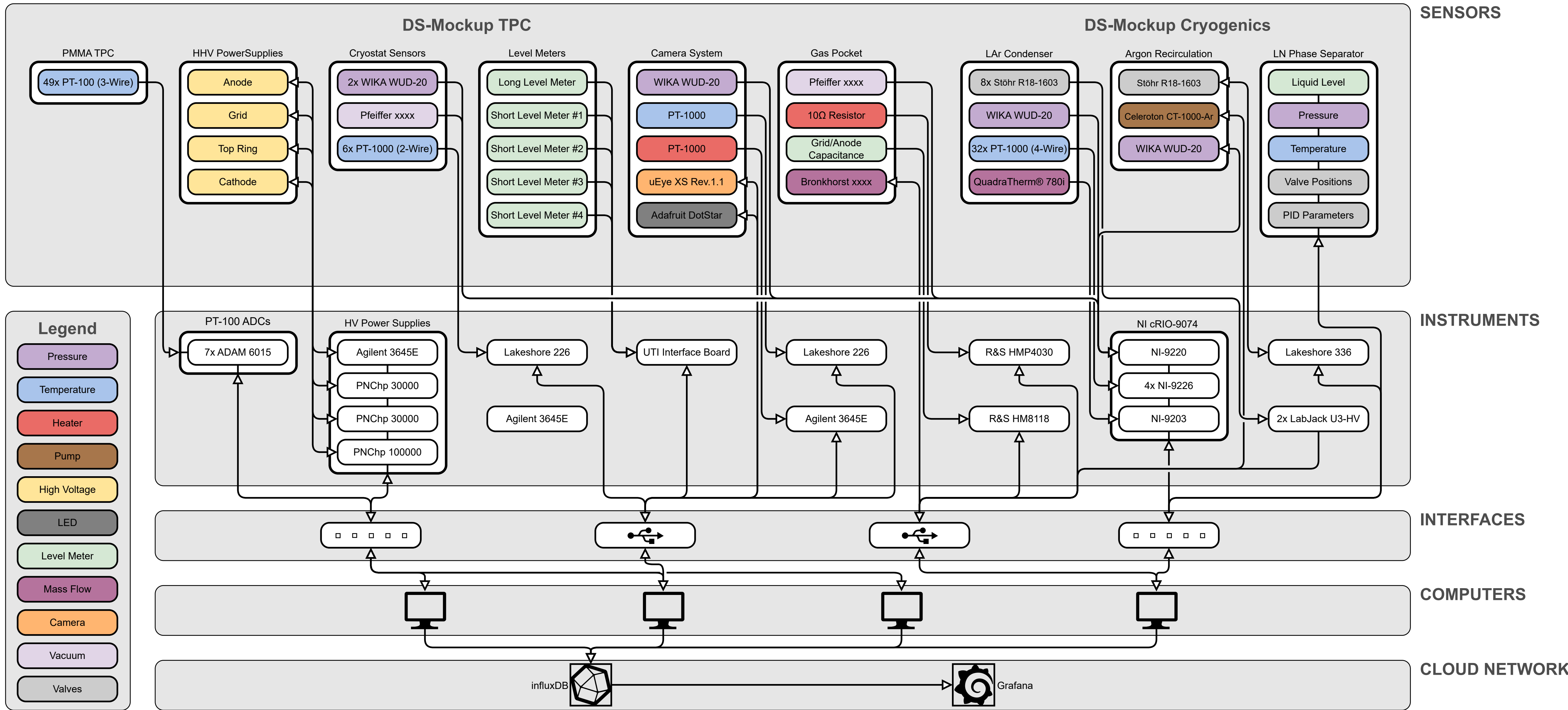
LNGS Cryogenic Test Bed Simple P&ID

Legend

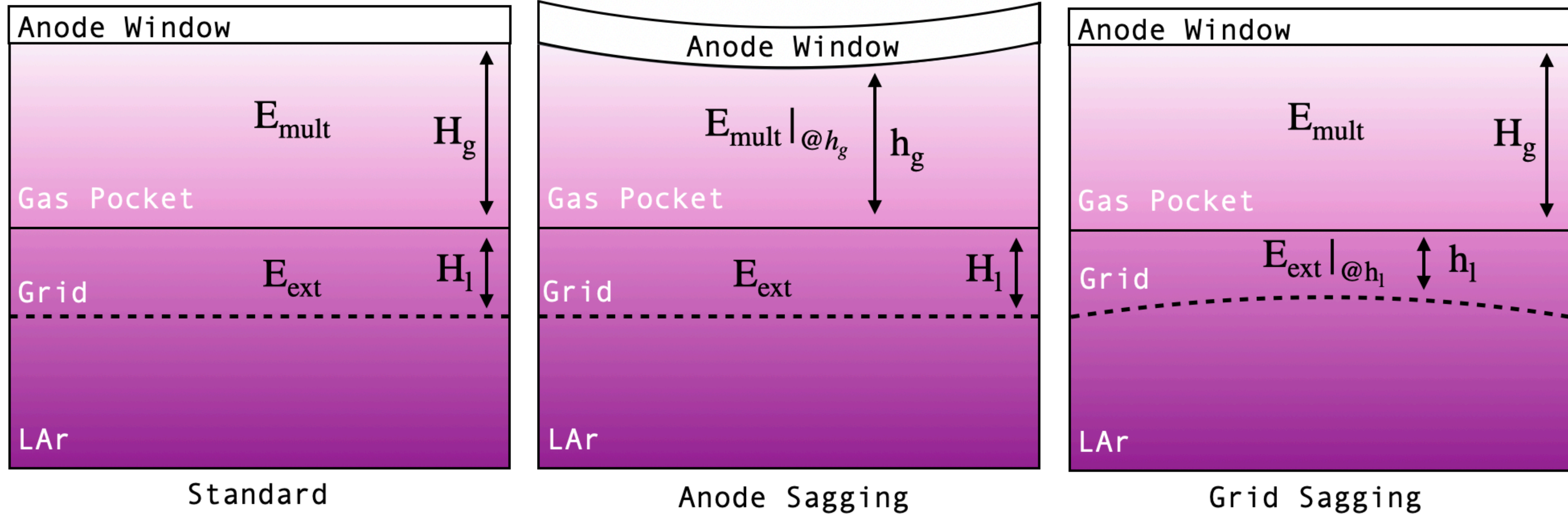
