

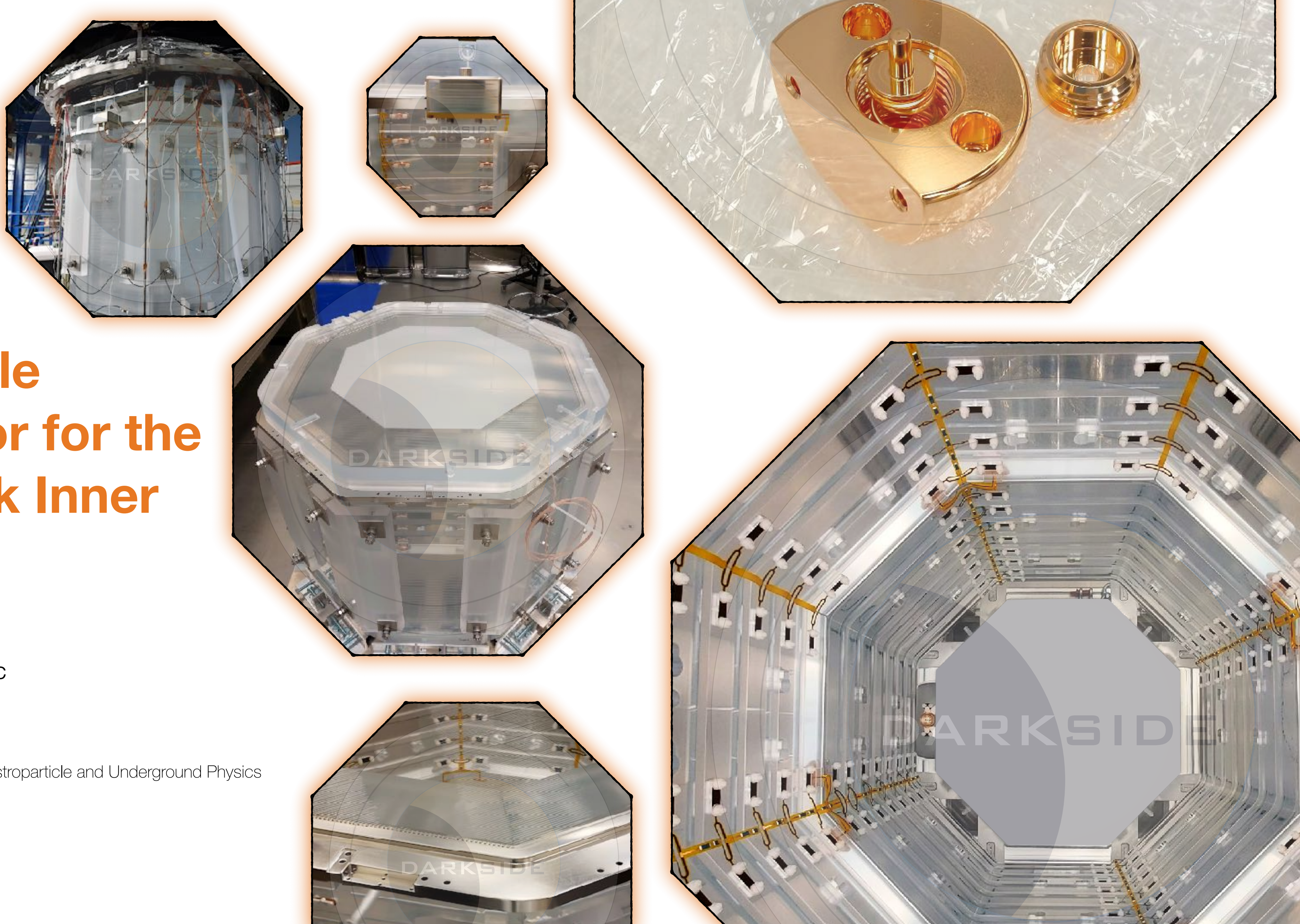
A Tonne-Scale Demonstrator for the DarkSide-20k Inner Detector

Ako Jamil on behalf of the GADMC
Princeton University

August 28, 2025

XIX International Conference on Topics in Astroparticle and Underground Physics

Xichang, China



Other Darkside-20k Talks at TAUP 2025

The DarkSide-20k Experiment at LNGS Status and Goals

Monday, August 25

Walter Bonivento

<https://indico-cdex.ep.tsinghua.edu.cn/event/175/contributions/2328/>

Searches for Light Dark Matter with DarkSide-20k and DarkSide-LowMass

Wednesday, August 27

Masayuki Wada

<https://indico-cdex.ep.tsinghua.edu.cn/event/175/contributions/2332/>

Characterization of argon recoils at the keV scale with ReD and ReD+

Thursday, August 28

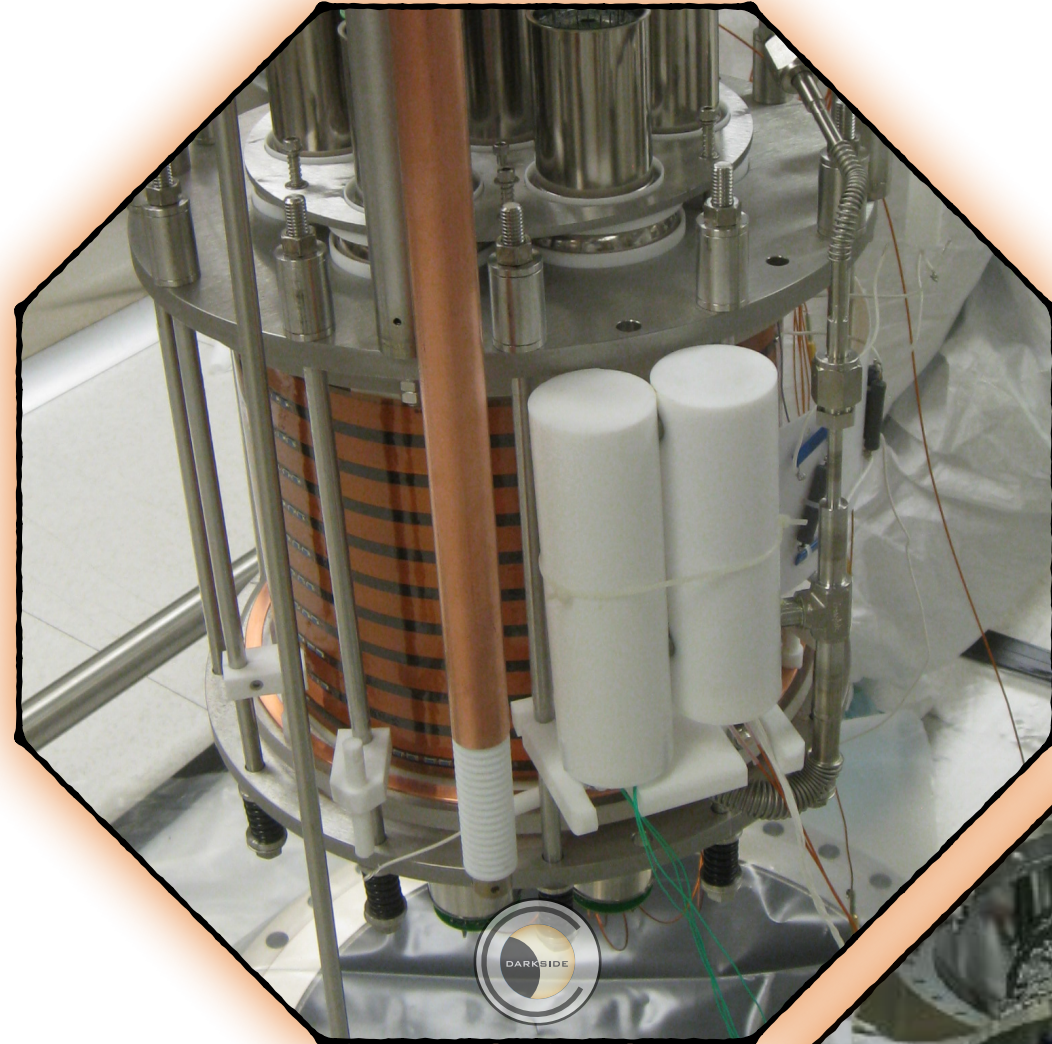
Luciano Pandola

<https://indico-cdex.ep.tsinghua.edu.cn/event/175/contributions/2327/>

The DarkSide Program

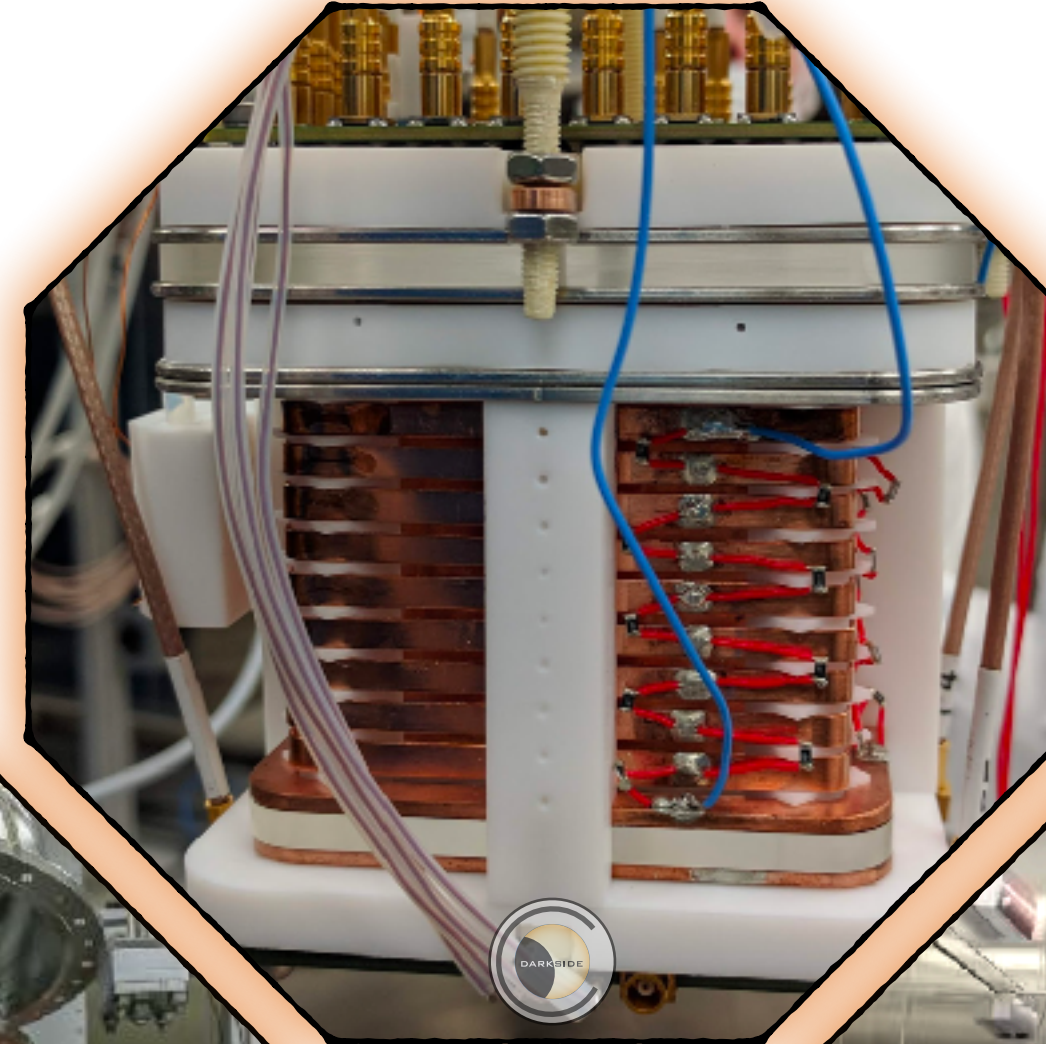
DS-10

2010



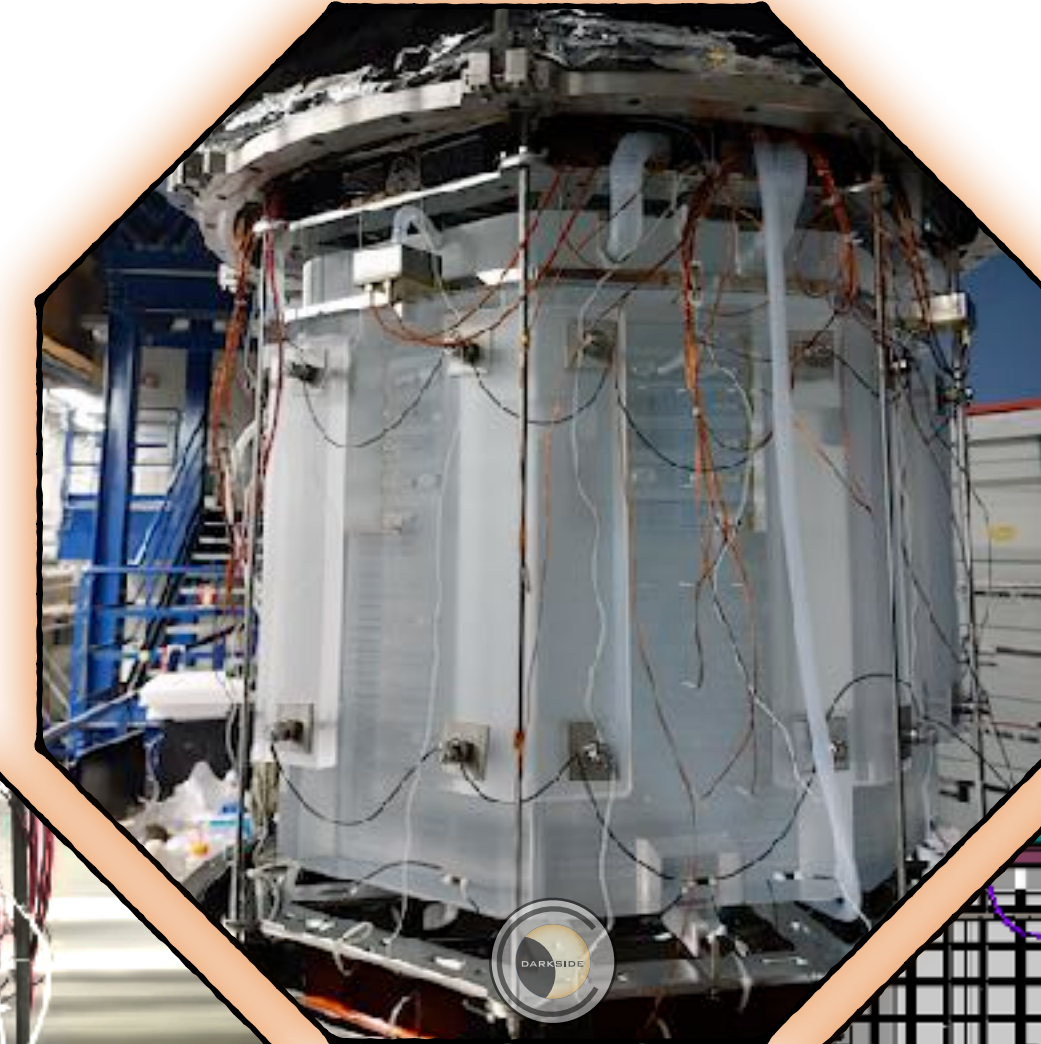
DS-ReD

2024-2025



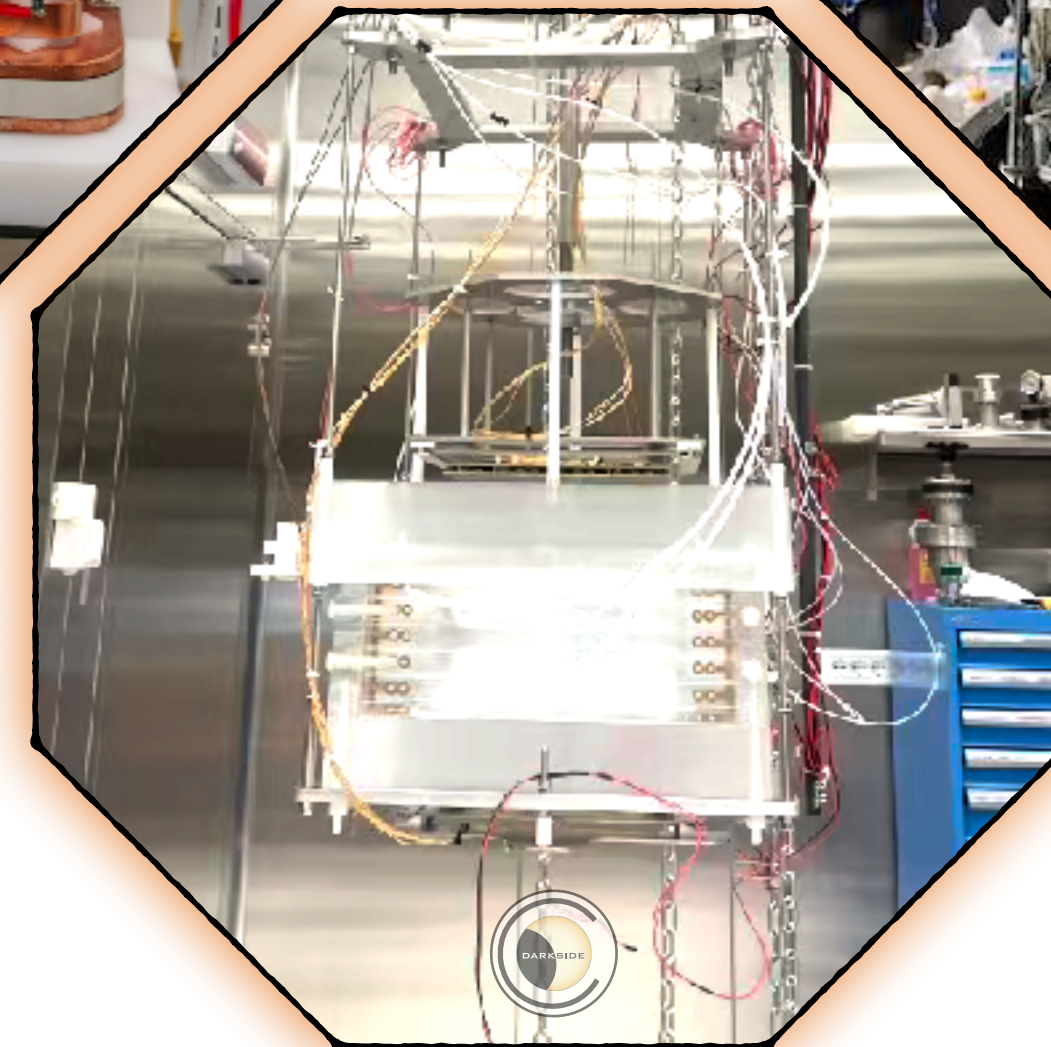
DS-Mockup

2025



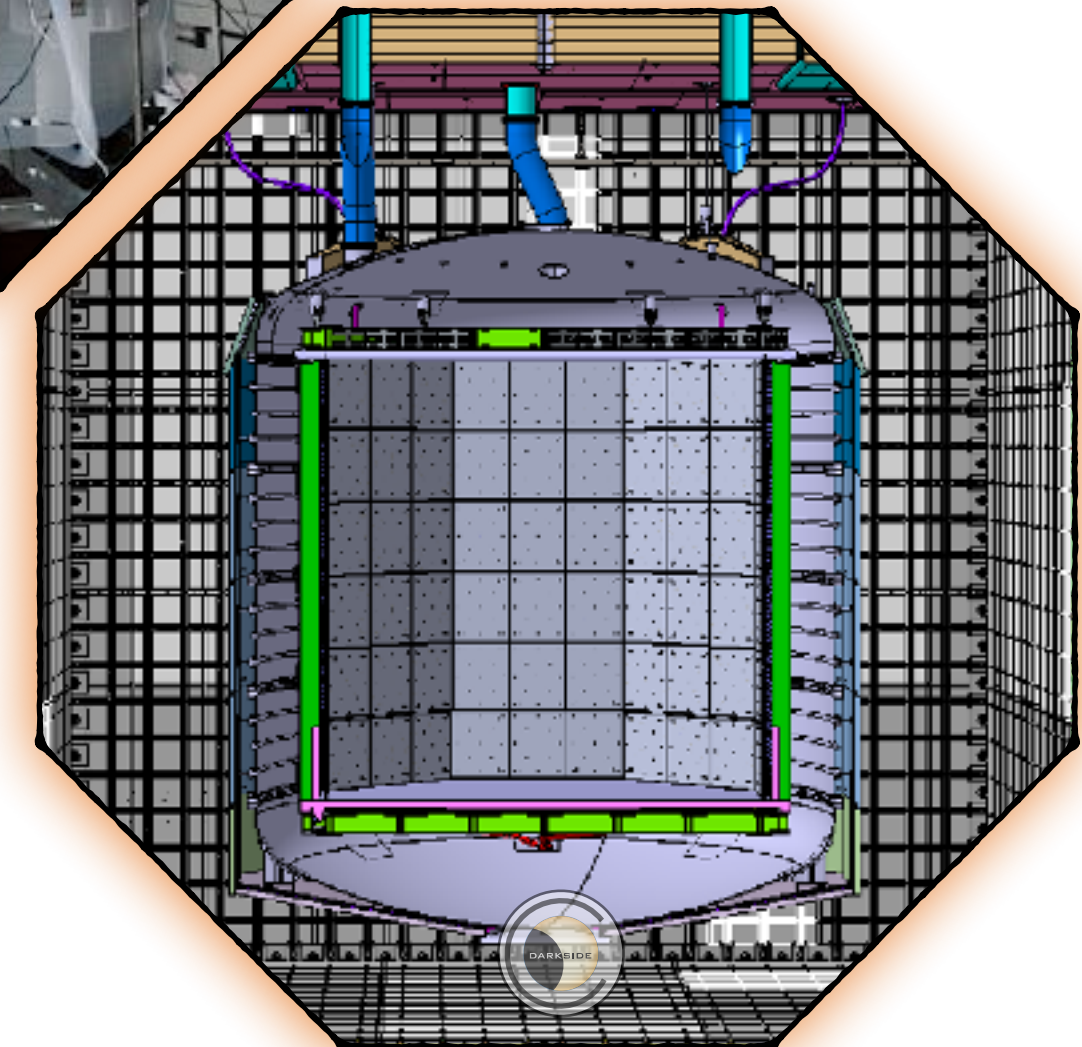
DS-50

2013-2020



DS-Proto-0

2024-2025



DS-20k

2027-

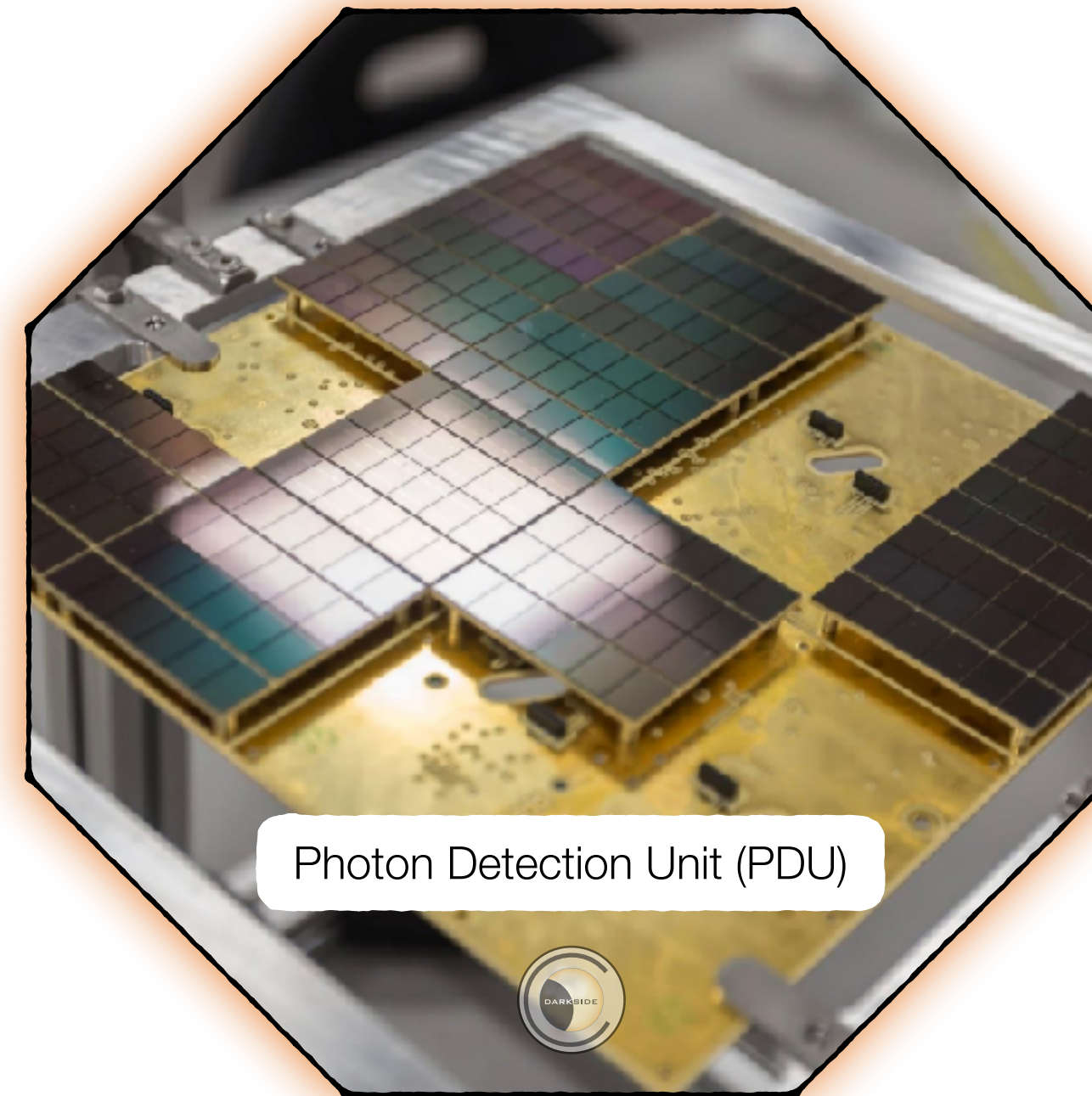
Key Technologies for DarkSide-20k

Underground Argon (UAr)



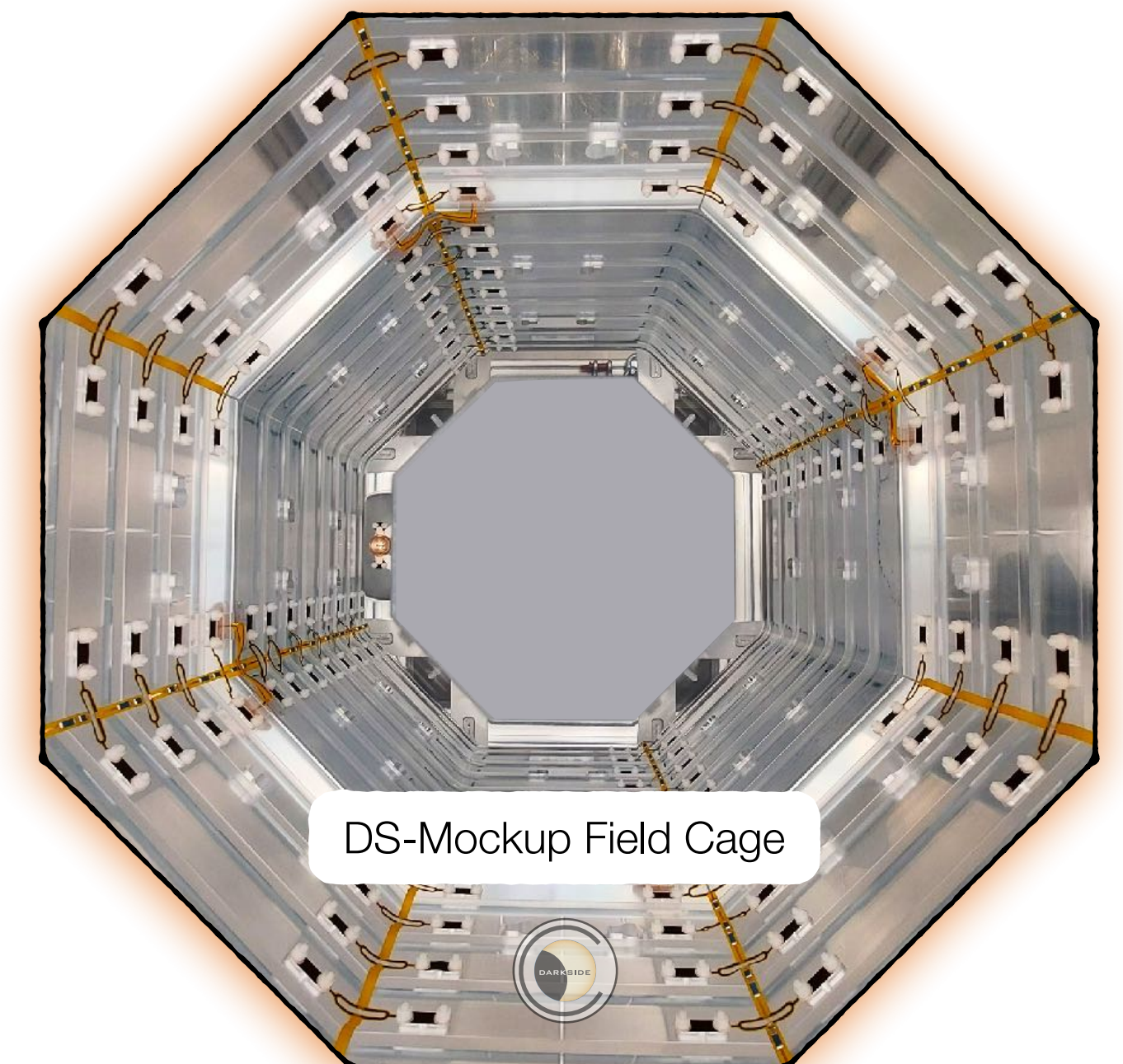
A detector medium with a reduction factor of ~ 1400 in ^{39}Ar compared to atmospheric argon

Silicon Photomultiplier (SiPM)



Large-area ($\sim 25 \text{ m}^2$), low-noise, low-radioactivity SiPM arrays

PMMA TPC



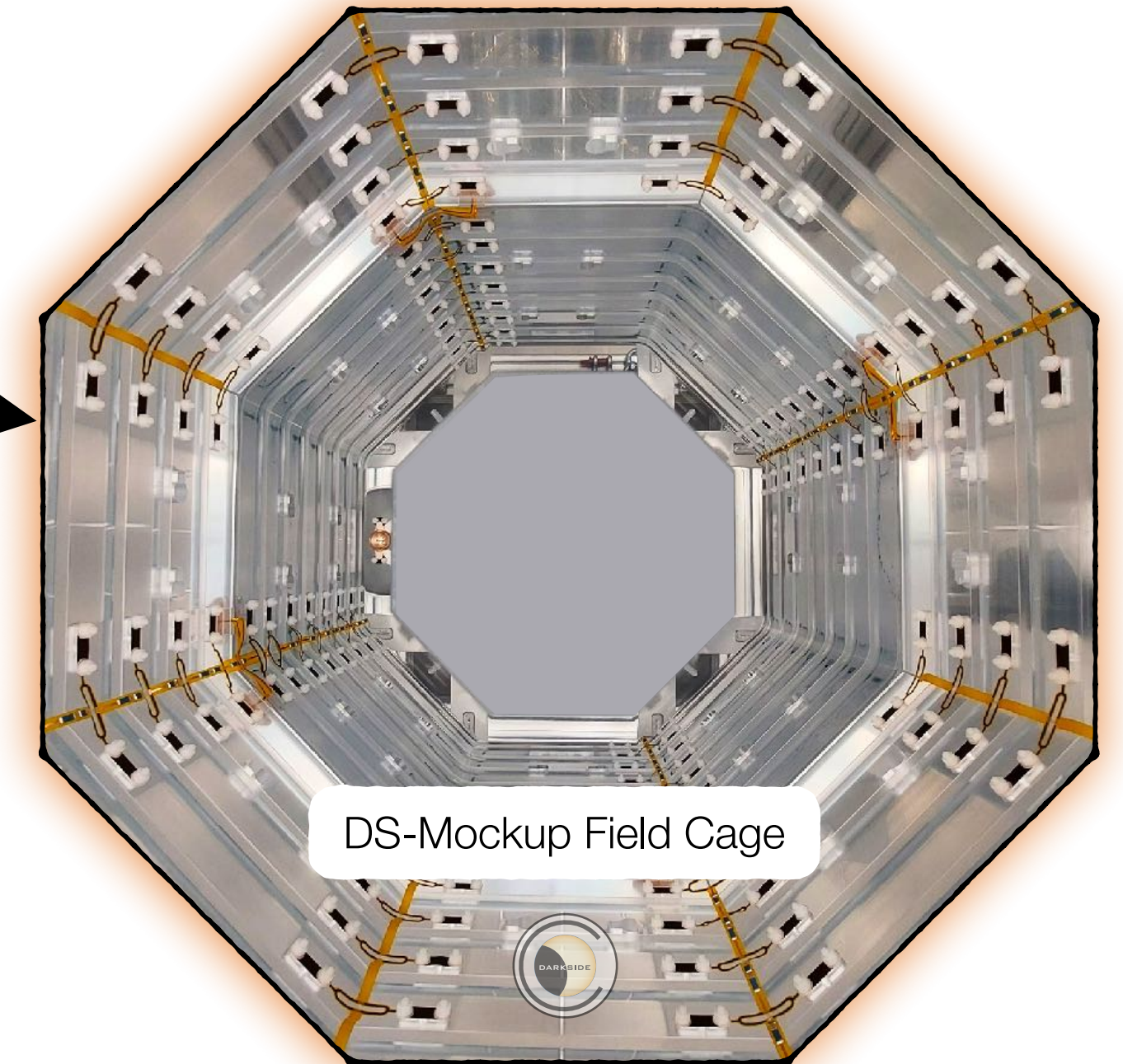
Transparent low-radioactivity **PMMA TPC** with conductive **Clevios™**-coated surfaces as electrodes

Key Technologies for DarkSide-20k

This Talk

- Assembly of a tonne-scale PMMA TPC (aka DS-Mockup)
- Thermal cycling of rigid octagonal PMMA TPC
- High voltage delivery and performance
- Gas pocket generation

PMMA TPC



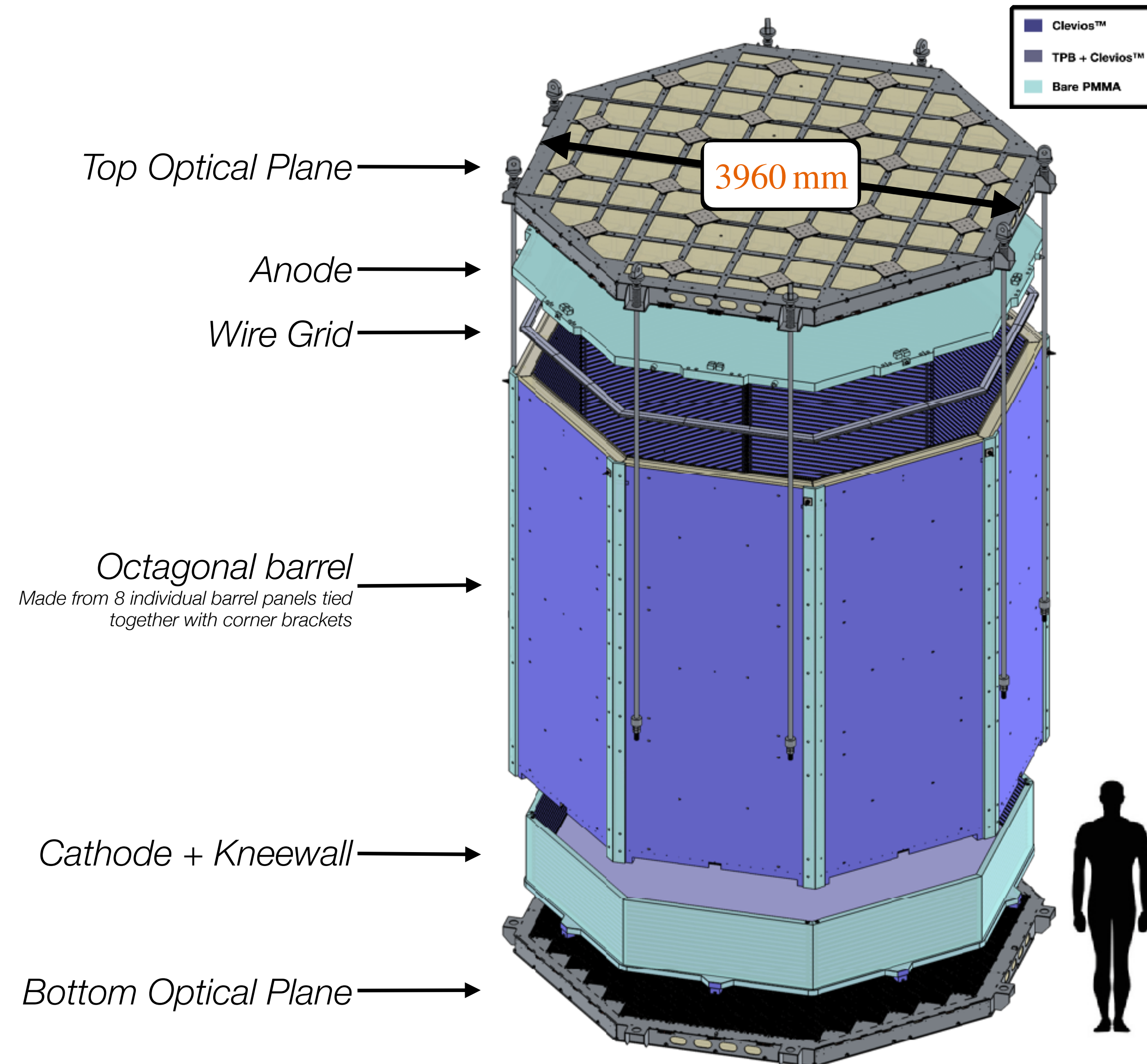
DS-Mockup Field Cage

Transparent low-radioactivity **PMMA TPC**
with conductive **Clevios™**-coated
surfaces as electrodes

The DarkSide-20k Inner Detector

- Octagonal vessel made from ultra-pure PMMA
 - Operated as a dual-phase time projection chamber (TPC) filled with **low radioactivity underground argon**
 - Active (fiducial) mass of **49.7 t (20.2 t)**
 - Drift length of **3480 mm**
- Two optical planes with 528 light readout channels each (total of **20 m²** of light sensors + **5 m²** in inner veto)
- Light wavelength-shifted via TPB from **128 nm** to **420 nm**
- Visible light reflected by foils of Enhanced Specular Reflector (ESR)
- Drift field of **200 V/cm** ($V_{\text{Cathode}} \approx -75 \text{ kV}$)

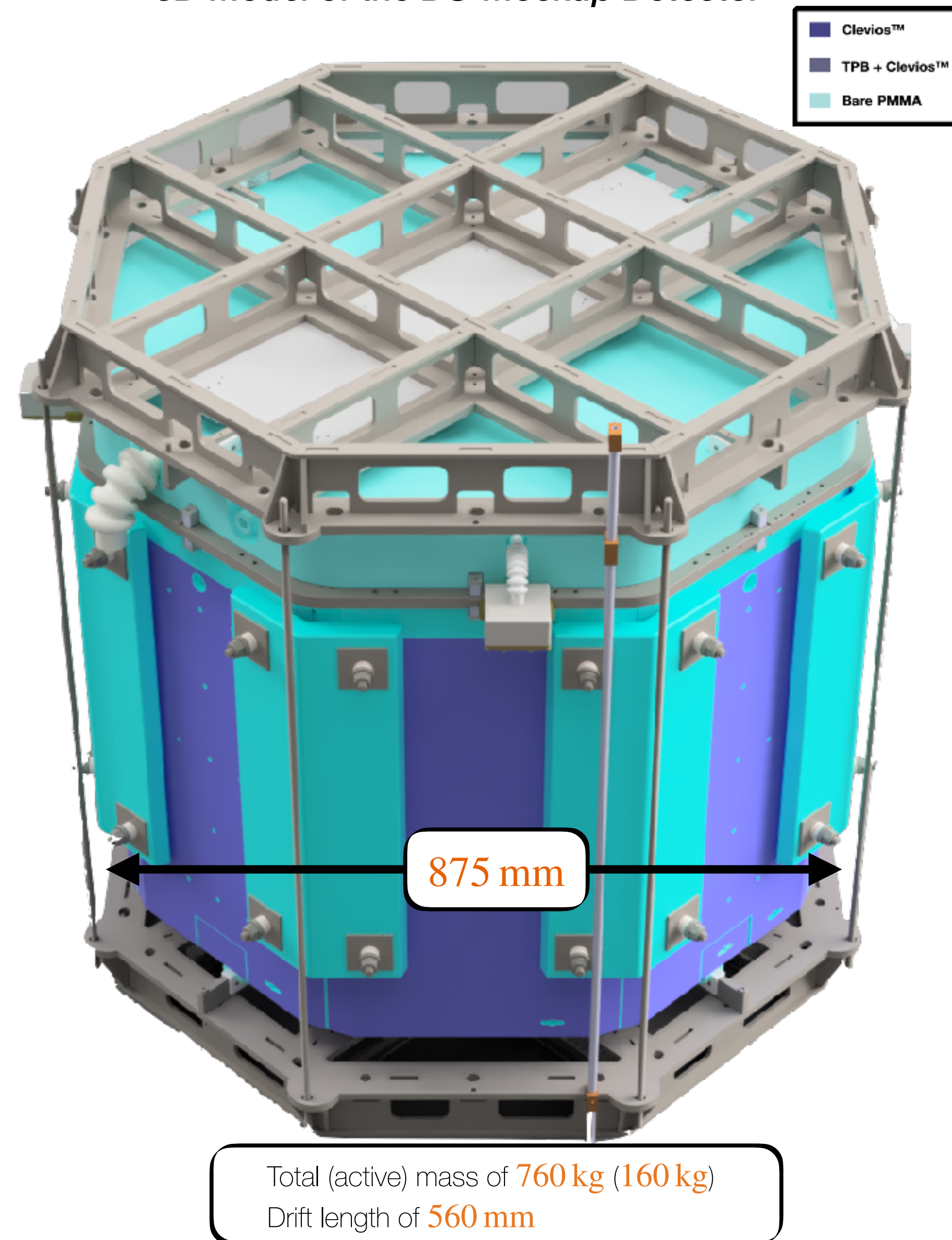
Exploded View of DS-20k Inner Detector 3D Model



DS-Mockup Objectives

- Integration exercise at the tonne-scale
- PMMA barrel assembly and flatness of the top surface to within $\sim 100\ \mu\text{m}$
 - ➔ g_2 non-uniformity
 - ➔ light readout saturation
- Thermal cycling of PMMA TPC
 - ➔ Cooldown time
- High-voltage (HV) delivery up to and beyond the nominal cathode voltage of $V_C \sim -75\ \text{kV}$
 - ➔ Drift field
 - ➔ Pile-up
 - ➔ S1-S2 identification
- Electrostatic stability with conductive **CleviosTM** coatings in LAr
 - ➔ Electric field non-uniformity
 - ➔ Fiducialization
- Power requirements for gas pocket generation
 - ➔ Cooling power
 - ➔ Proper sizing of generation method