- Gas Argon
- Liquid Argon
- Gas Nitrogen
- Liquid Nitrogen
- Compressor
- Angular Valve
- Bellow Valve



LNGS Test Bed



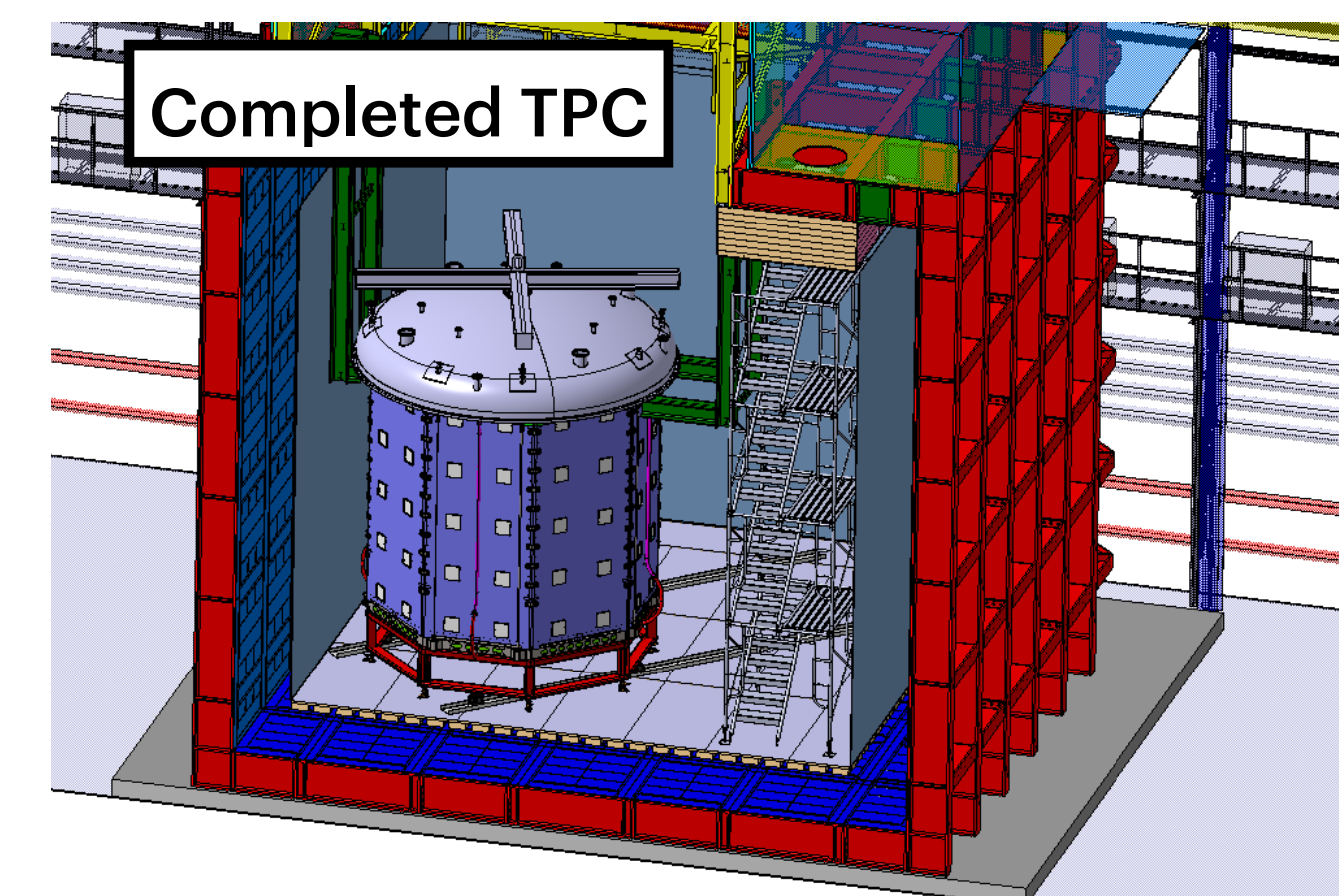
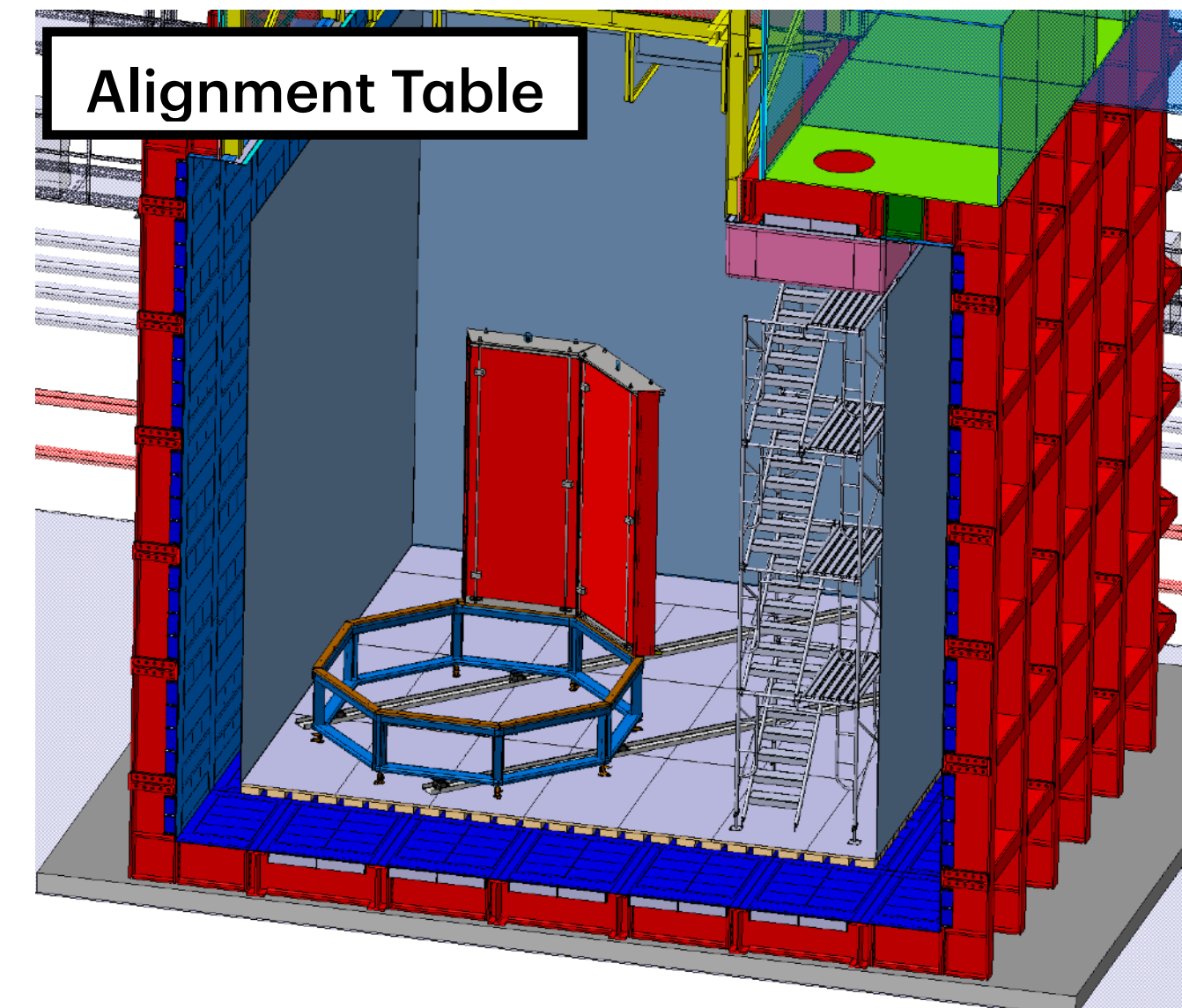
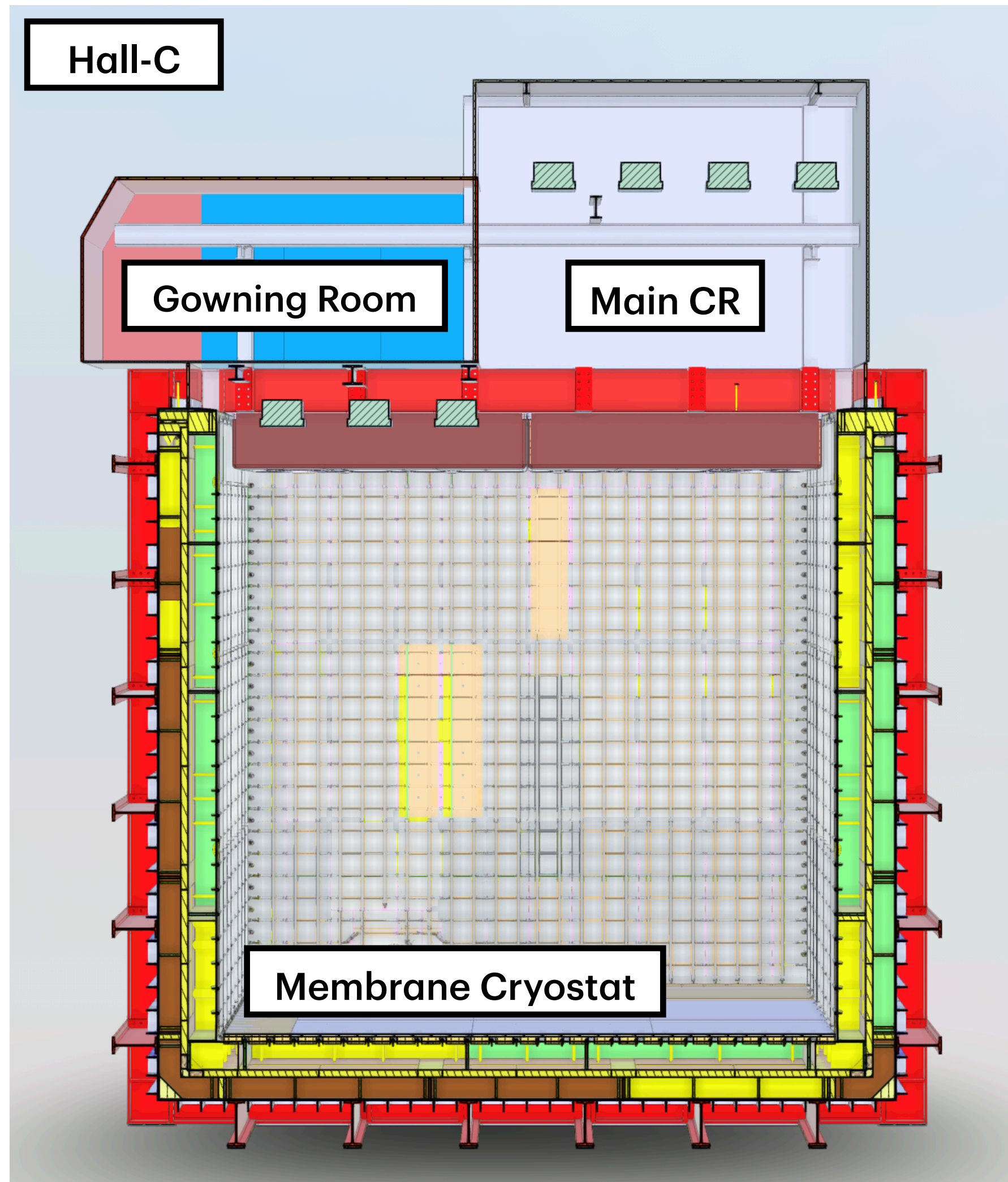