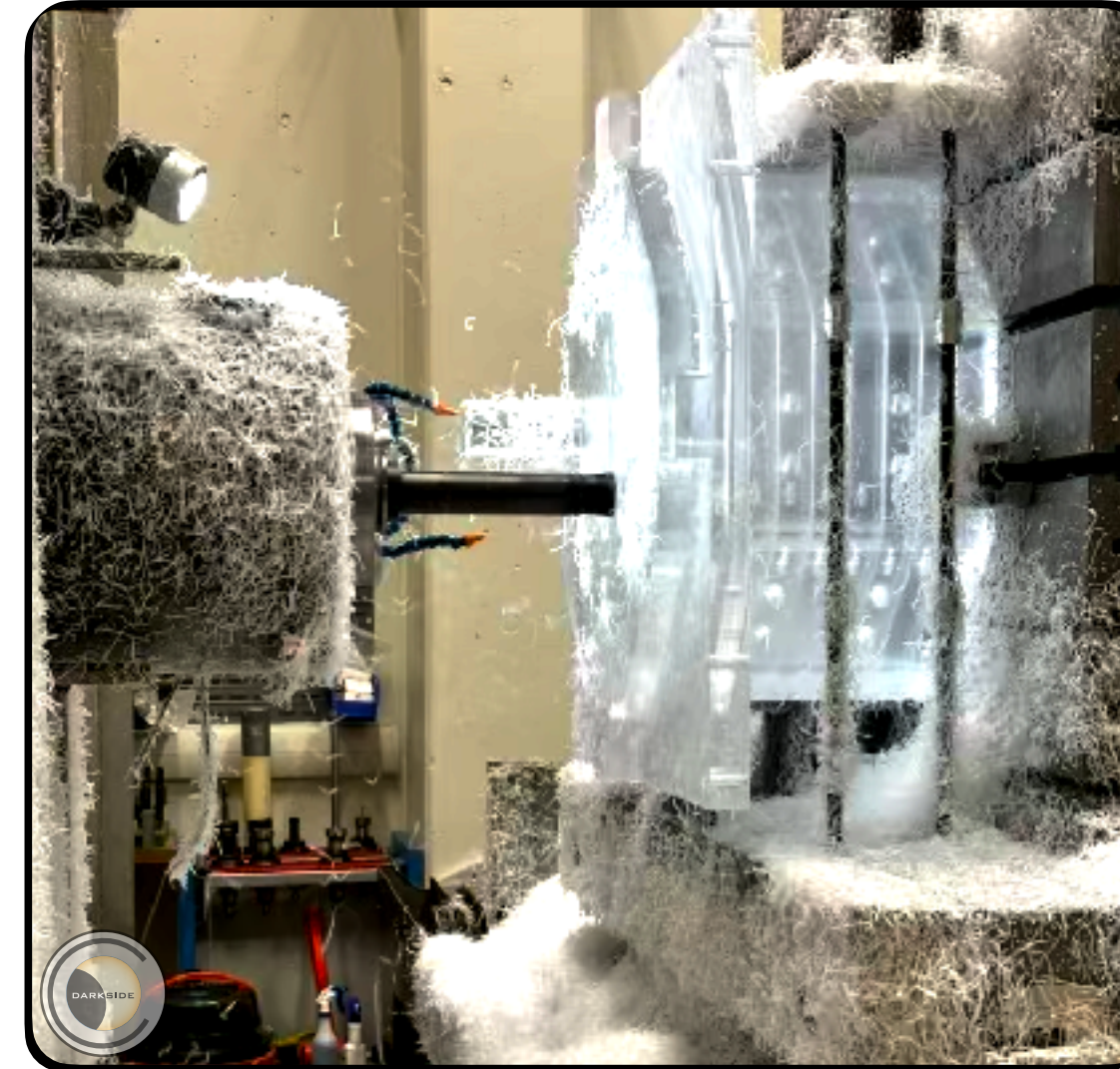
3D Model of the DS-Mockup Detector



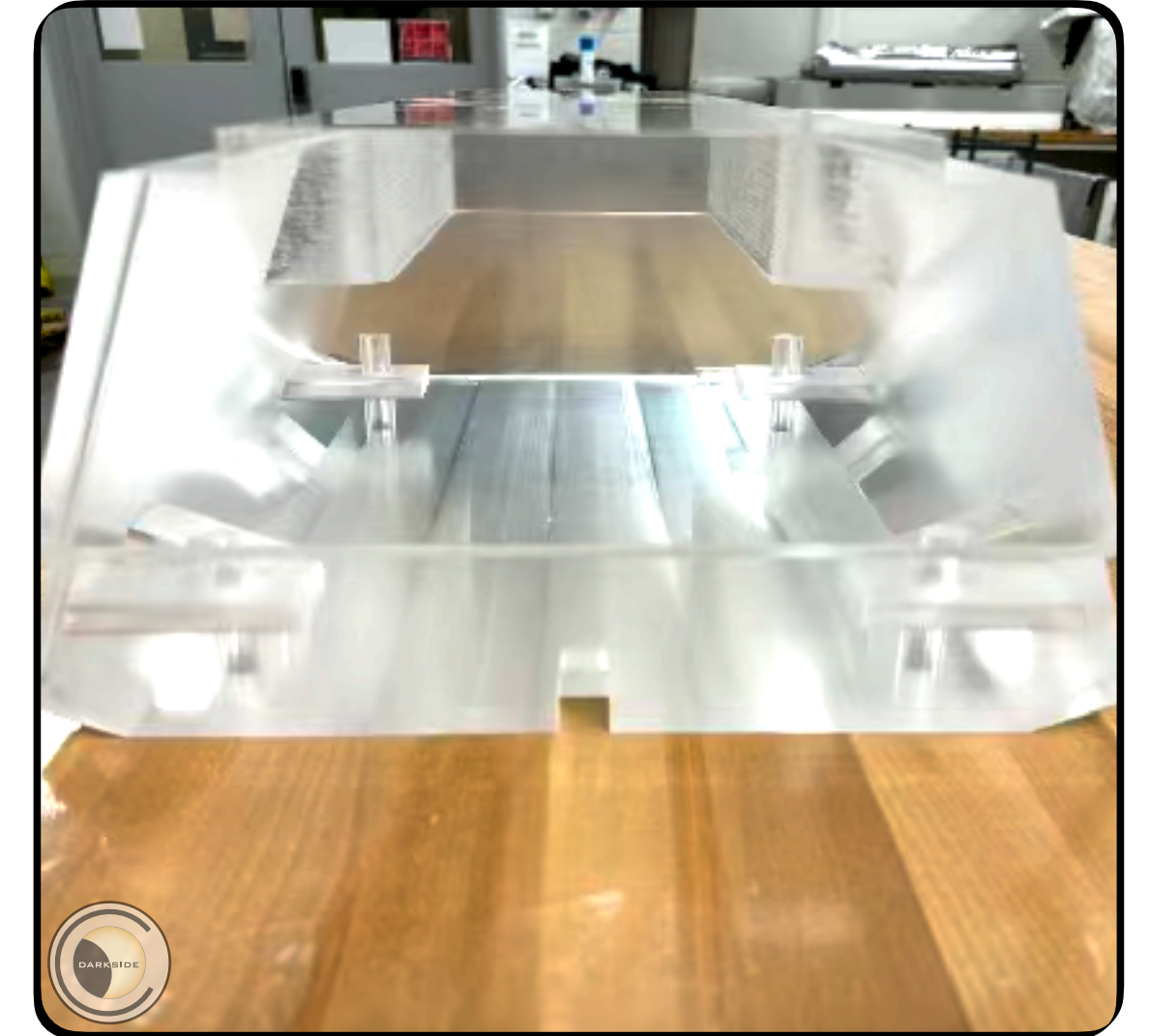
DS-Mockup PMMA Machining and Mechanical Tests

- The machining of all PMMA components was done at the **University of Alberta**
- Valuable experience gained during the **"dry – fit"** of the DS-Mockup barrel
(prior to cleaning and coating)
- Definition of procedures
- Experience with operating tools
 - 3D scanner
 - alignment table
 - lifting arm

Machining of the DS-Mockup Cathode



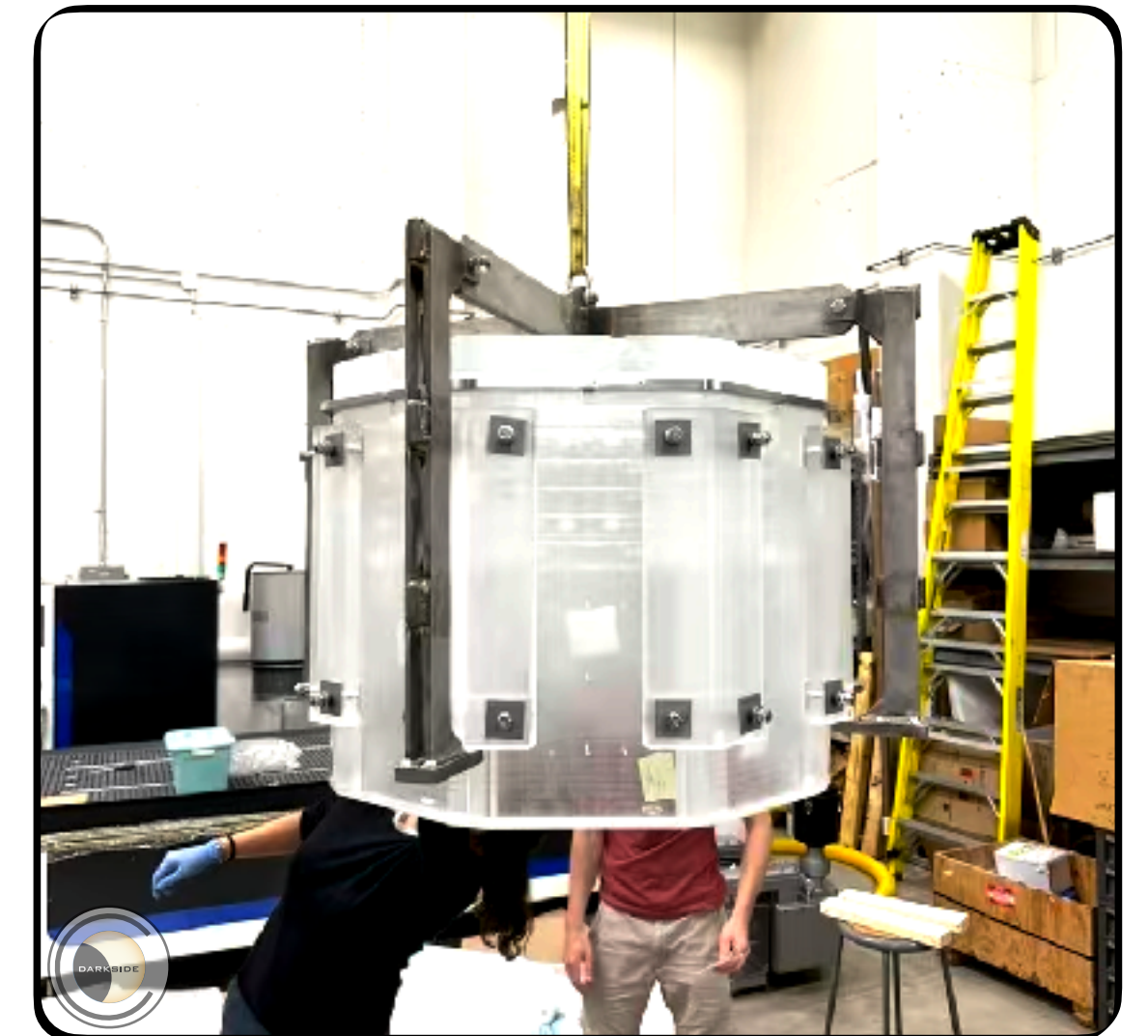
Fully Machined DS-Mockup Barrel Panel



Test Assembly of the DS-Mockup Barrel



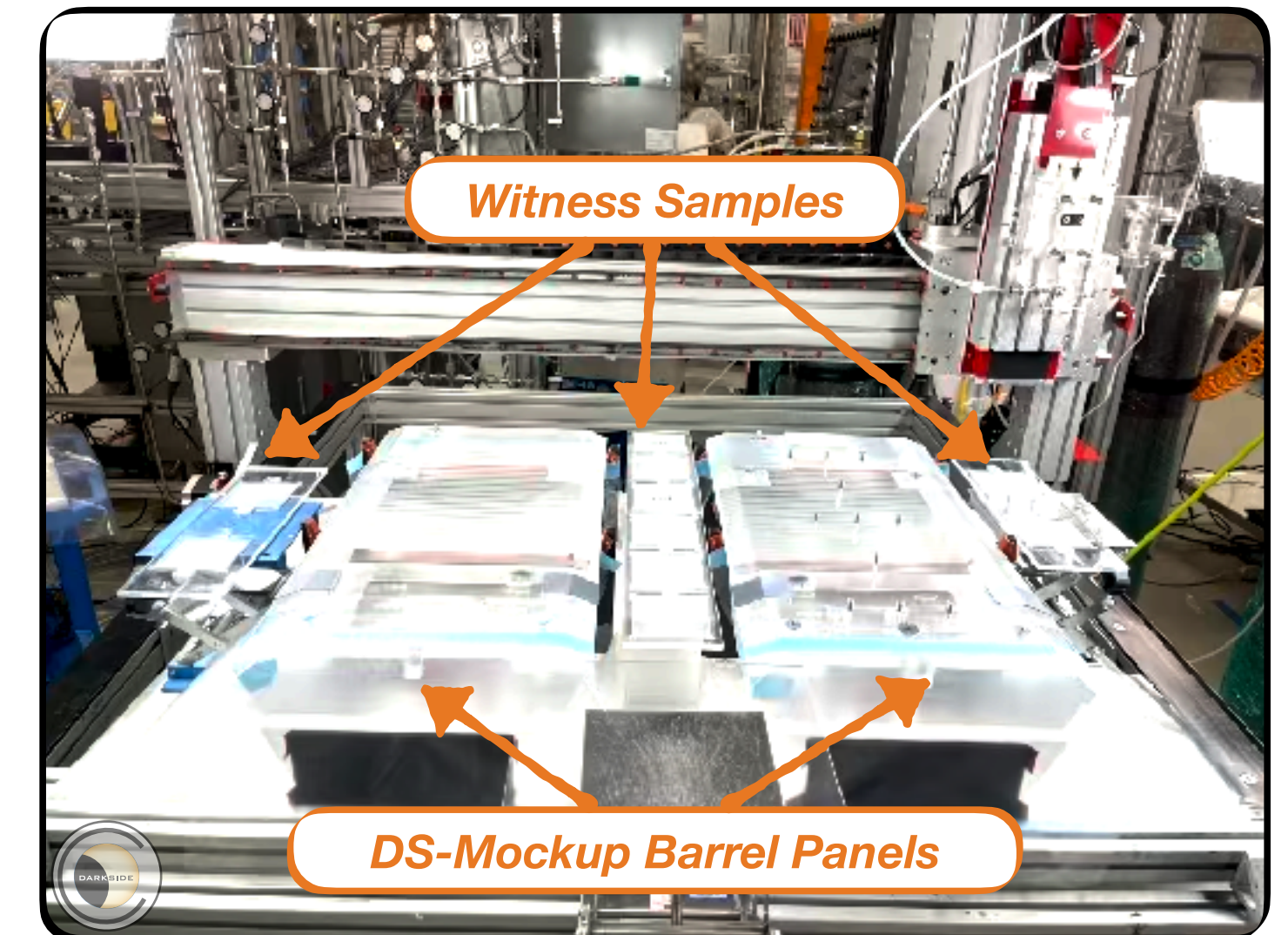
Lifting of the DS-Mockup Barrel



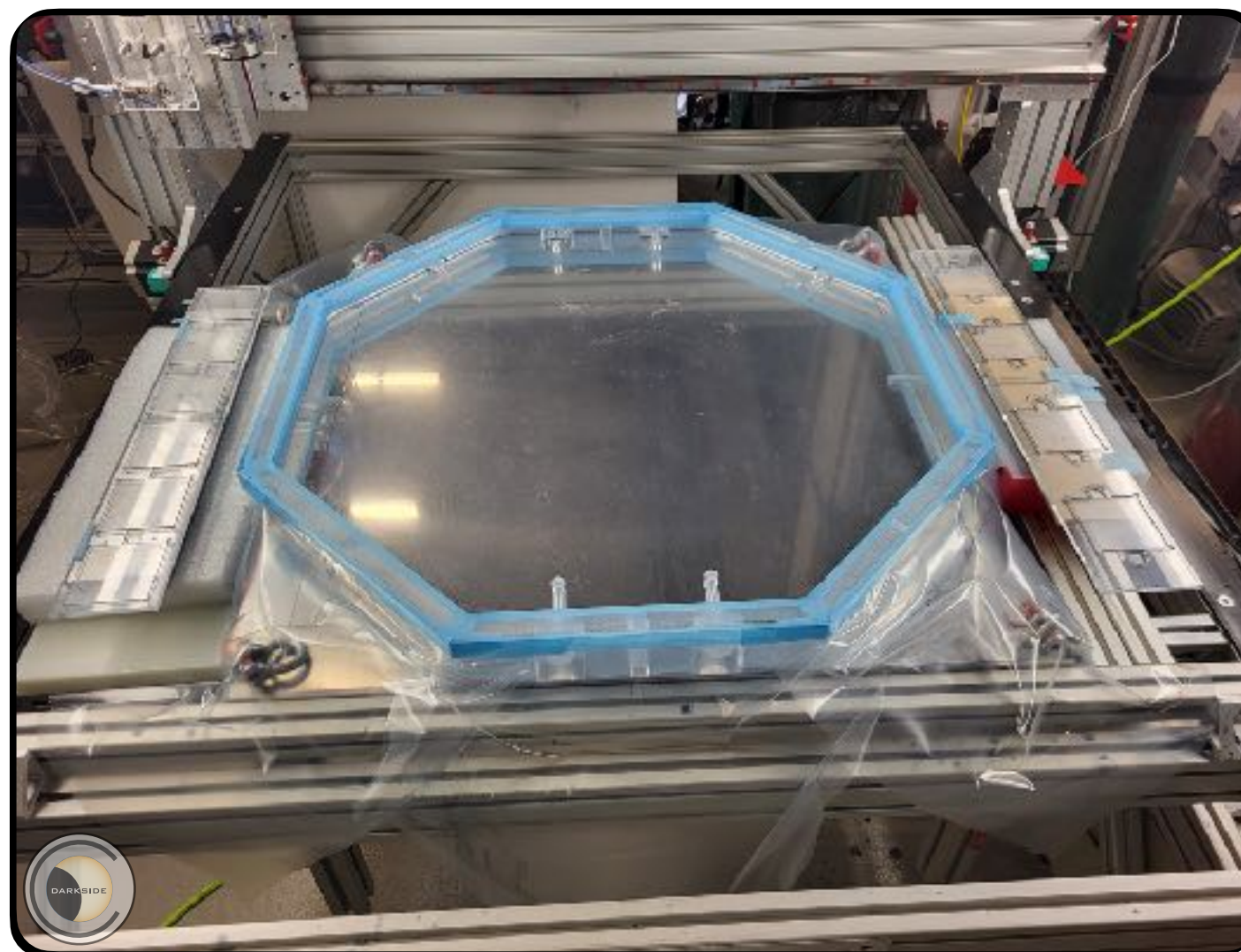
DS-Mockup Coating

- Coating operations performed at **Carleton University**
 - Clevios™** coated surfaces as electrodes (cathode, anode, field shaping rings)
 - TPB** for wavelength-shifting from **128 nm** to **420 nm**

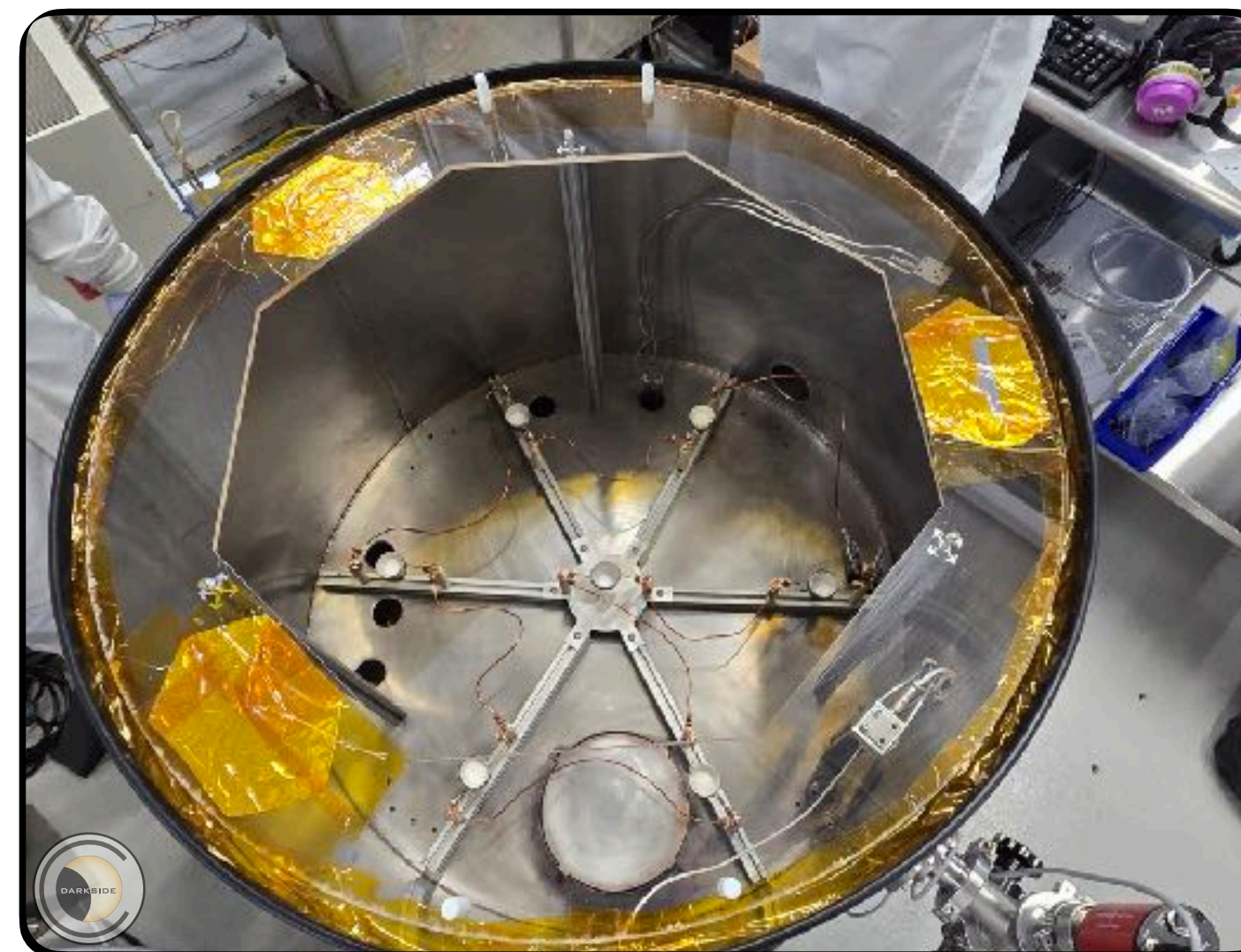
Clevios™ Coating Setup



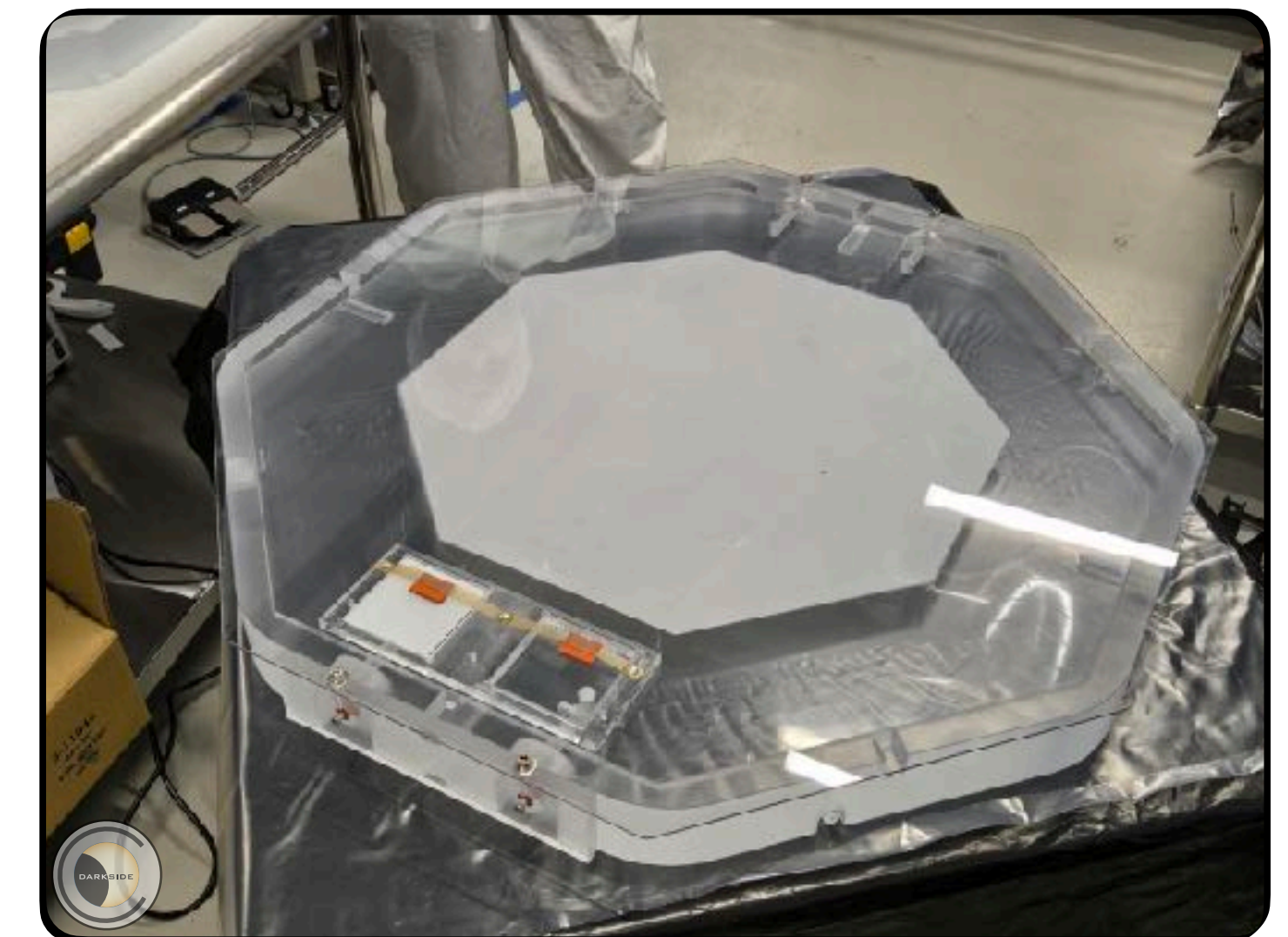
Clevios™ Coating of the DS-Mockup Anode



TPB Evaporation Chamber

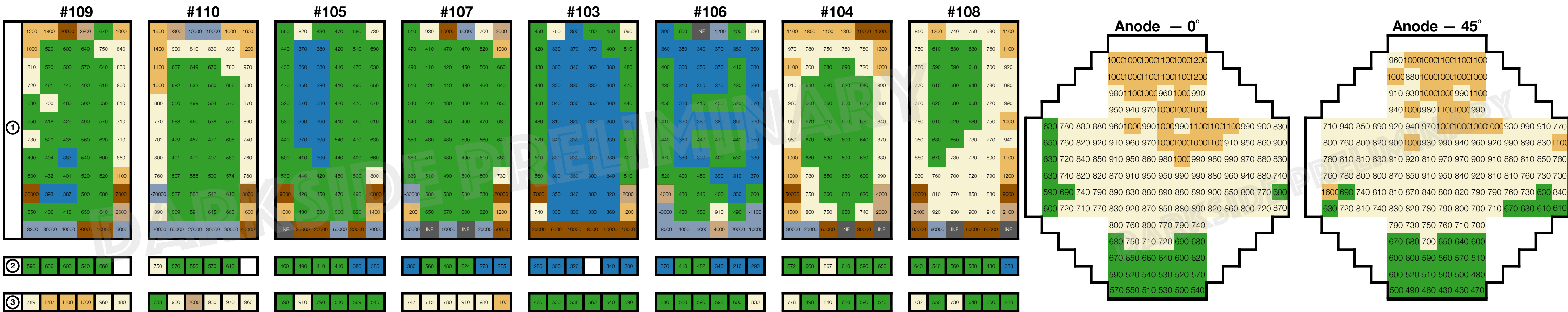
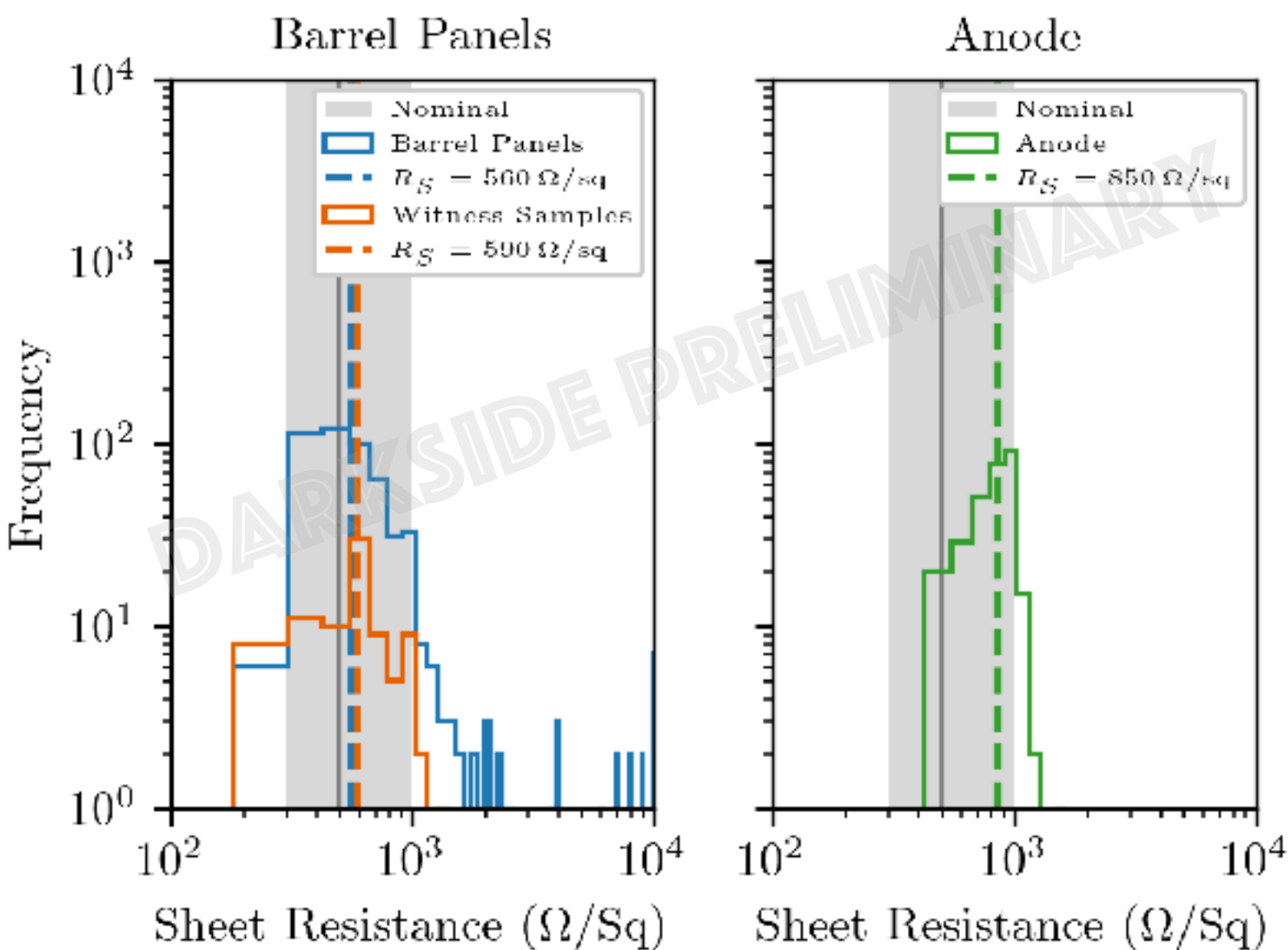


Fully Coated (Clevios™ + TPB) DS-Mockup Anode



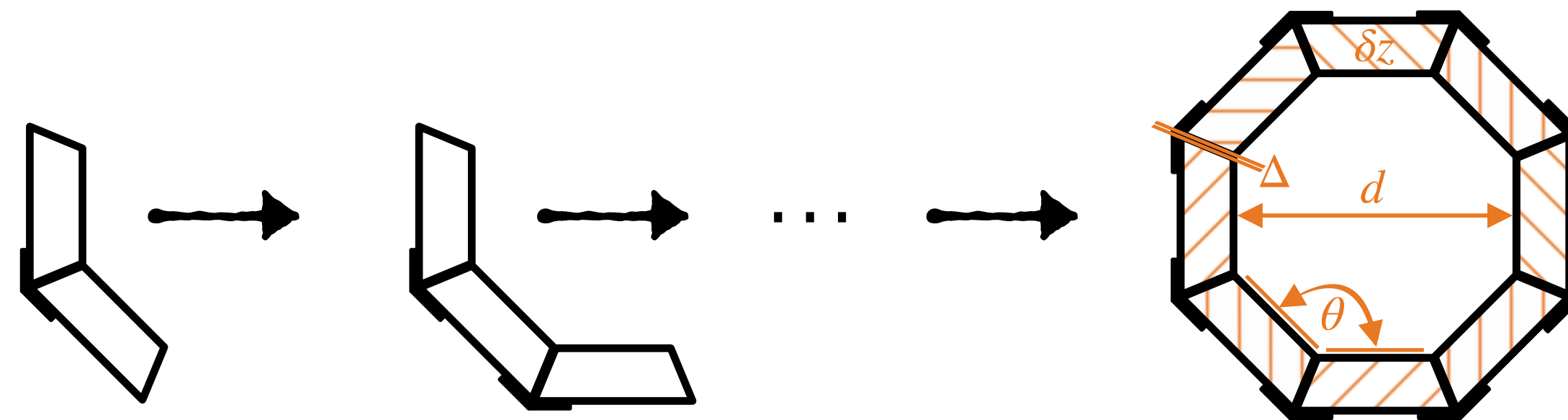
DS-Mockup Coating

- **CleviosTM**-coating quality is assessed via
 - **Non – contact** eddy-current measurements on larger pieces
 - Resistivity measurements on **~ 140 witness samples**



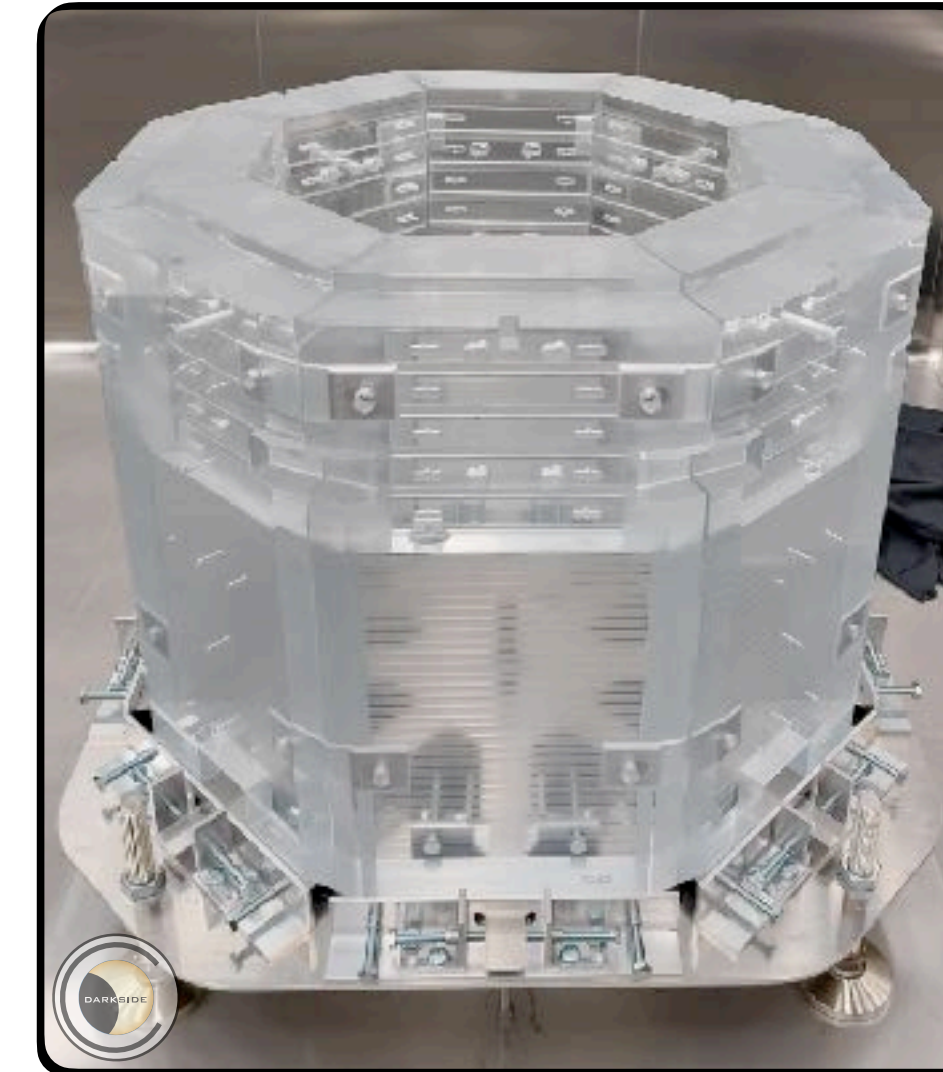
DS-Mockup Barrel Assembly Procedure

- Assembly and installation at **LNGS**
 - ➔ *ISO-6 cleanroom above ground*
- MetraScan 3D scanner for assessing the planarity
 - ➔ *$\sim 25\ \mu\text{m}$ spatial resolution*
- Goals:
 - Gaps between panels to be kept at $\Delta \leq 2\ \text{mm}$
 - Octagonality θ and panel spacing d
 - $\delta z \approx 100\ \mu\text{m}$ flatness of the barrel top surface
 - ➔ *Surface on which the grid rests*