Gas Pocket Uniformity Impact on S2



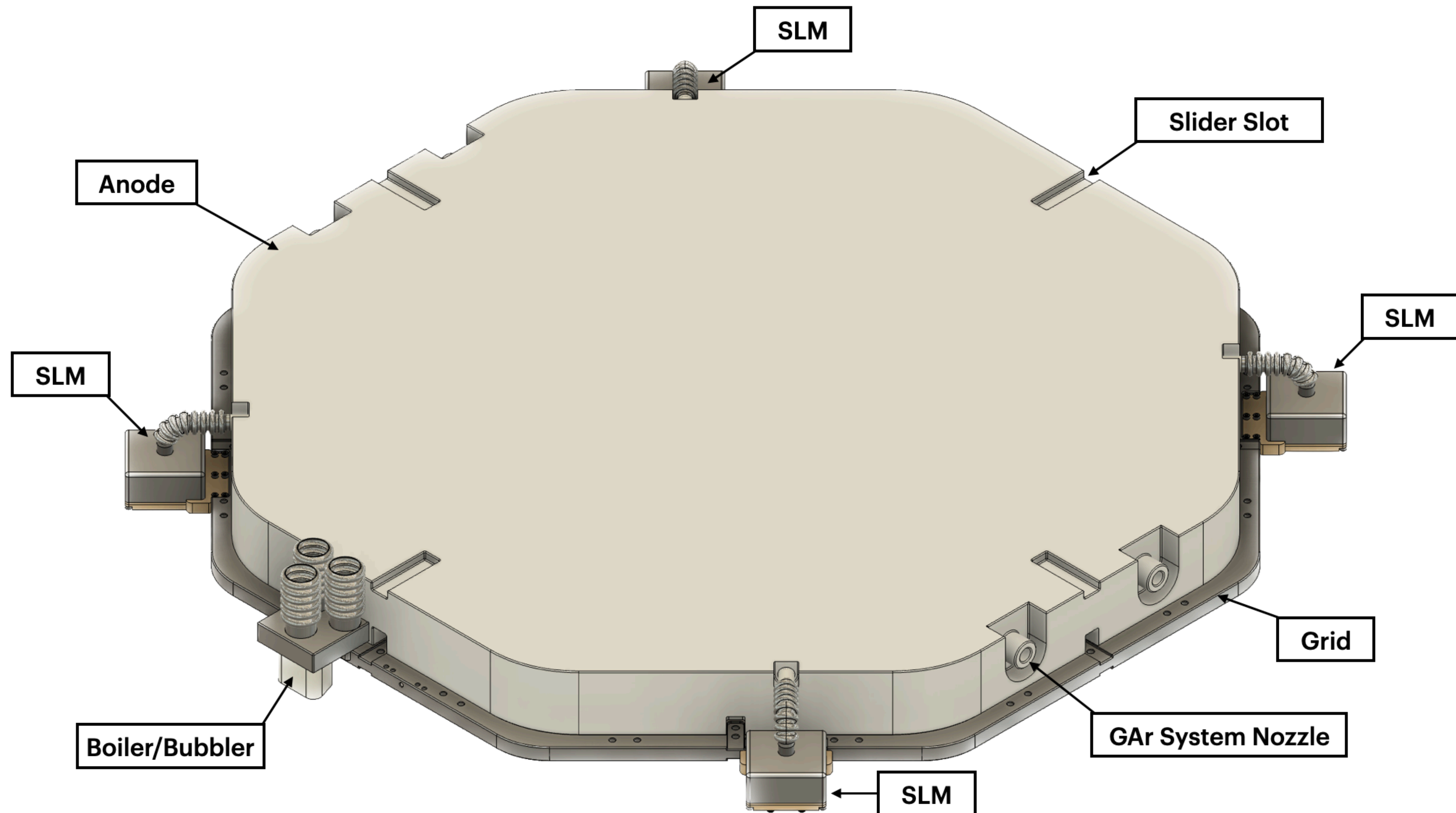
$$E_{\text{mult}} = \frac{\epsilon_{\text{rel}} \cdot \Delta V}{\epsilon_{\text{rel}} \cdot h_g + h_l}$$

$$N_{\text{ph/e}^-} = \left(\frac{A \cdot E_{\text{mult}}}{P} - B \right) \cdot P \cdot h_g$$

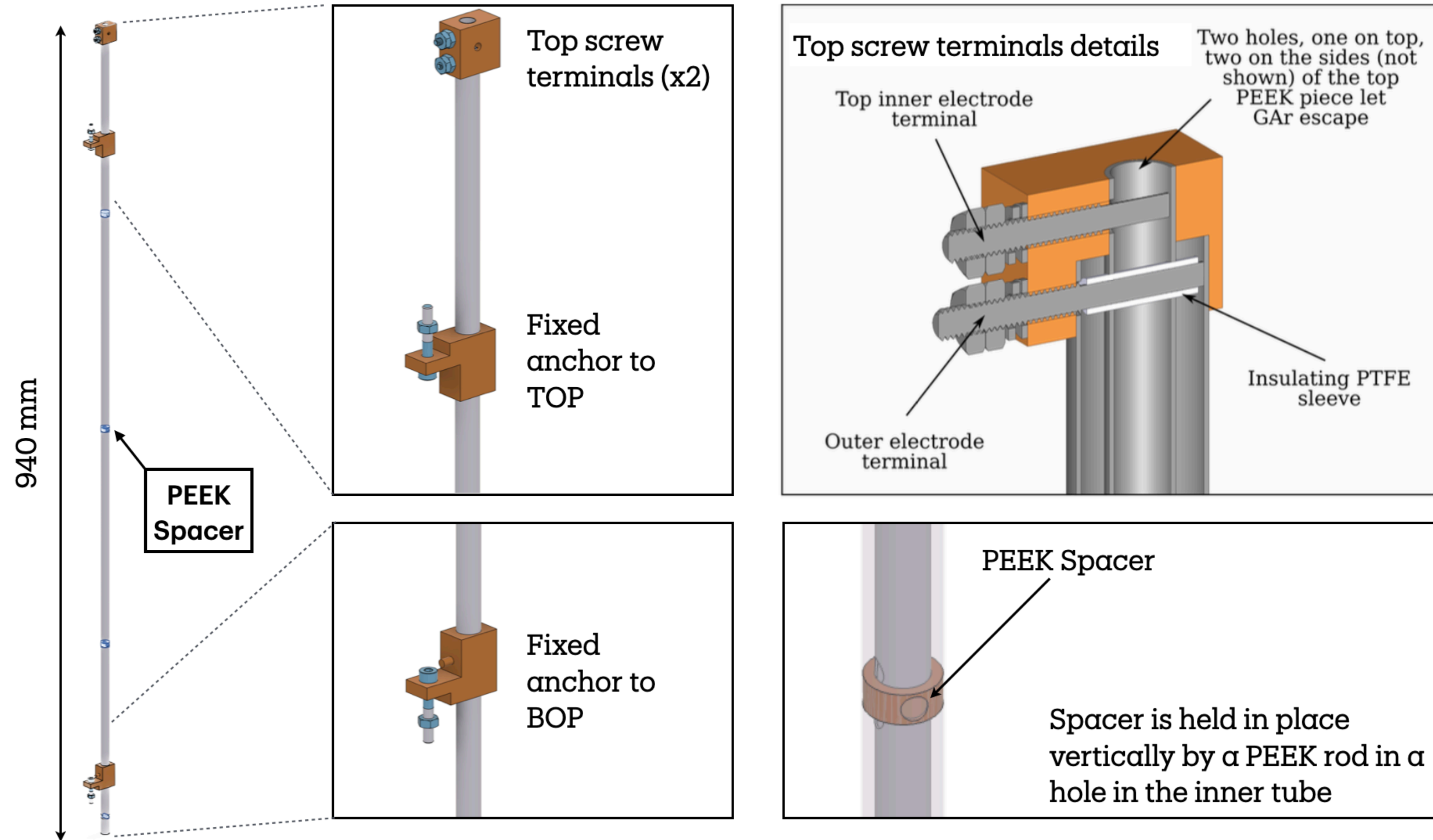
DarkSide-20k Assembly