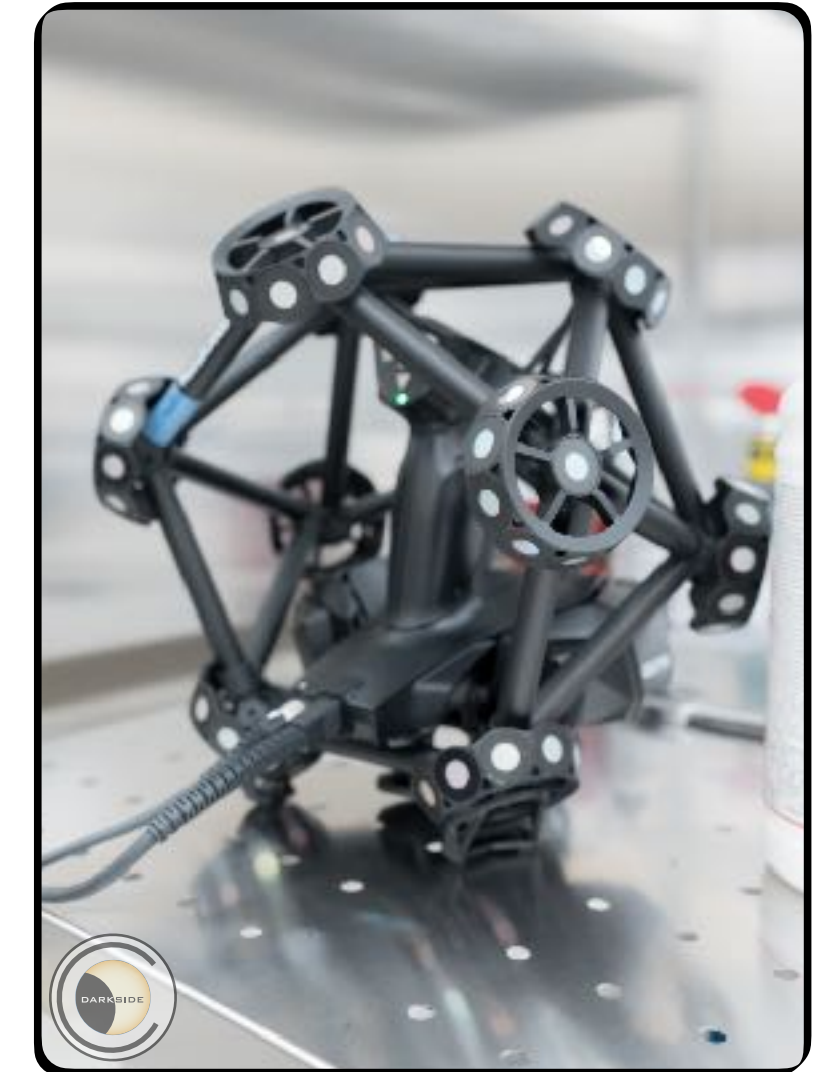


Schematic assembly of octagonal barrel from individual panels

DS-Mockup Barrel on Alignment Platform



MetraScan Handy Probe



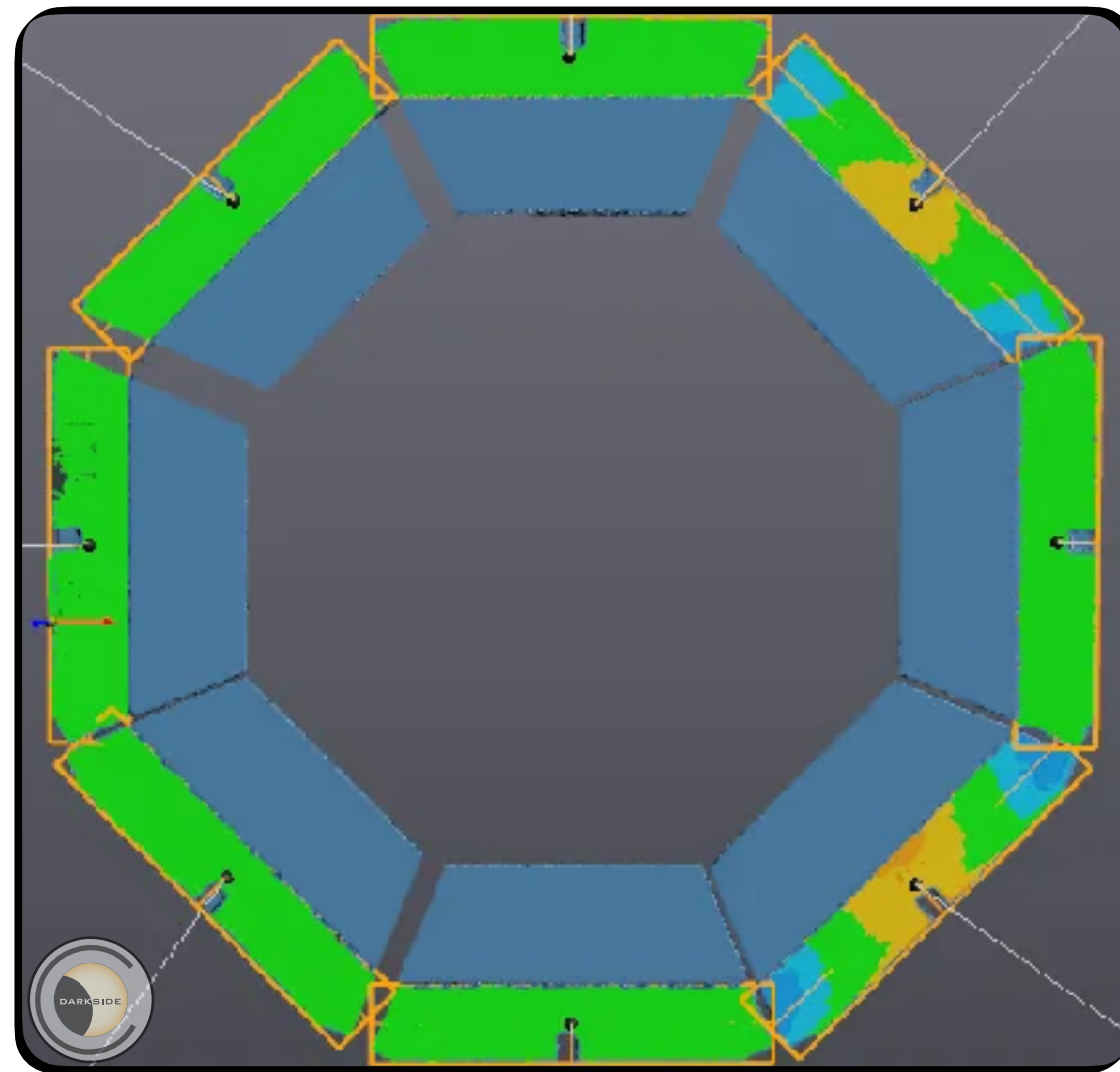
MetraScan C-Track



3D Scan of DS-Mockup Barrel

DS-Mockup Barrel Alignment Results

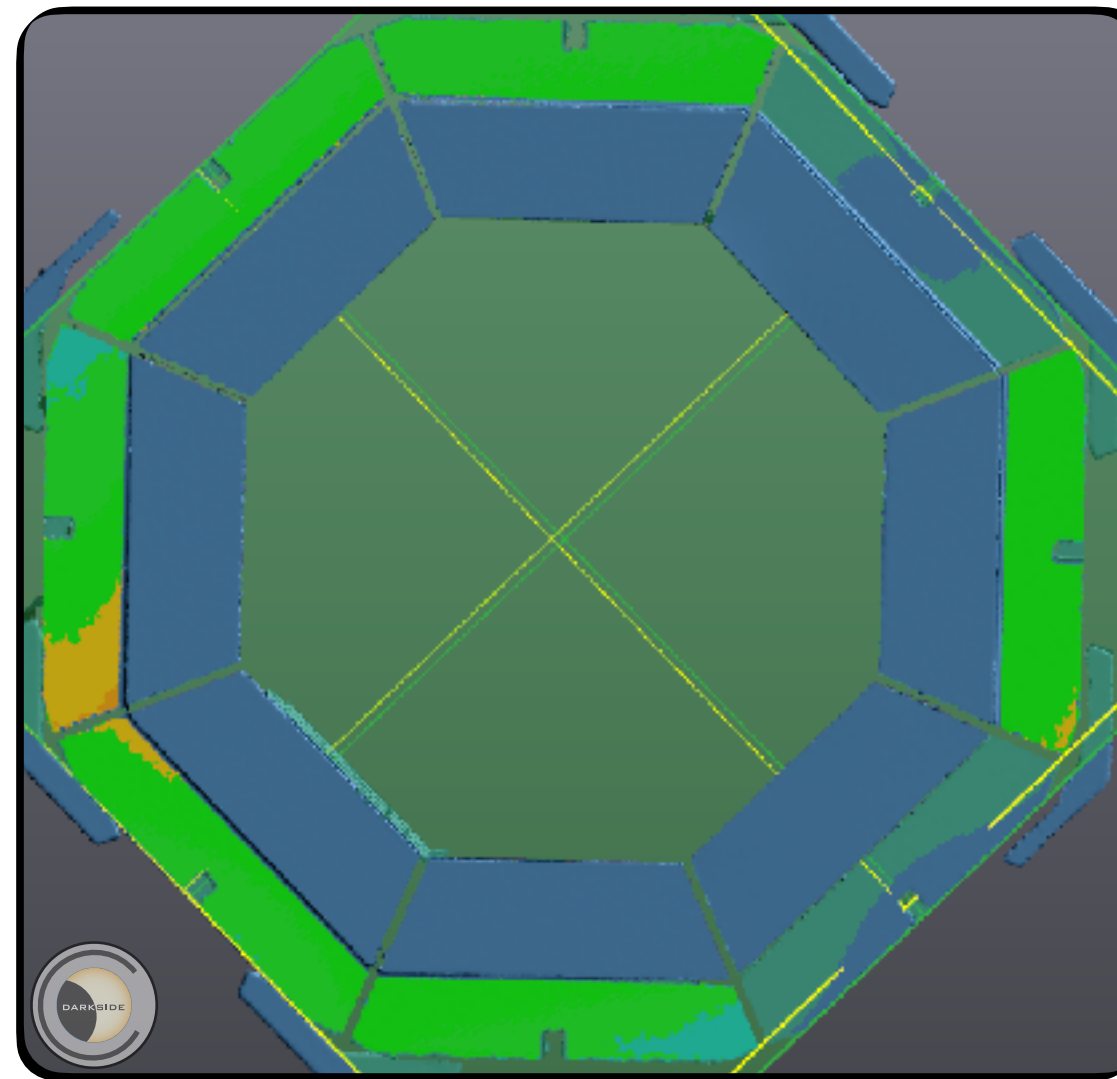
Flatness of individual panels



6 out of 8 panels are shown to be flat to within $< 100 \mu\text{m}$

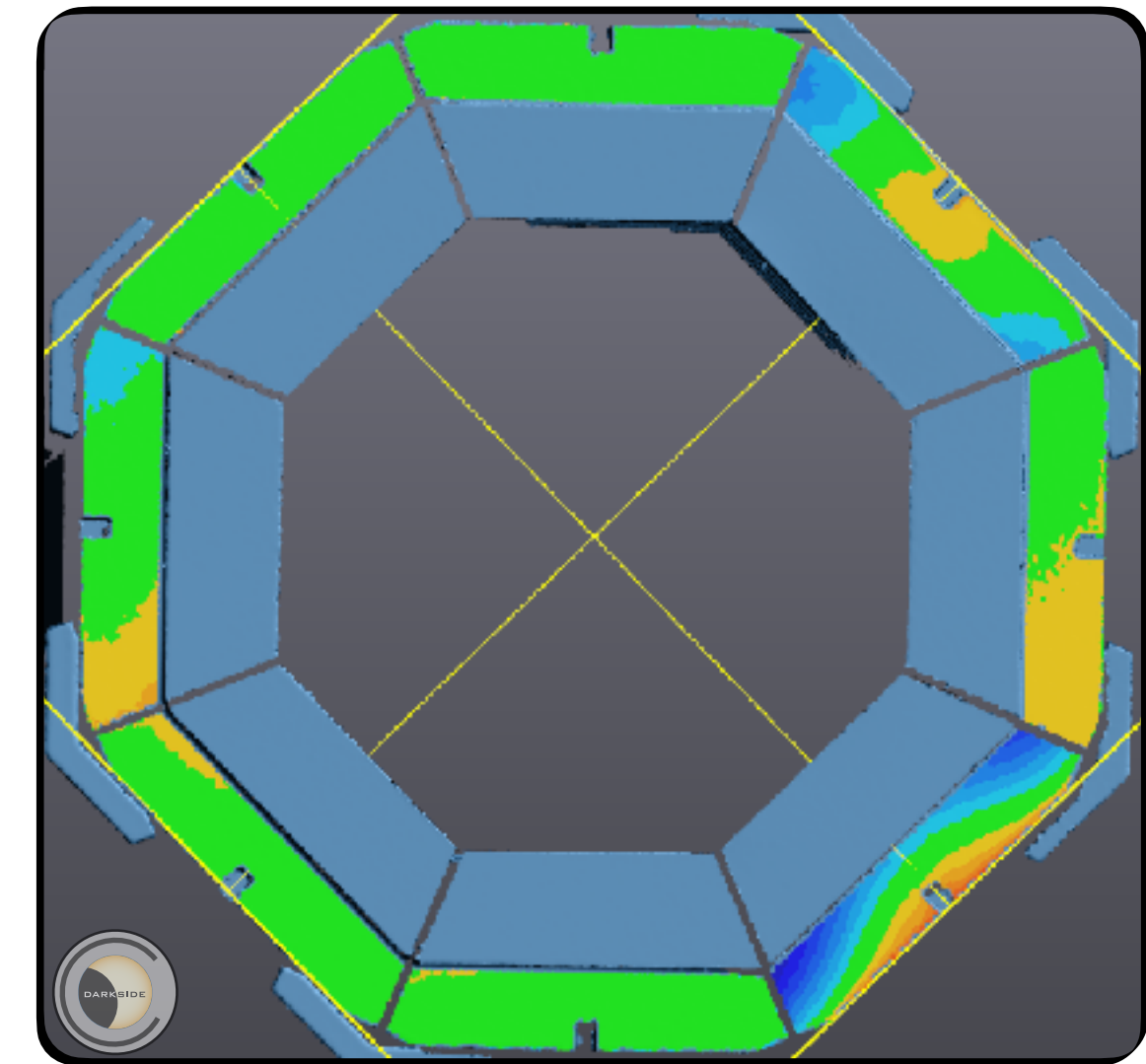
The other 2 got deformed during an uncontrolled annealing cycle

Combined flatness of “good” panels

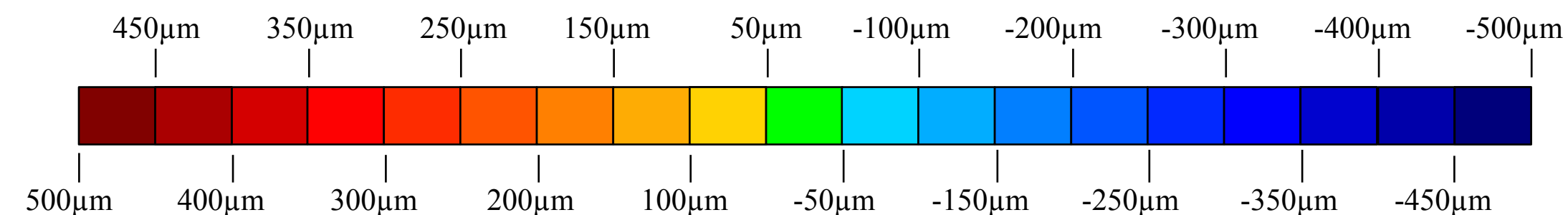


90 % of the barrel top surface of 6 out of 8 panels is flat to within $< 100 \mu\text{m}$ globally

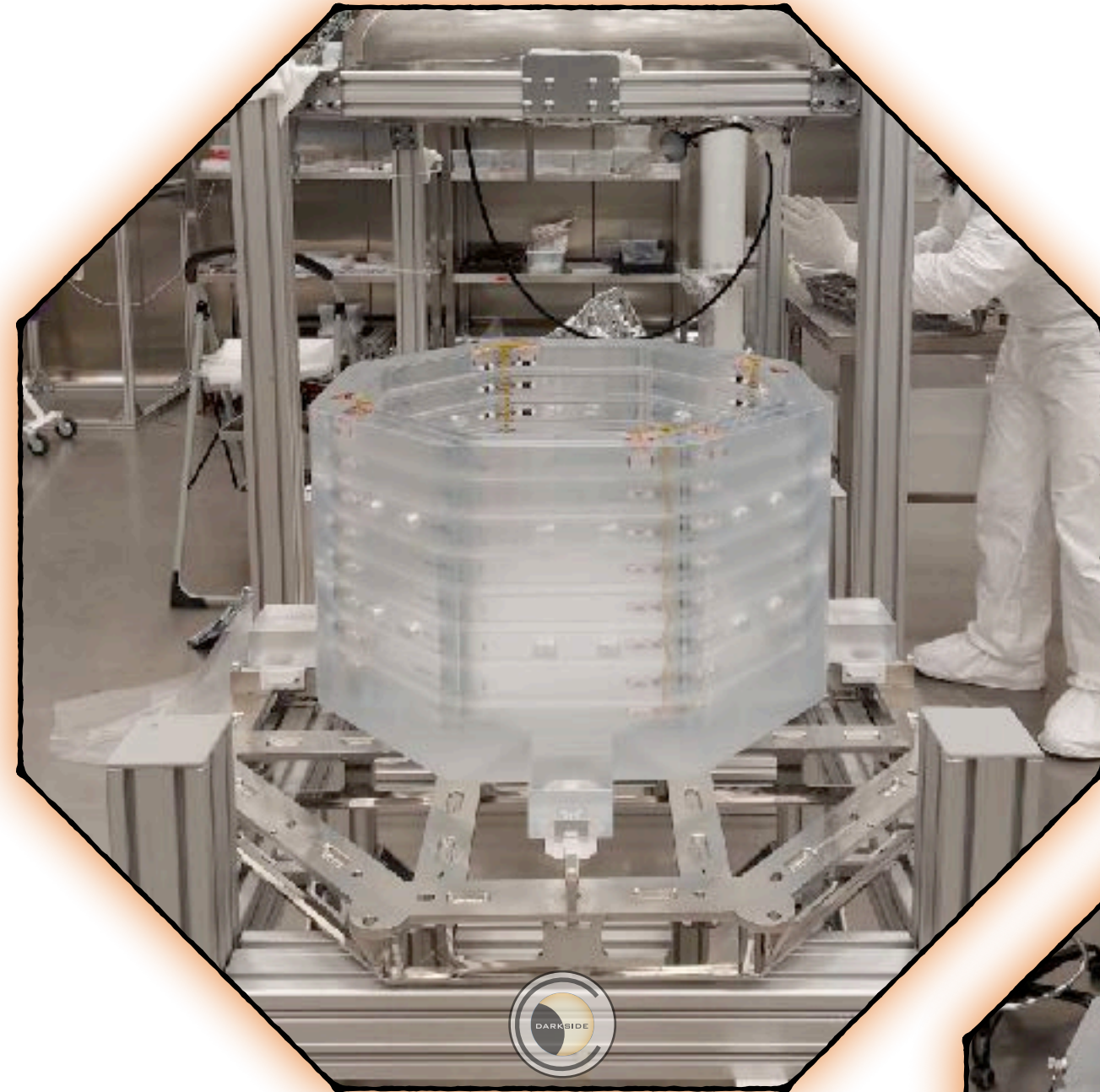
Combined flatness of all panels



72 % of the total barrel top surface is flat to within $< 100 \mu\text{m}$ globally

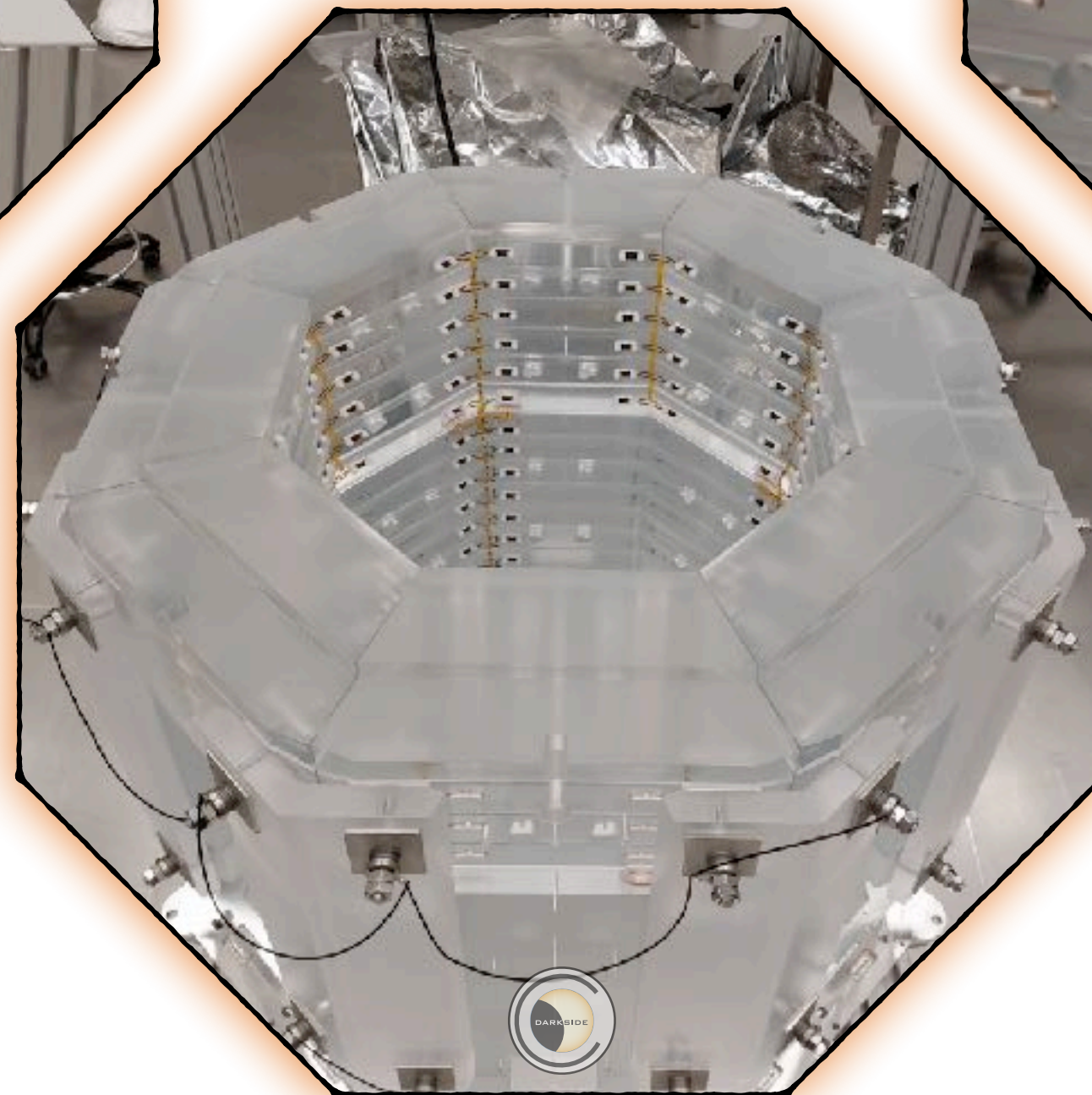


DS-Mockup Full Assembly

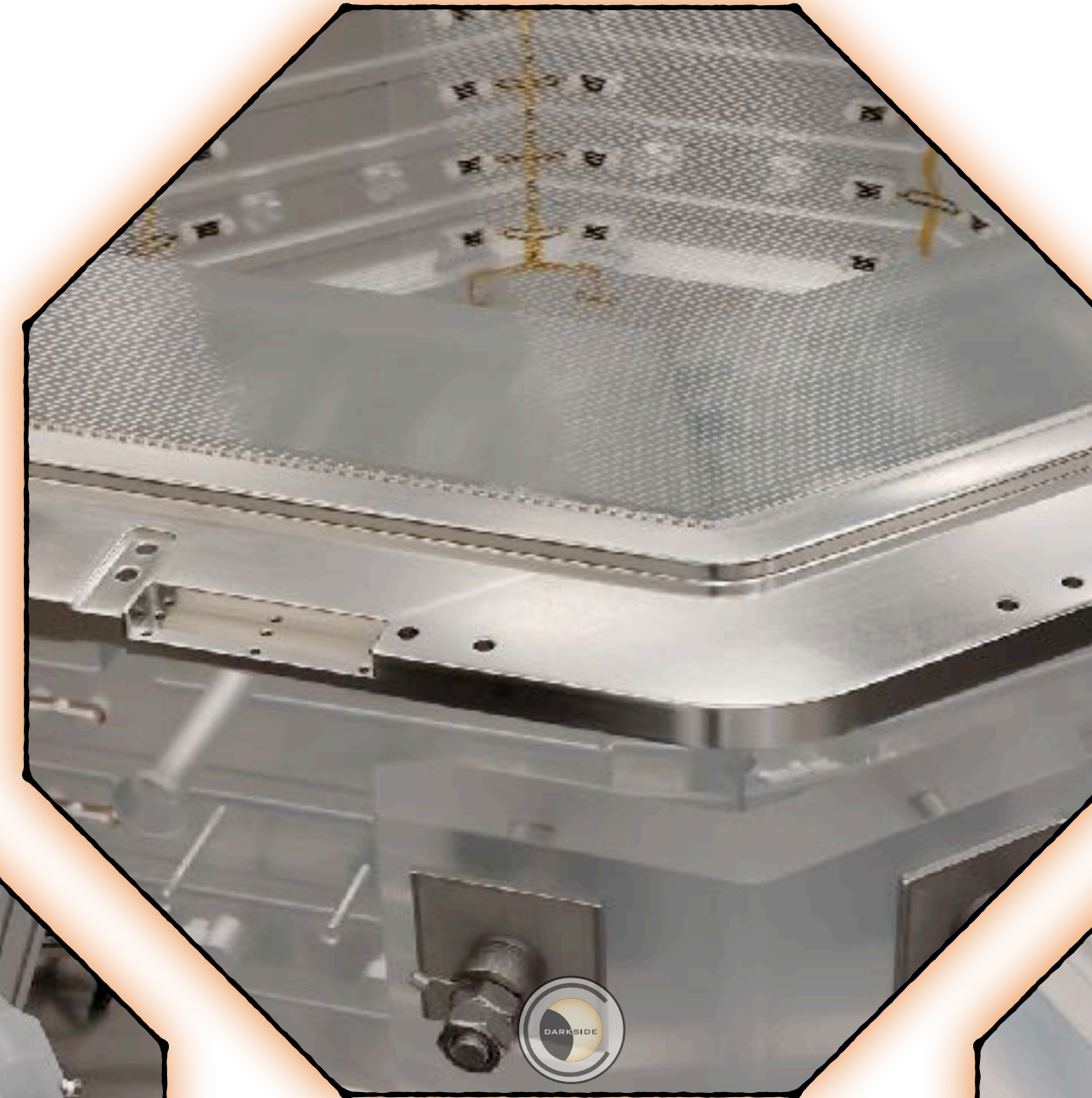


**Bottom Optical Plane
+
Cathode/Kneewall**

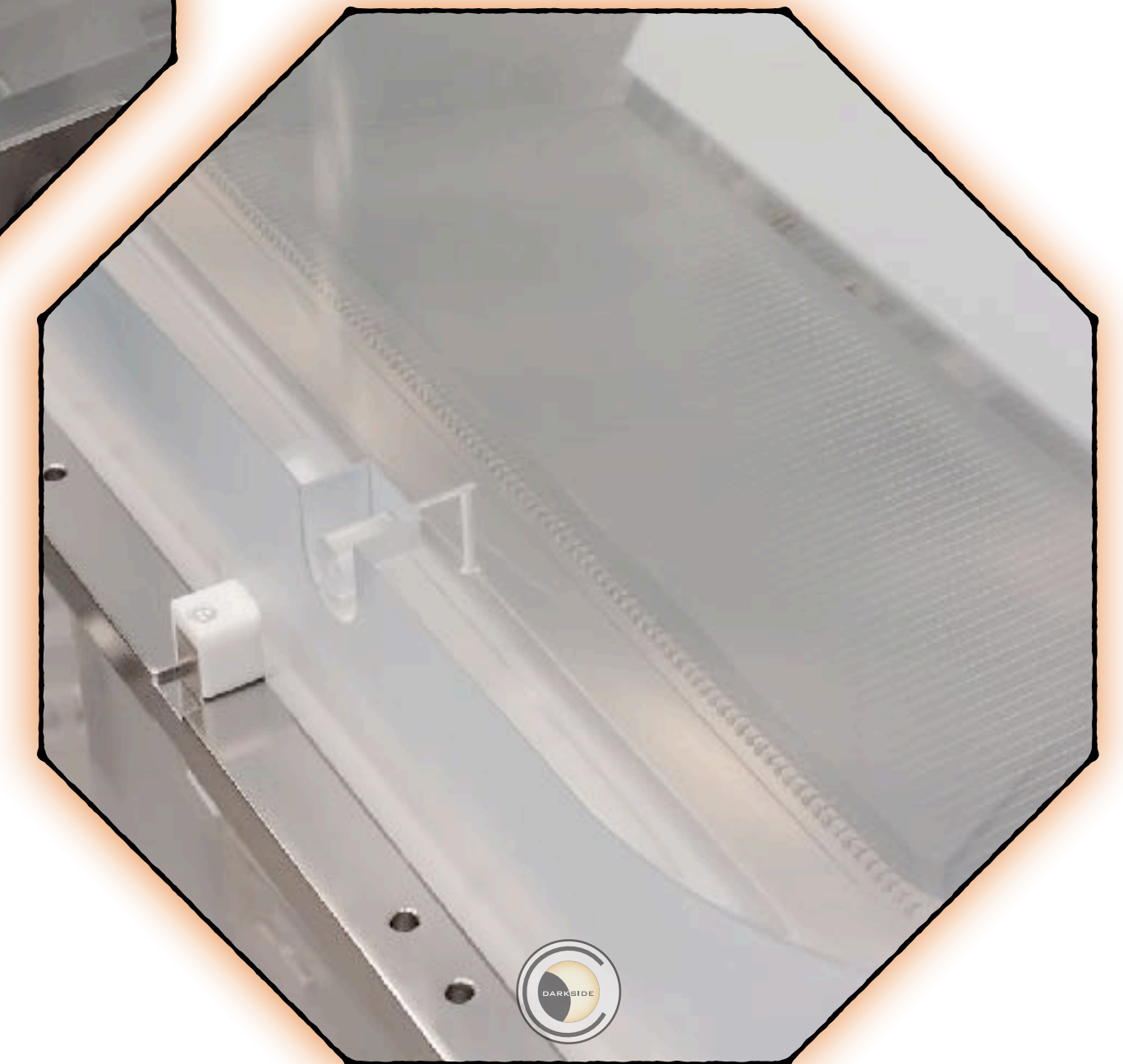
**Bottom Optical Plane
+
Cathode/Kneewall
+
Barrel**