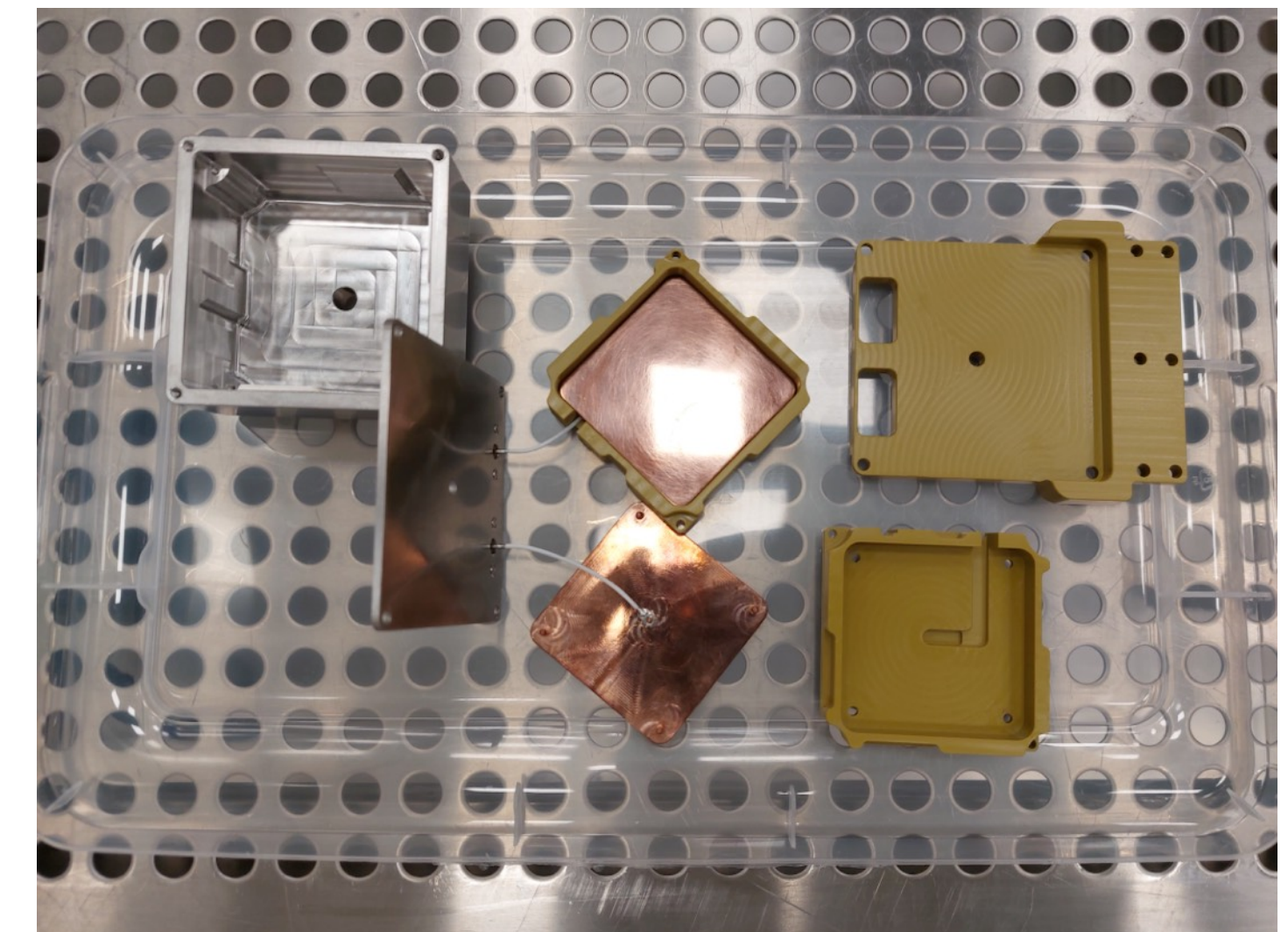
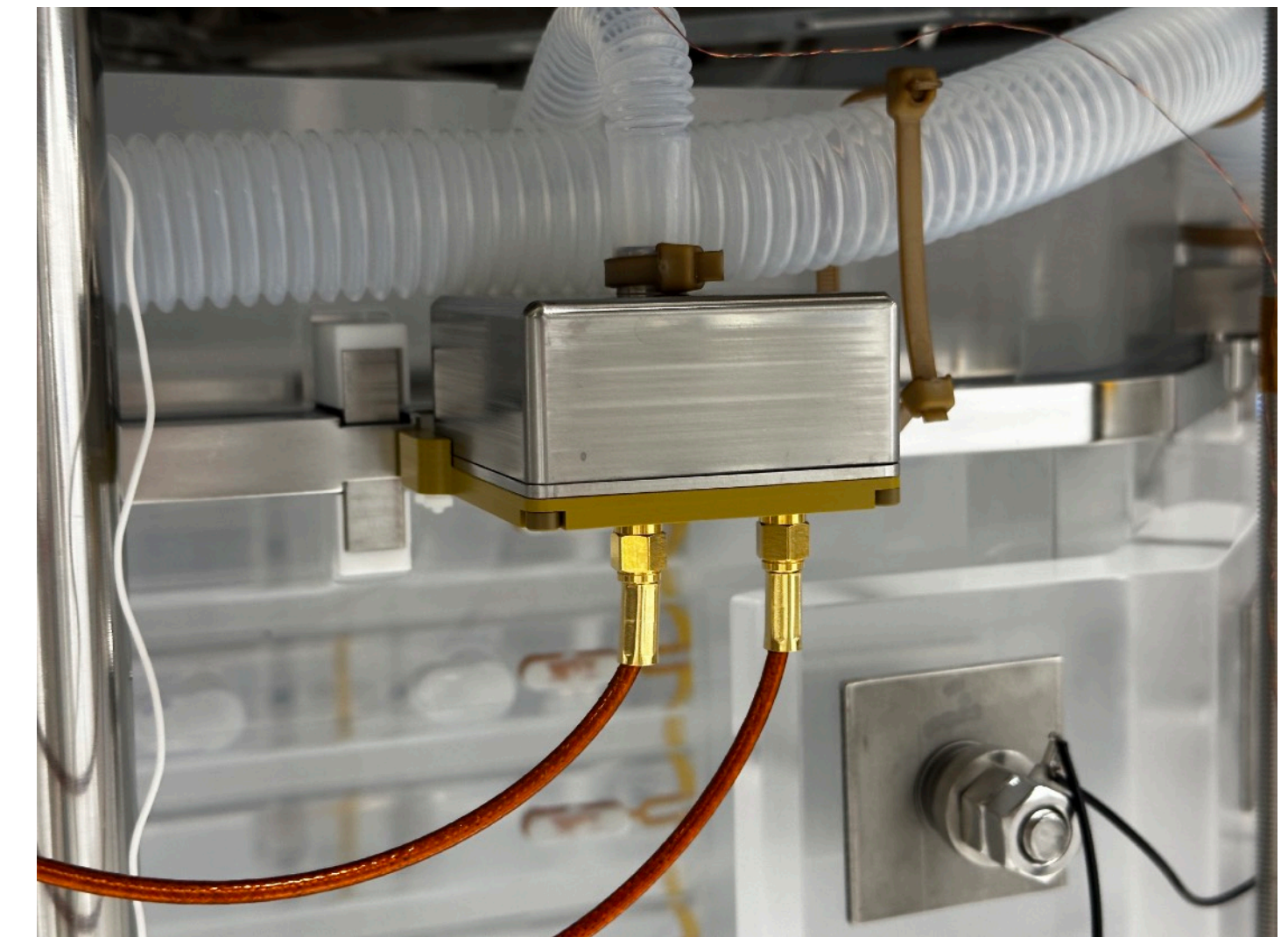
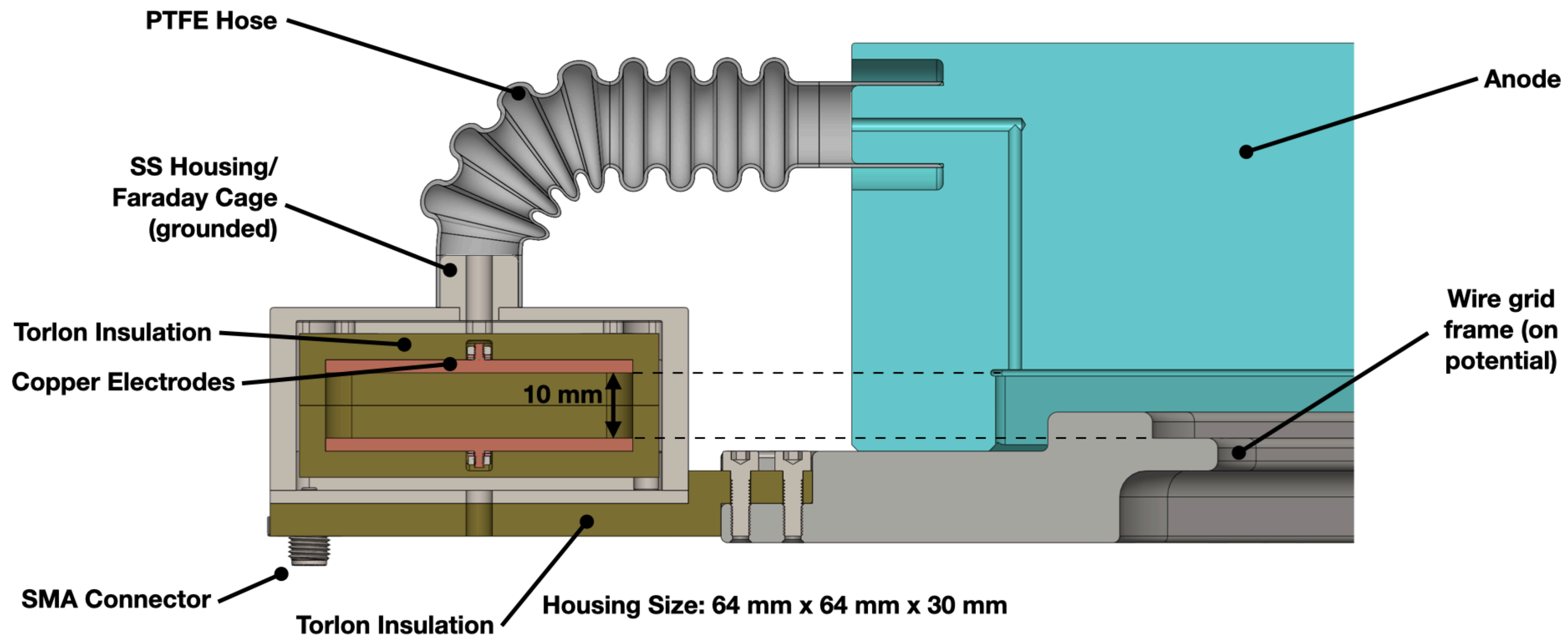
DS-Mockup Gas Pocket System



Liquid Level Sensors: LLM



Liquid Level Sensors: SLM



DS-Mockup Gas Pocket Formation