**Bottom Optical Plane
+
Cathode/Kneewall
+
Barrel
+
Grid**

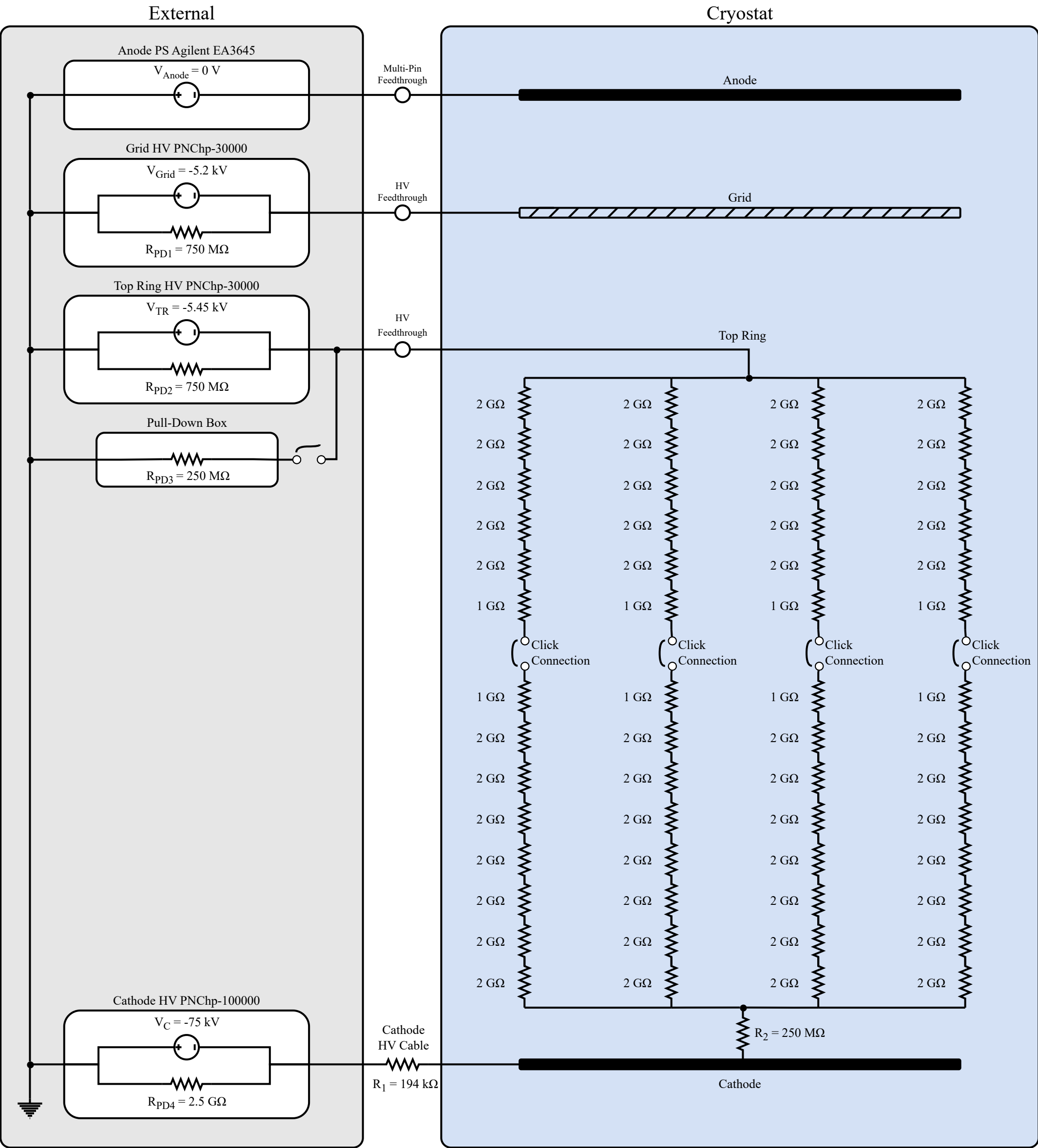


**Bottom Optical Plane
+
Cathode/Kneewall
+
Barrel
+
Grid
+
Anode**



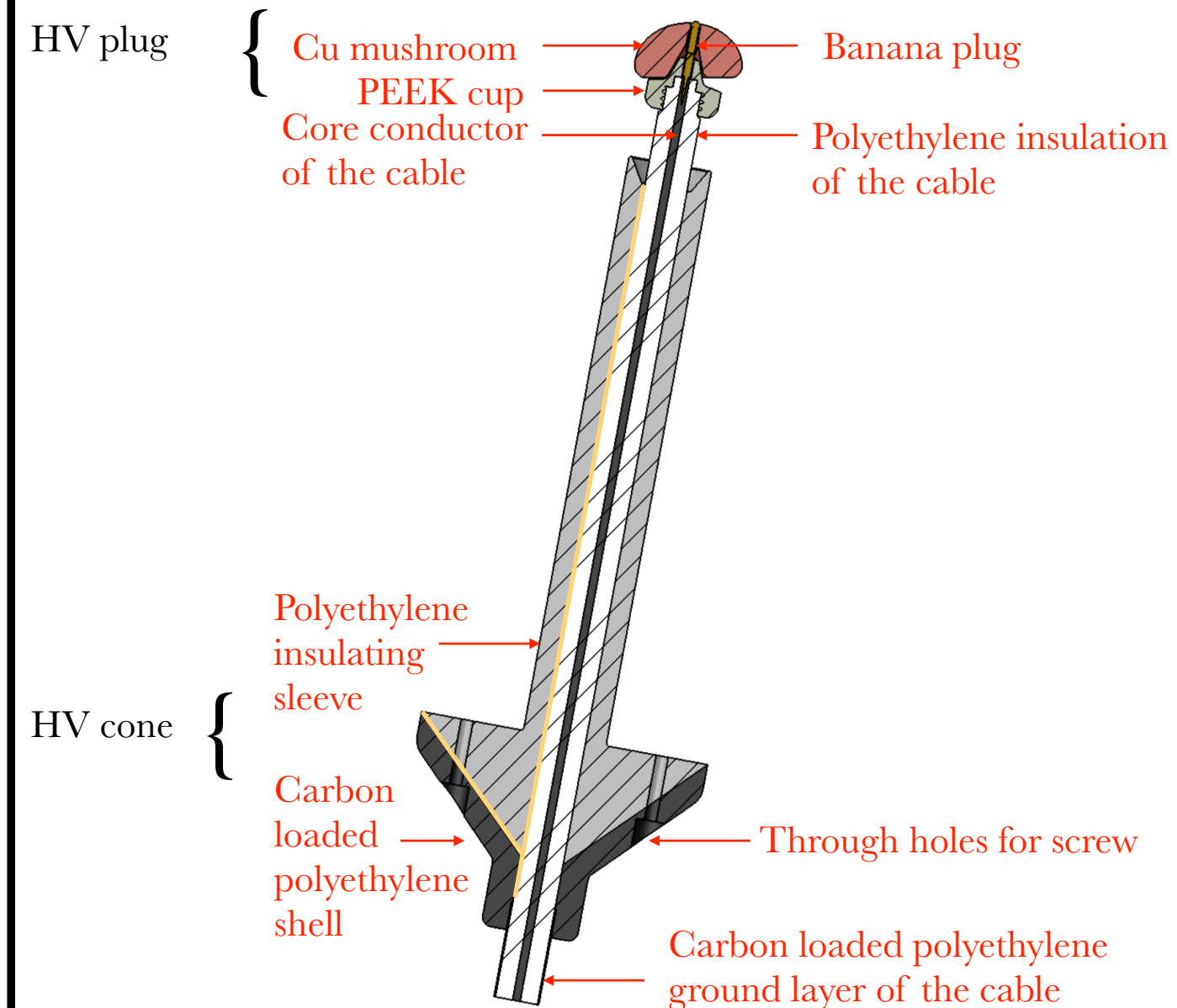
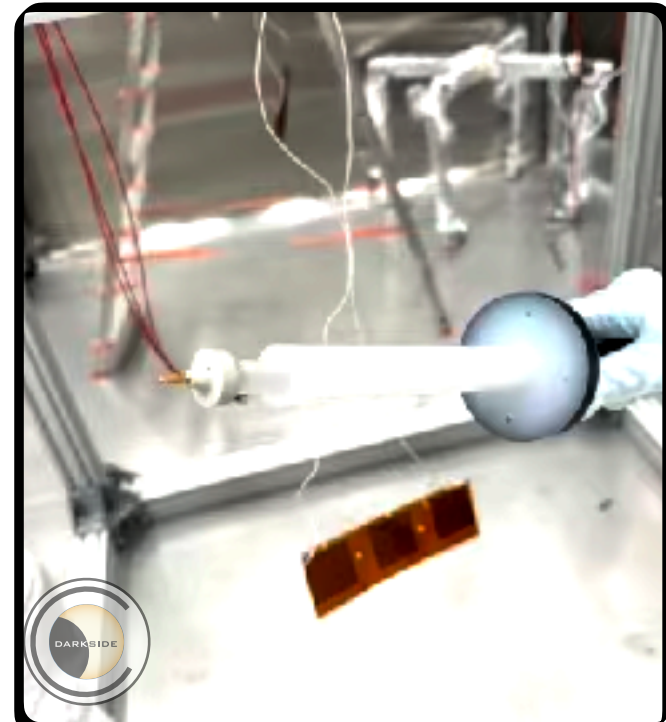
DS-Mockup High Voltage Delivery

Schematic Circuit Diagram of the DS-Mockup High Voltage Distribution

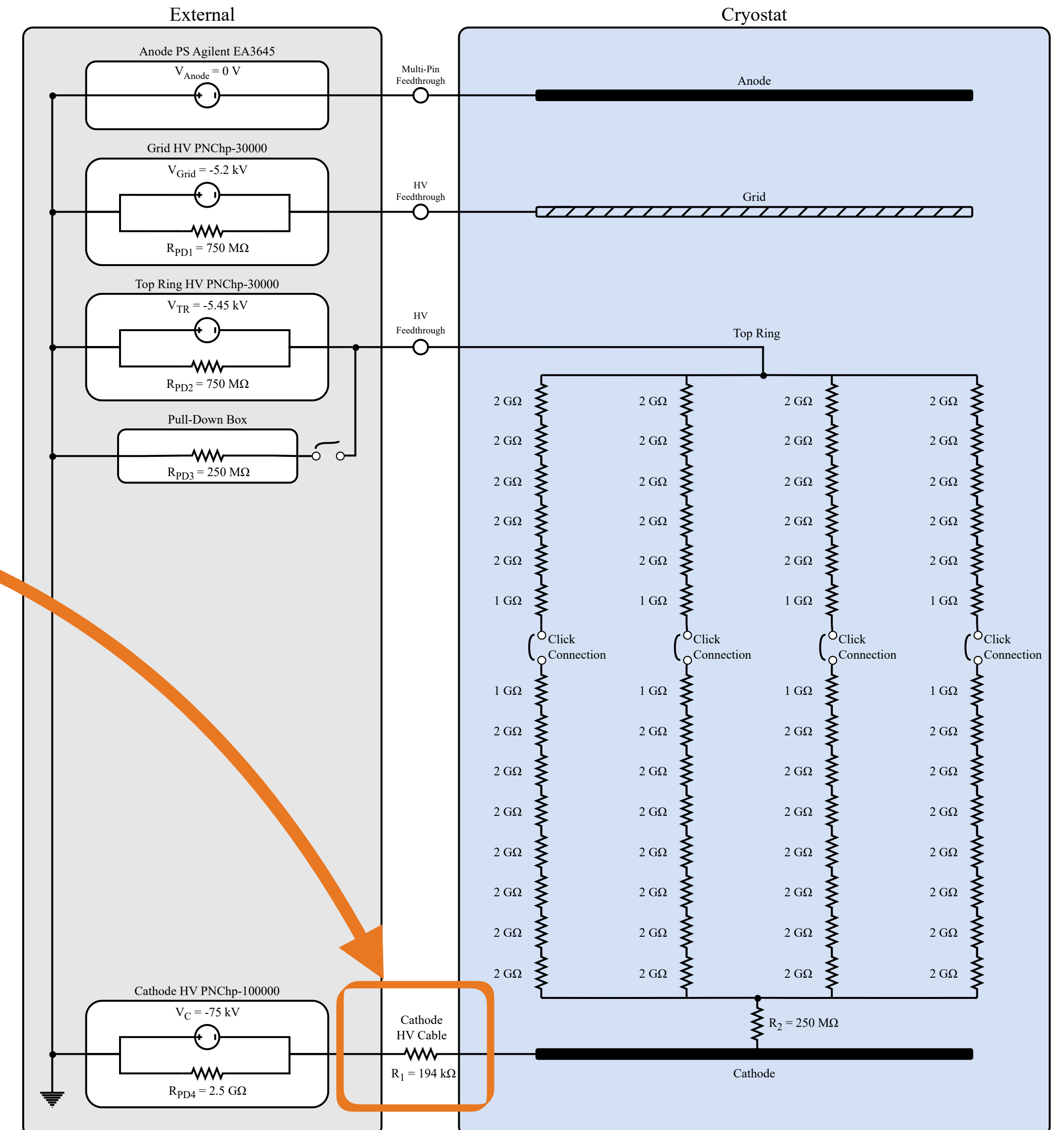


DS-Mockup High Voltage Delivery

Cathode High Voltage Cable



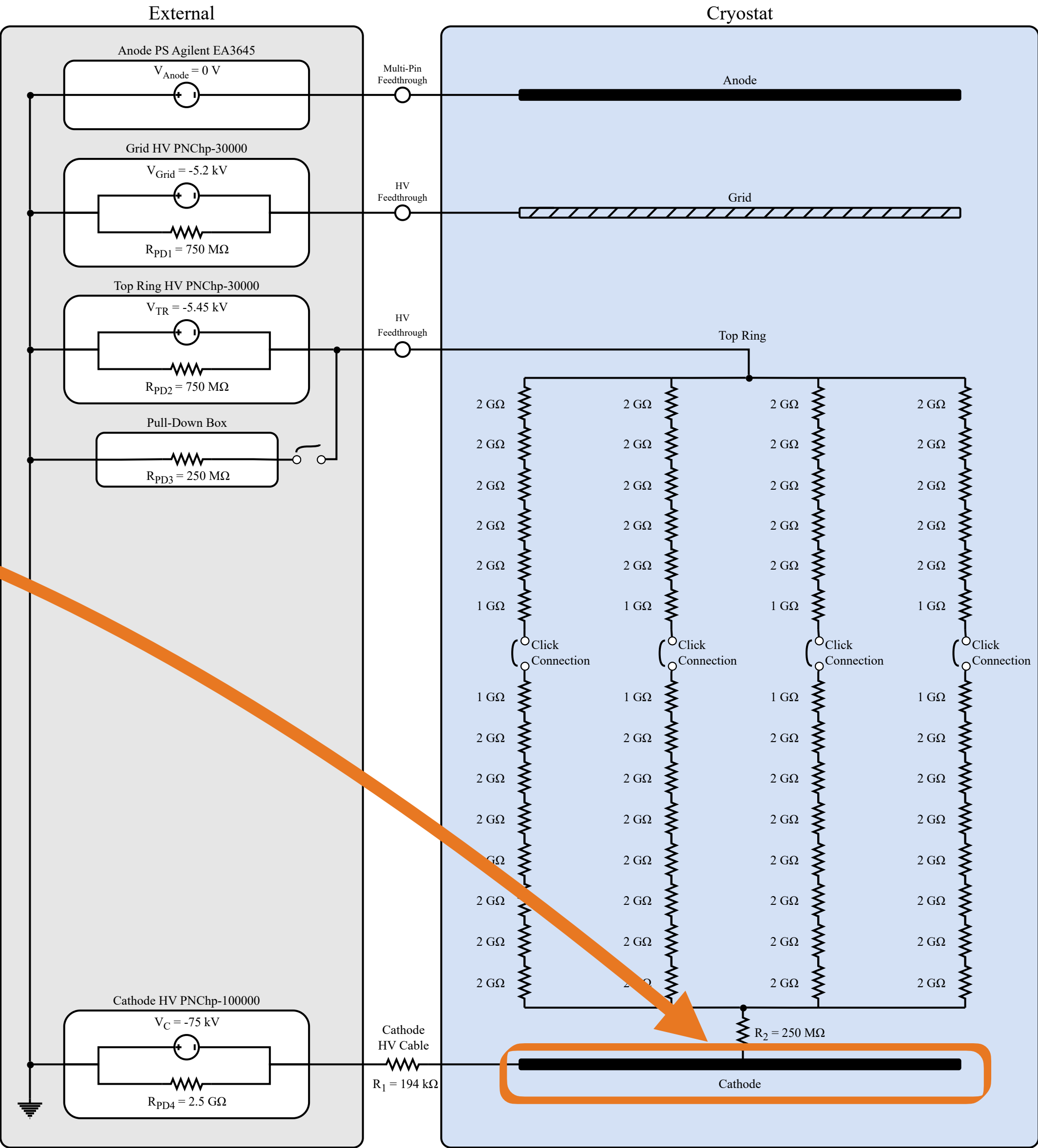
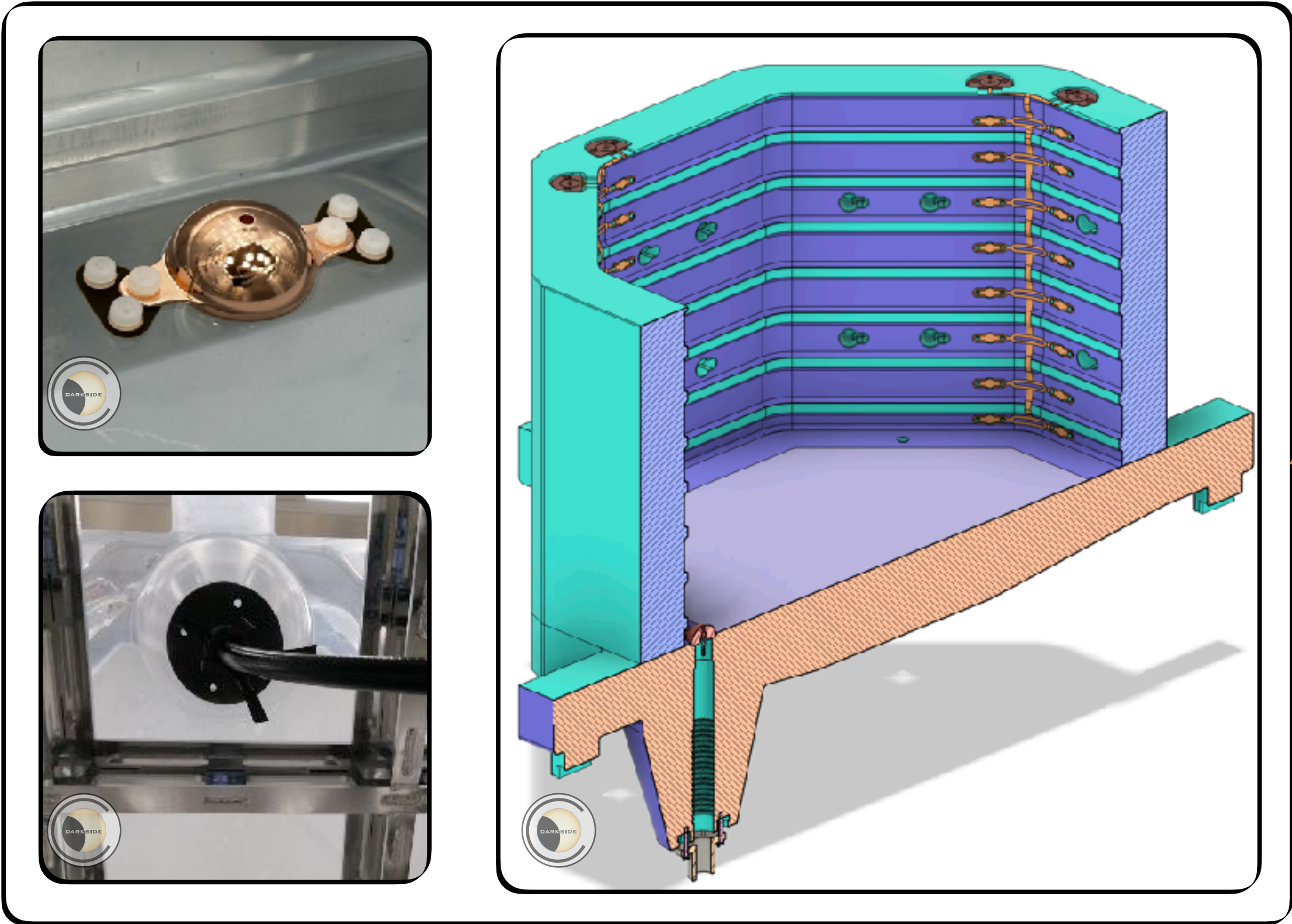
Schematic Circuit Diagram of the DS-Mockup High Voltage Distribution



DS-Mockup High Voltage Delivery

Schematic Circuit Diagram of the DS-Mockup High Voltage Distribution

Cathode High Voltage Stress Cone and Clevios-Interface



A photograph of the interior of the Large Hadron Collider (LHC) tunnel. The image shows a long, narrow, octagonal-shaped tunnel with a complex arrangement of superconducting magnets and support structures. The central opening is a bright, circular light source. The walls are lined with various components, including cables and structural elements, creating a sense of depth and scale.

The diagram illustrates the electrical connections between the external power supplies and the cryostat components. The external section (left) includes four high-voltage (HV) power supplies and a pull-down box, all connected to ground. The cryostat section (right) shows the internal components, including the anode, grid, top ring, and cathode, connected to the external supplies via feedthroughs. The top ring is connected to the top ring HV supply, and the cathode is connected to the cathode HV supply. The grid is connected to the grid HV supply. The anode is connected to the anode HV supply. The pull-down box is connected to the top ring. The cathode is connected to the cathode HV supply via a cable. The top ring is connected to the top ring HV supply via a cable. The grid is connected to the grid HV supply via a cable. The anode is connected to the anode HV supply via a cable. The pull-down box is connected to the top ring via a cable. The cathode is connected to the cathode HV supply via a cable. The top ring is connected to the top ring HV supply via a cable. The grid is connected to the grid HV supply via a cable. The anode is connected to the anode HV supply via a cable. The pull-down box is connected to the top ring via a cable. The cathode is connected to the cathode HV supply via a cable.

External Components:

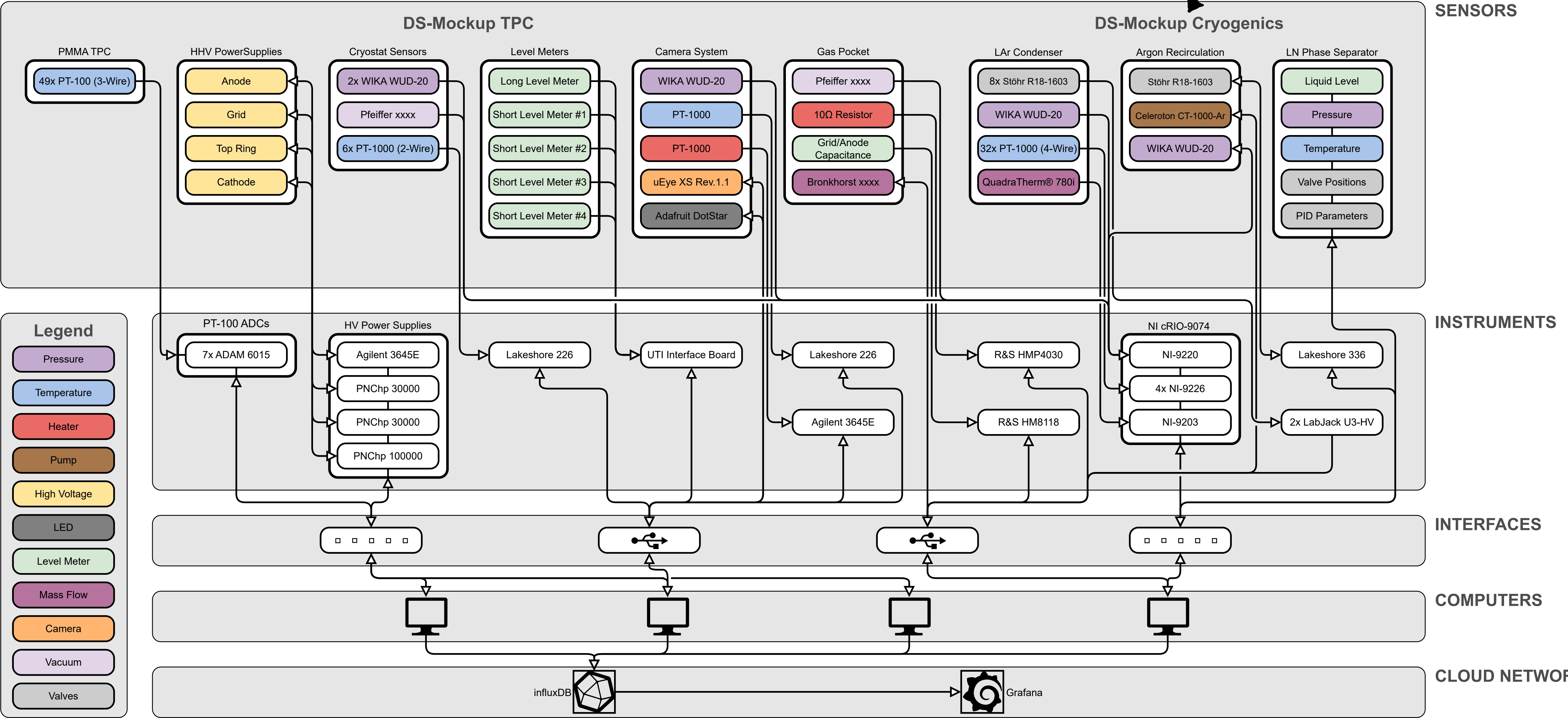
- Anode PS Agilent EA3645: $V_{\text{Anode}} = 0 \text{ V}$
- Grid HV PNChp-30000: $V_{\text{Grid}} = -5.2 \text{ kV}$, $R_{\text{PD1}} = 750 \text{ M}\Omega$
- Top Ring HV PNChp-30000: $V_{\text{TR}} = -5.45 \text{ kV}$, $R_{\text{PD2}} = 750 \text{ M}\Omega$
- Pull-Down Box: $R_{\text{PD3}} = 250 \text{ M}\Omega$
- Cathode HV PNChp-100000: $V_{\text{C}} = -75 \text{ kV}$, $R_{\text{PD4}} = 2.5 \text{ G}\Omega$

Cryostat Components:

- Anode
- Grid
- Top Ring
- Cathode
- Click Connection
- Resistors: $2 \text{ G}\Omega$, $1 \text{ G}\Omega$, $R_1 = 194 \text{ k}\Omega$, $R_2 = 250 \text{ M}\Omega$

DS-Mockup Slow Control and Monitoring

Benchmarking the design of the cryogenics system for the underground argon in DarkSide-20k
JINST 20 P02016 (2025)

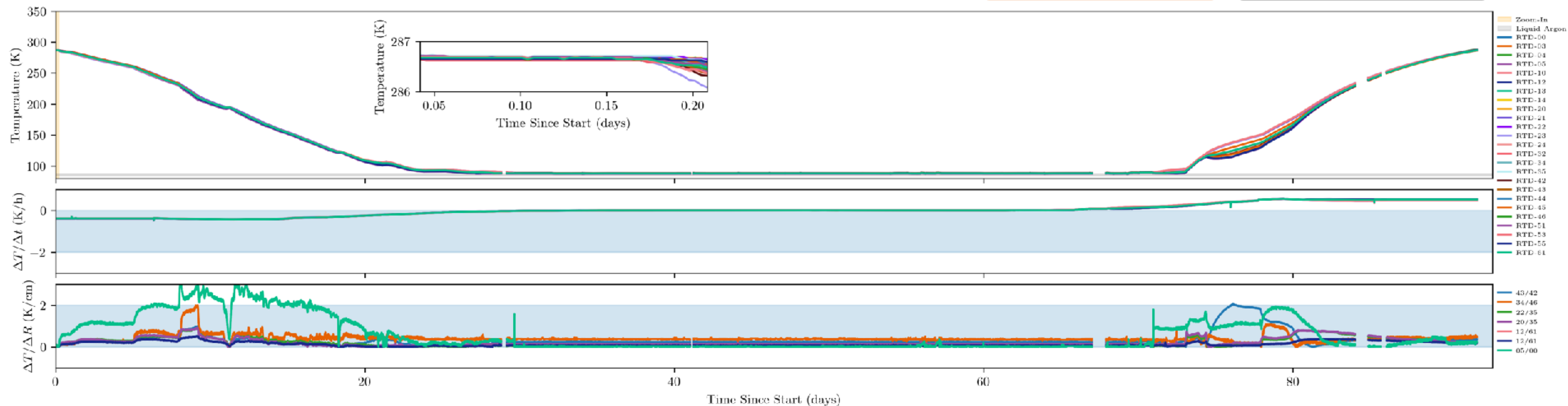
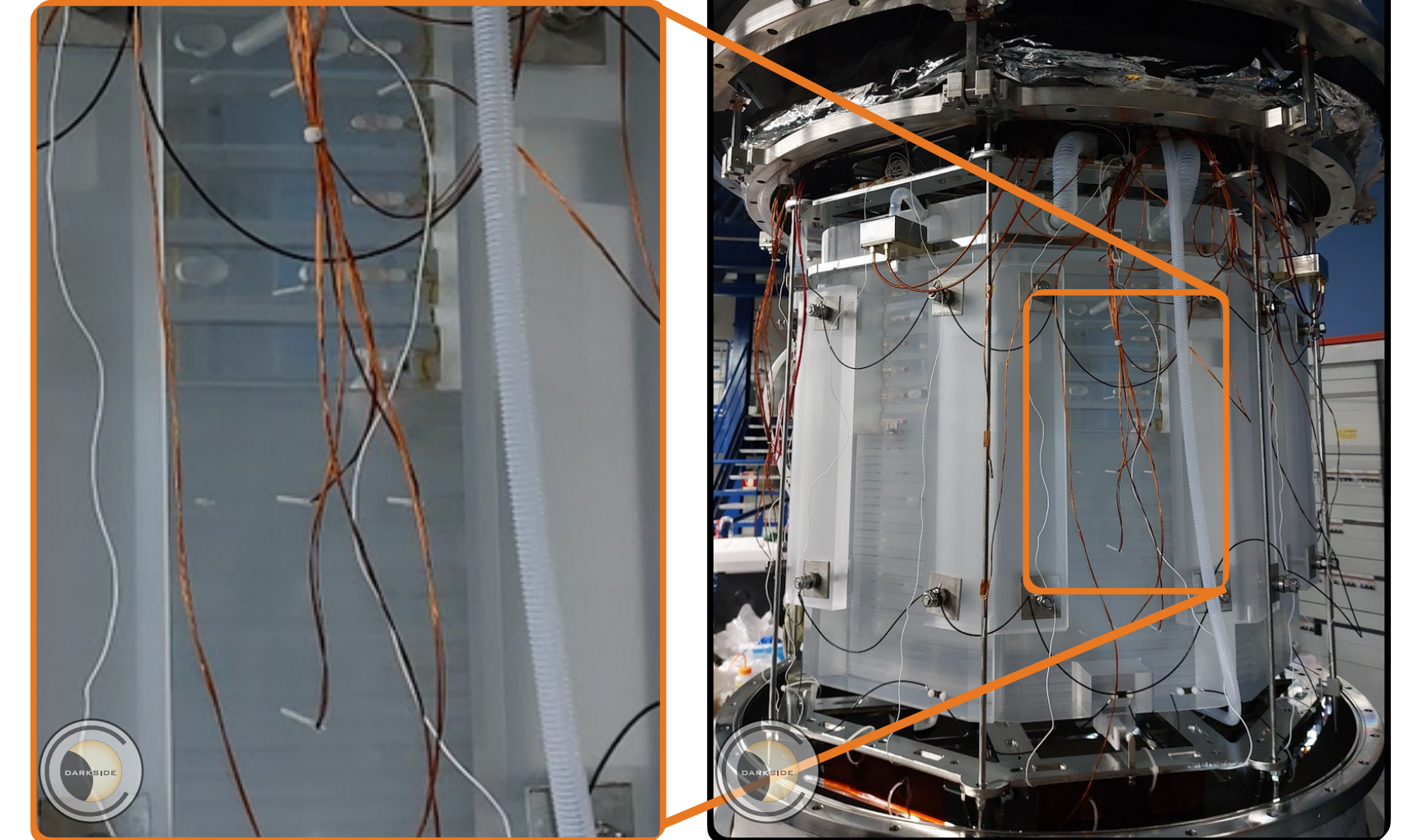


Thermal Cycling of PMMA TPC

- Thermal stress due to temporal and spatial gradients needs to be minimized
- Thermal simulations indicate that a $\sim 0.5 \text{ K/h}$ is needed to stay below $\sim 2 \text{ K/cm}$
- Measured internal temperature of the PMMA Barrel Panels

- ➔ This is a safety factor of 10
- ➔ Cooldown via continuously colder GAr only
- ➔ Various radial and vertical placements

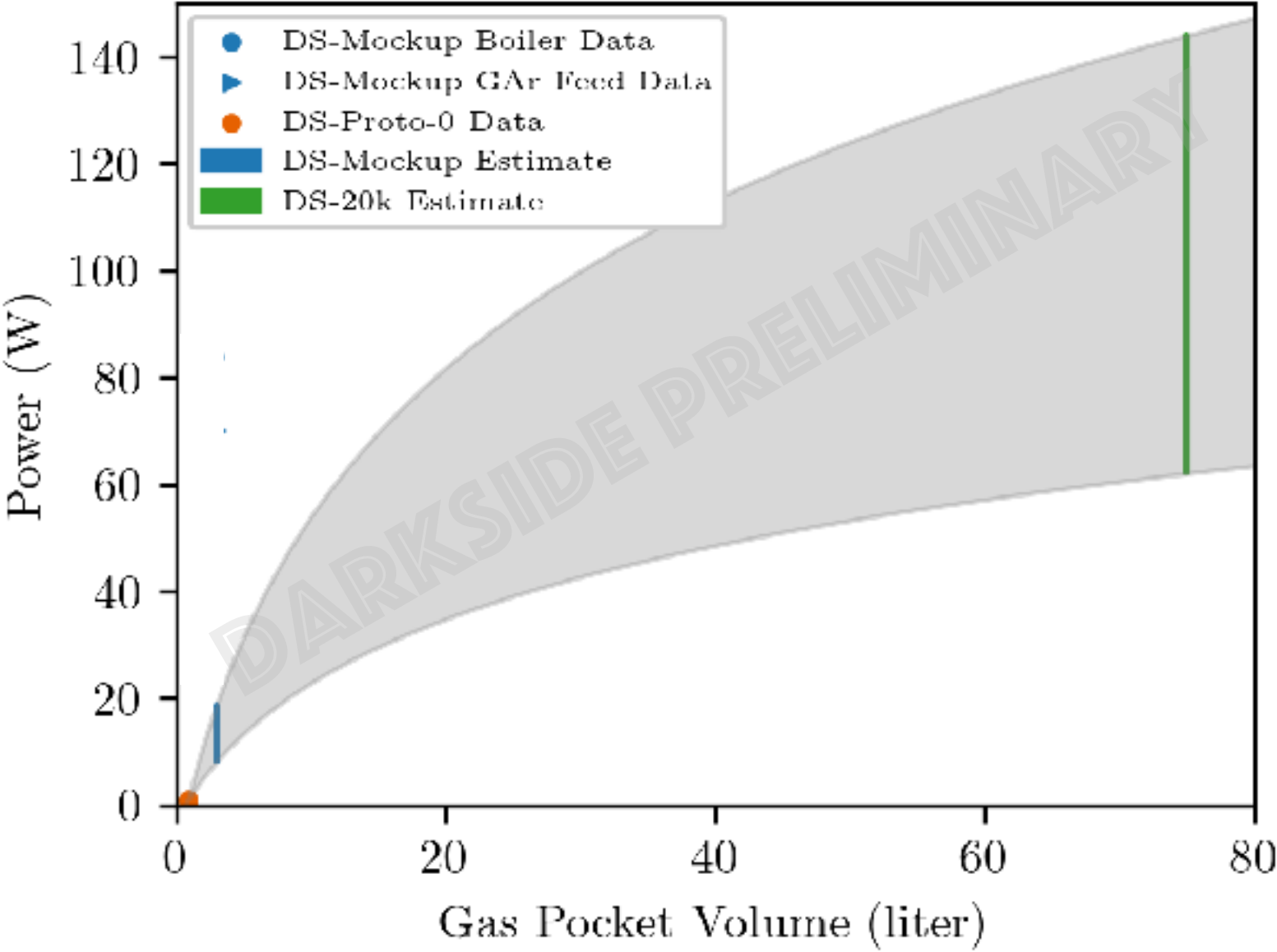
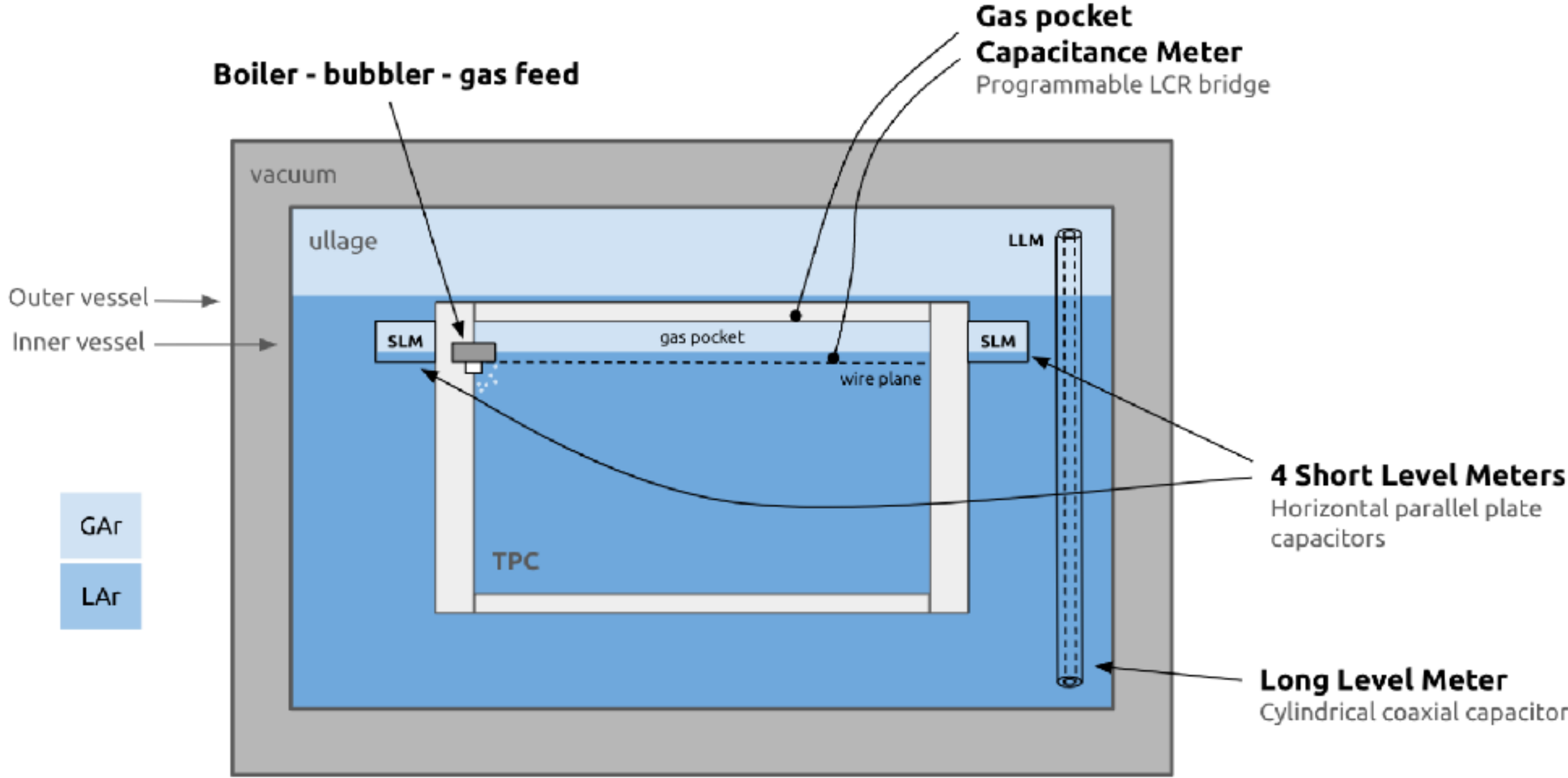
Custom Press-Fit Stainless Steel Encapsulated Ceramic RTDs



Gas Pocket Generation — Idea

- Generation of gas pocket via
 - Internal LAr vaporization via a 10Ω resistor
 - Direct feed of GAr from an external bottle

Source	Power (W)
Heat dissipation through anode	3
Heat dissipation through grid frame	1.6
Heat transfer over liquid-gas interface	3
Heat transfer over piping	0.5
Total Power	8.1



Gas Pocket Generation — Data

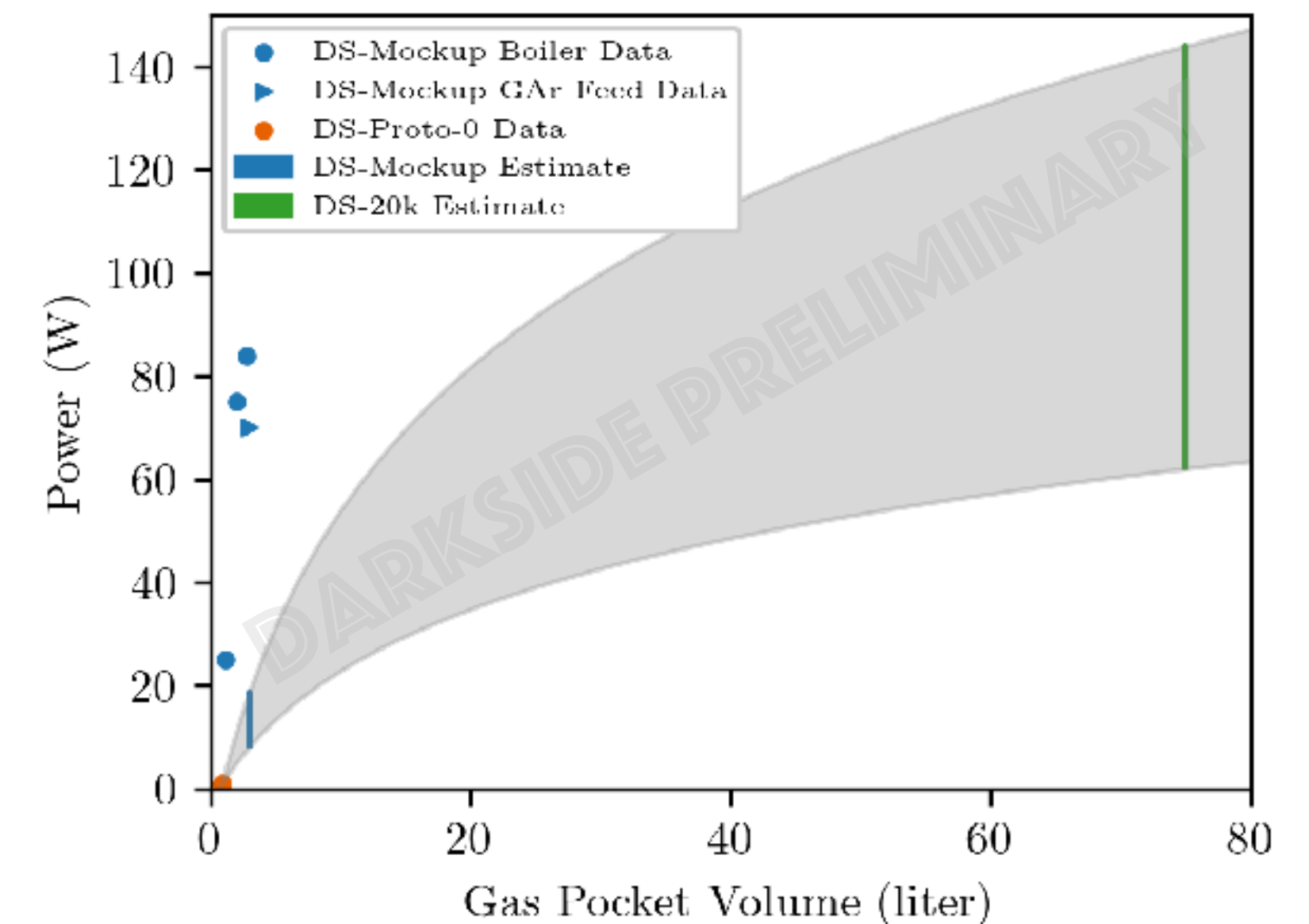
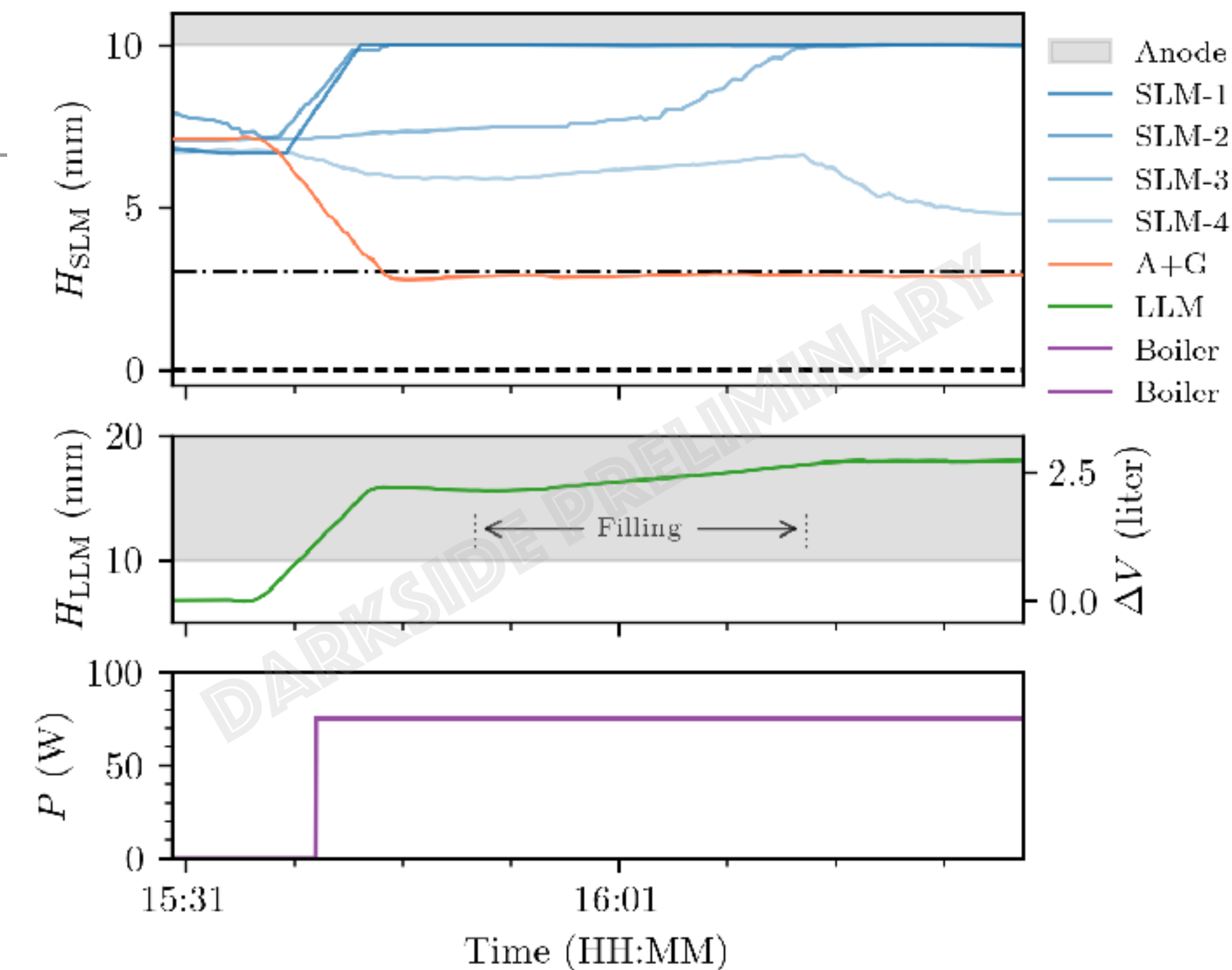
- Multiple attempts in different configurations yielded
- Power to generate and maintain the gas pocket is multiple times higher than expected
- Likeliest explanation
- Imperfect seal between PTFE connections and PMMA
- Standalone gas pocket test using DS-20k-like fittings for sealing is underway

➔ Internal vaporization
➔ External gas feed
➔ Overall LAr level

➔ Camera feed shows bubbling

➔ Relied on differential thermal contraction to ensure a proper seal at LAr temperatures

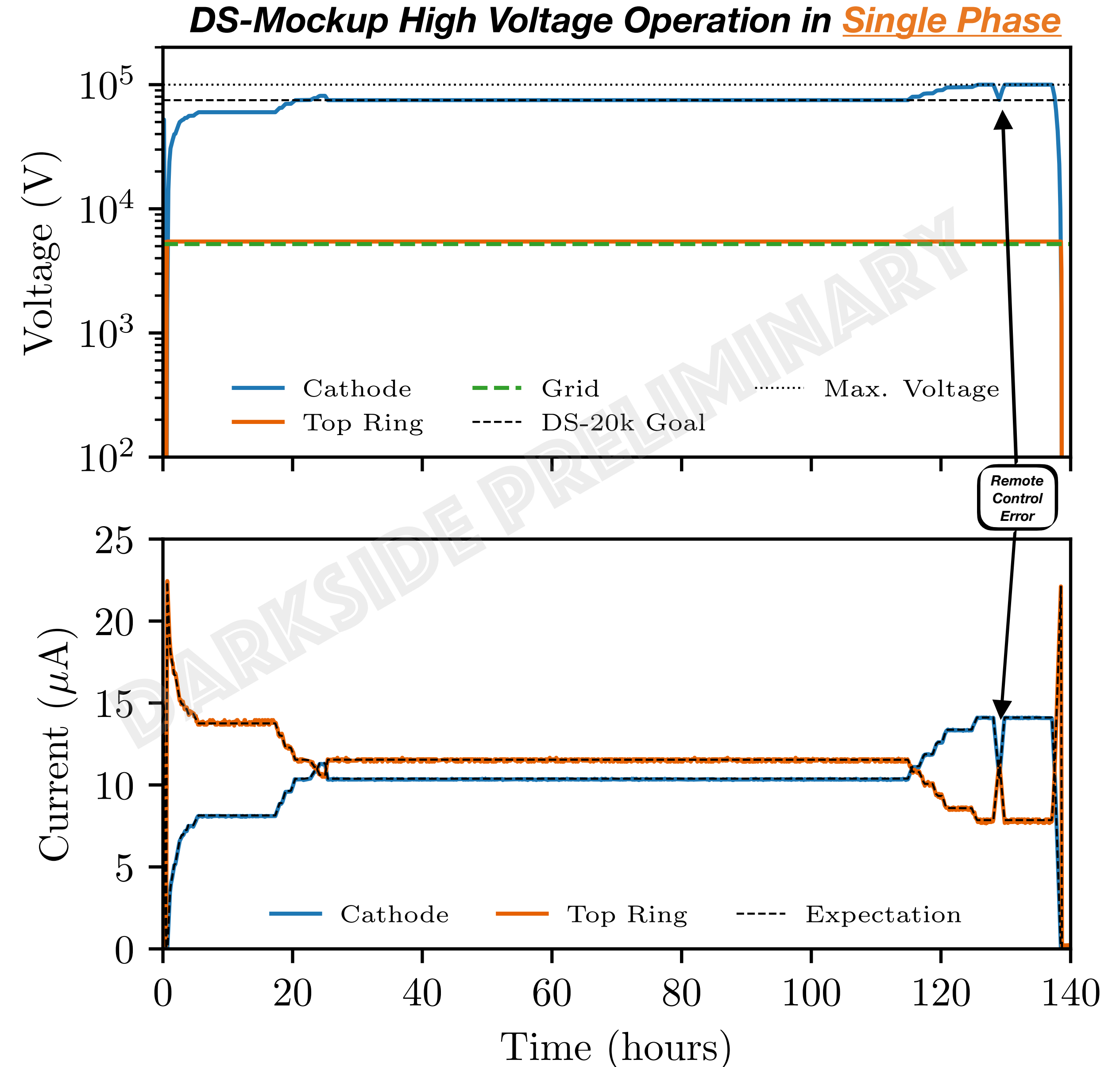
➔ Final design of DS-20k moved to PMMA inserts and metal fittings



DS-Mockup High Voltage Data — Single Phase

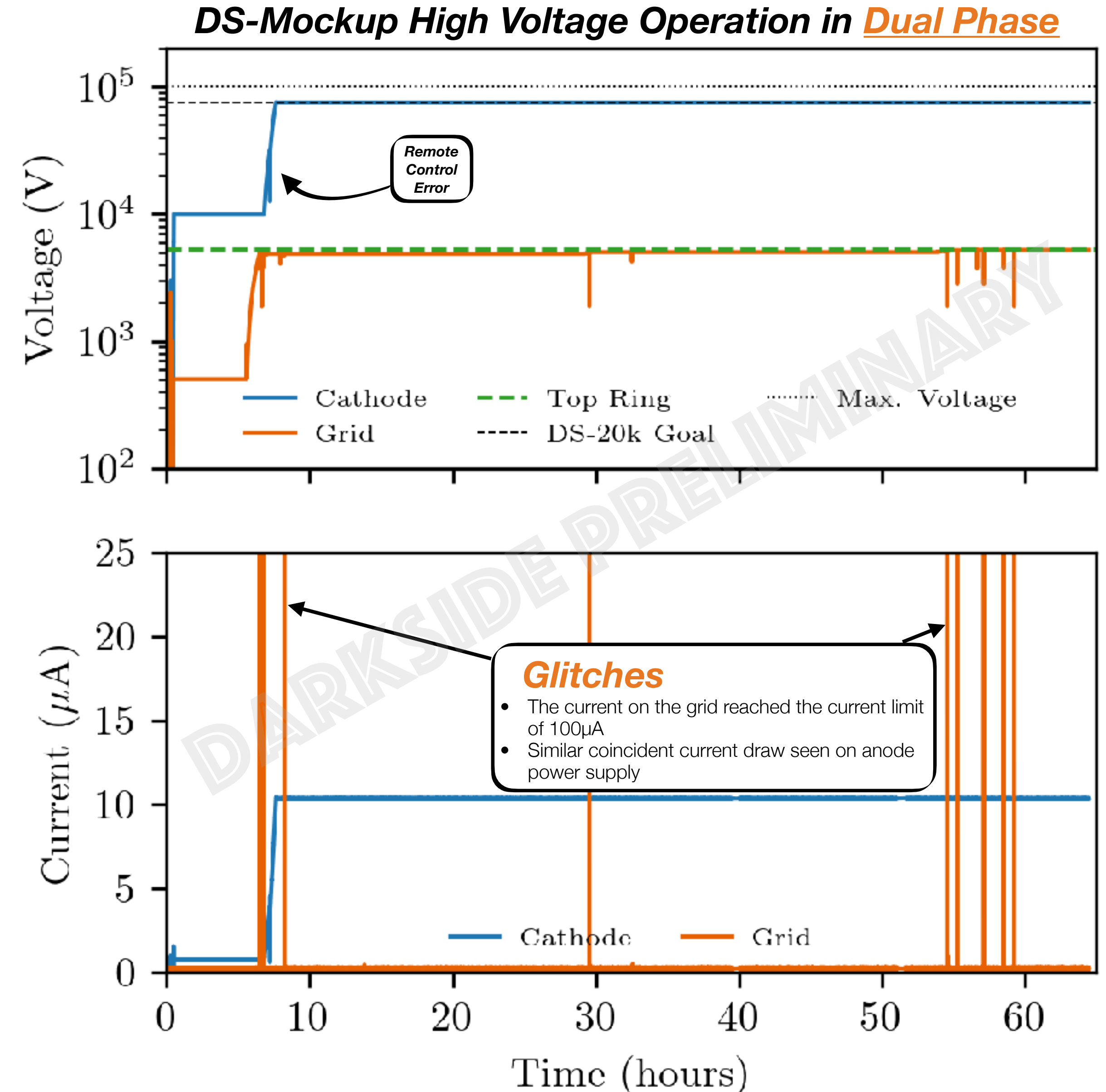
- Automated high voltage ramp up of **100 V/10 s**
- Current draw from cathode and top ring power supply match expectations
- Successfully delivered up to **−100 kV** to the cathode

➔ Drift field of ~ 1800 V/cm



DS-Mockup High Voltage Data — Dual Phase

- Grid HV instabilities likely due to
 - Gas pocket instability
 - Slightly out-of-spec tension of a few grid wires
- ➔ Grid design in DS-20k has been completely overhauled
- ➔ Will use a spring-loaded system to ensure proper tension
- HV recovers quickly after ~10s



DS-Mockup Post-Run Inspection

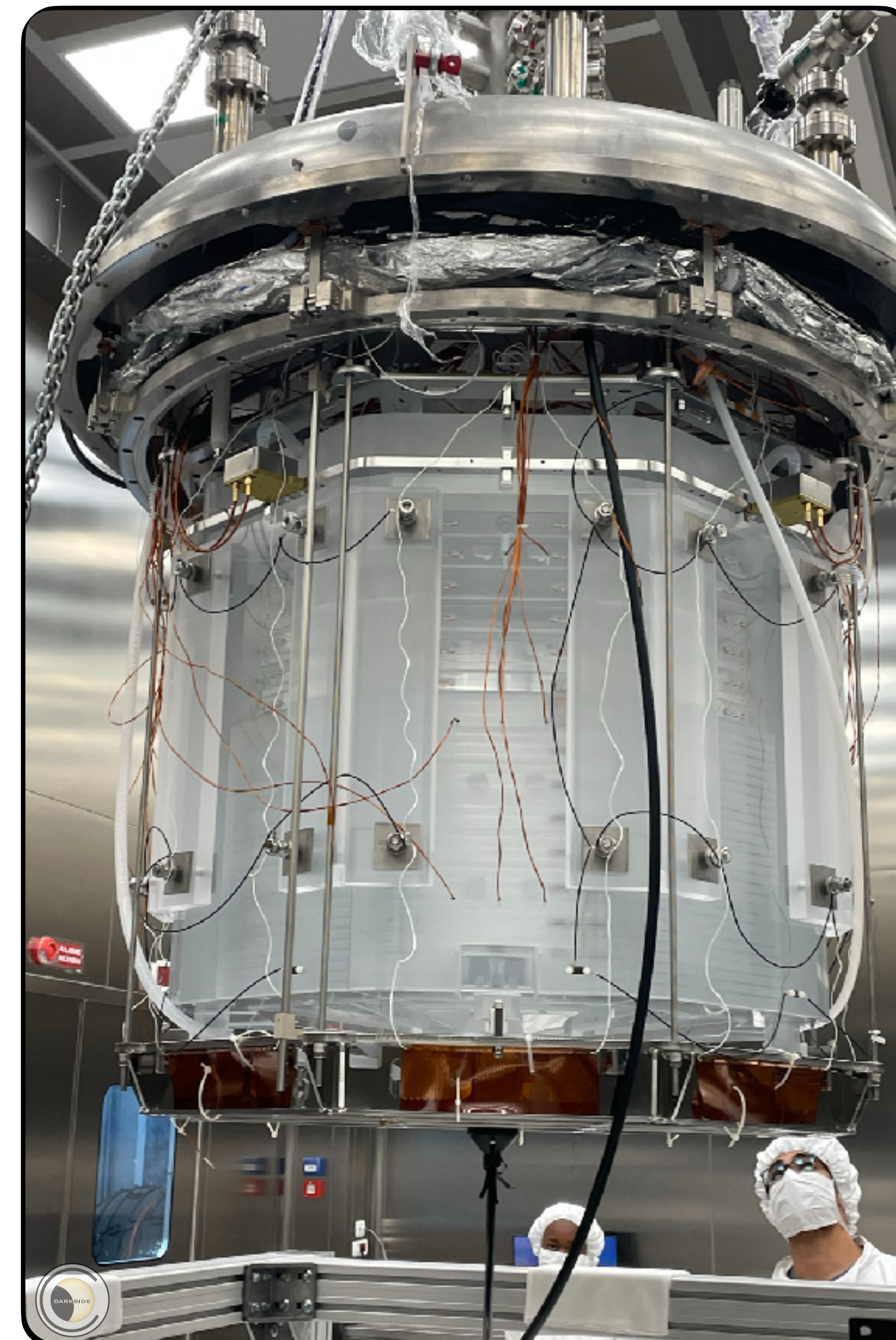
- Custom HHV cable undamaged after thermal cycling and HV operations
- Clevios coatings are intact
- Leak hypothesis “confirmed” through tests with compressed air
- PMMA remained undamaged

➔ *resistivity consistent with pre-run measurements*

➔ *standalone test with DS-20k-like fittings is being worked on*

➔ *well understood cooldown procedure for DS-20k*

DS-Mockup Detector Opened Post-Run



Summary and Outlook

- Successfully built, assembled, and ran a tonne-scale octagonal PMMA TPC
 - PMMA barrel assembly and flatness to within $\sim 100\mu\text{m}$ is achievable
 - Thermal cycling of PMMA TPC is reliable
 - HV delivery beyond the nominal cathode voltage of $V_C \sim -75\text{ kV}$ achieved
 - Electrostatic stability with conductive Clevios™ coatings in LAr not accessible
 - Power requirements for gas pocket generation are higher than expected
- **Publication in progress!**

➔ Major milestone towards the assembly of DS-20k

* More tests with purity control and longer-term stability underway

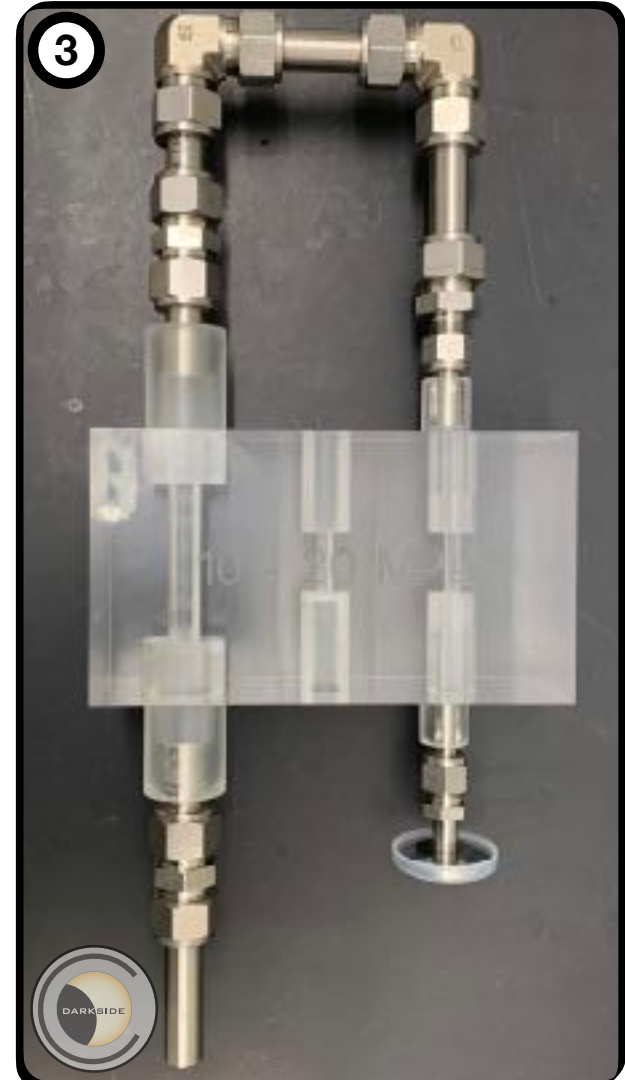
➔ Additional data from DS-Proto-0

* Leaks made measurements difficult; standalone test being planned

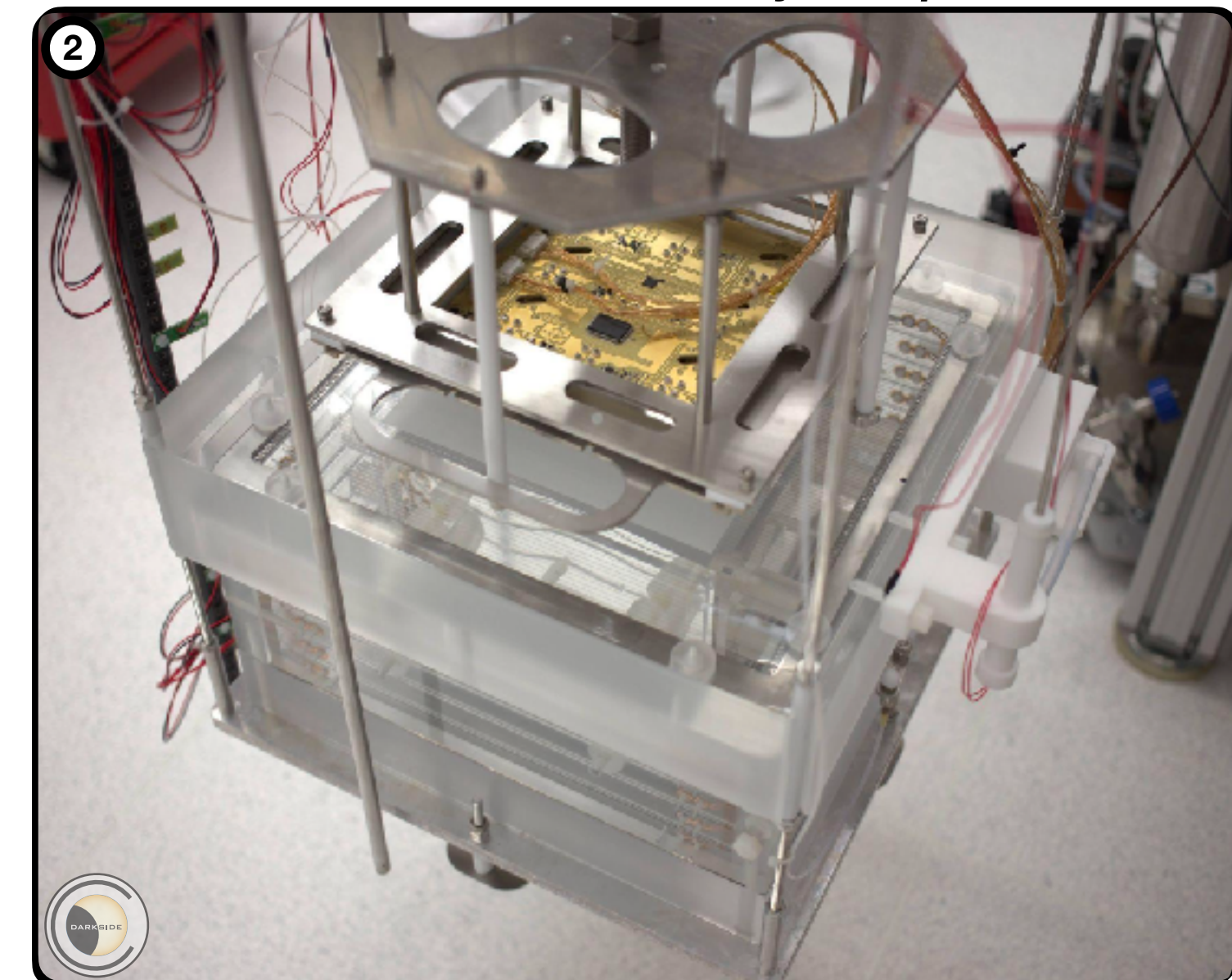
HV Test Setup at UC Davis



PMMA Press Fit



DS-Proto-0 at University of Naples



United States



United Kingdom



Italy



Canada



Germany



Brazil



France



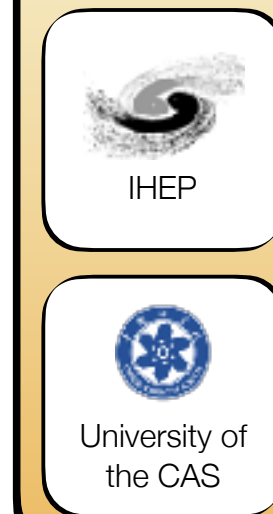
Switzerland



Poland



China



Russia



Spain



The  -20k Collaboration

Bonus Slides

Overview of High Voltage Data

Experiment	Anode HV (kV)	Grid HV (kV)	Top Ring HV (kV)	Cathode HV (kV)	Operation	Glitches?	LAr Purity
UC Davis Setup	X	X	X	-100	Single Phase	No	X
DS-Proto-0	0	-4.9	-5.7	-10.7	Dual Phase	No	~0.3ppb
DS-Mockup	0	-3.8	-4.2	-15	Single Phase	No	~50ppb*
DS-Mockup	0	-5.2	-5.45	-75	Single Phase	No	~50ppb*
DS-Mockup	0	-5.2	-5.45	-100	Single Phase	No	~50ppb*
DS-Mockup	0	-5.2	-5.45	-75	Dual Phase	Some on the grid due to gaspocket instability	~50ppb*
DS-20k	0	-5.2	-5.45	-73.38	Dual Phase	X	~0.06ppb

*not directly measured but estimated from outgassing of detector components
input argon was filled through a hot getter