Prototype Validation Studies for the DarkSide-20k TPC

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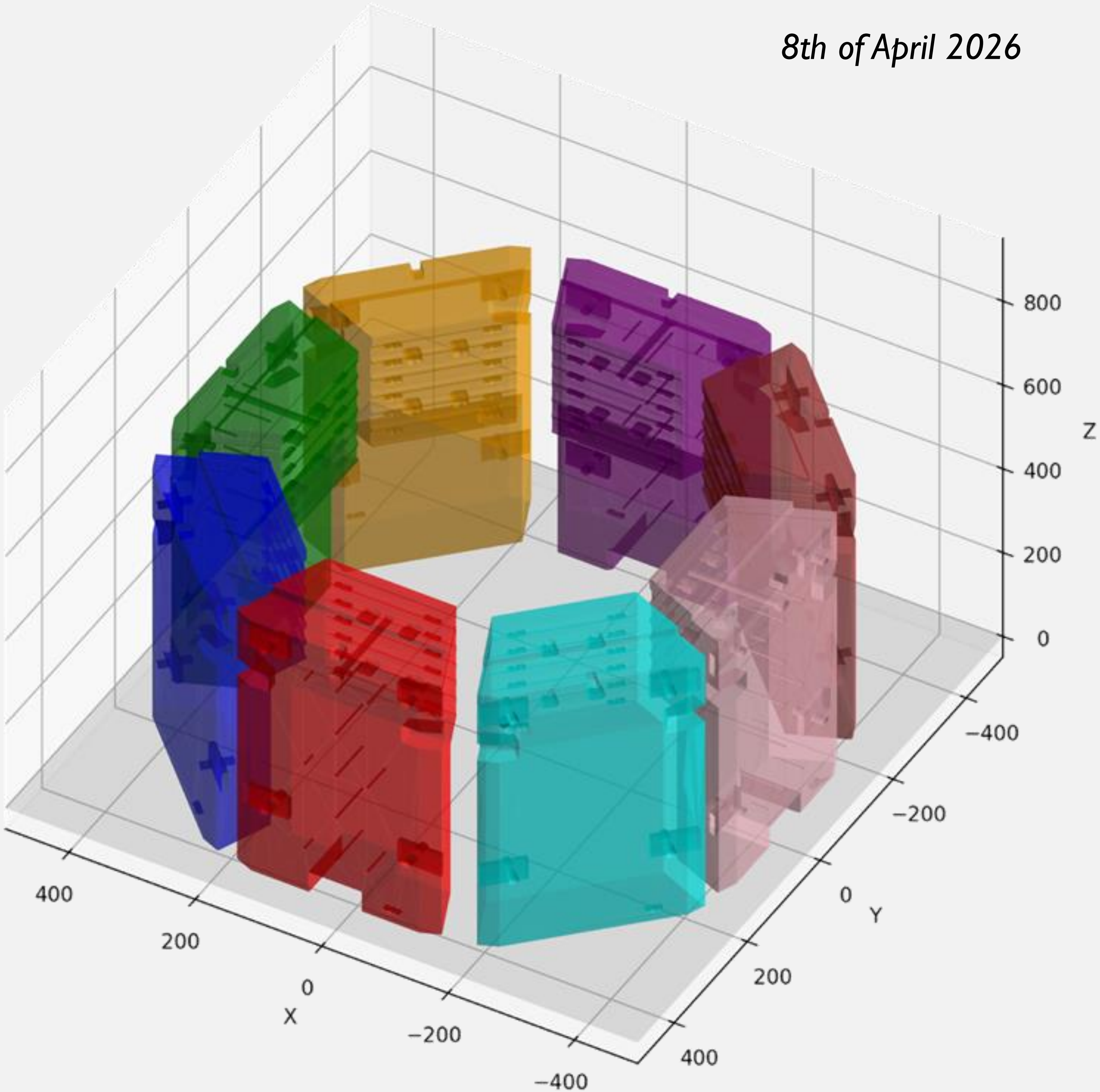
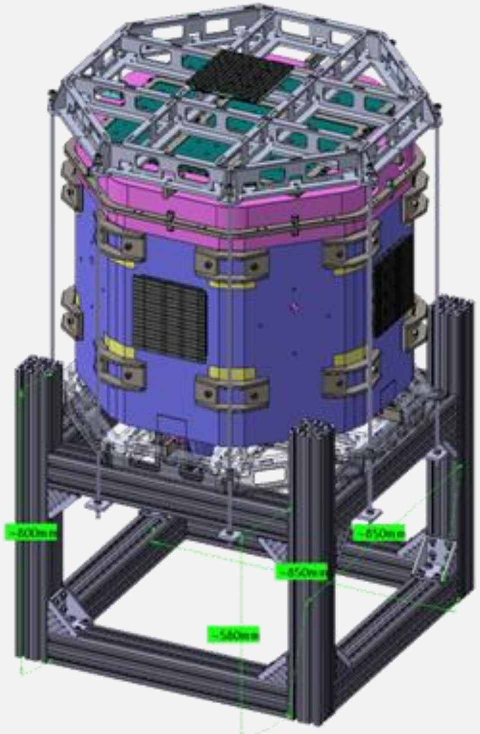


Introduction

This talk will cover:

1. What is DarkSide-20k (DS-20k)?
2. The challenges posed by the scale of DS-20k
3. How the Prototype (Mockup) is designed to test:
   - *The dry fit*
   - *Planarity of PMMA and grid*
   - *Clevios, field cage, and HV system*
   - *Cryogenic system*
4. The virtual alignment of the DS-20k TPC



The Mockup TPC on its assembly platform

DarkSide-20k

Main detector sections of DarkSide-20k

- **Outer veto**

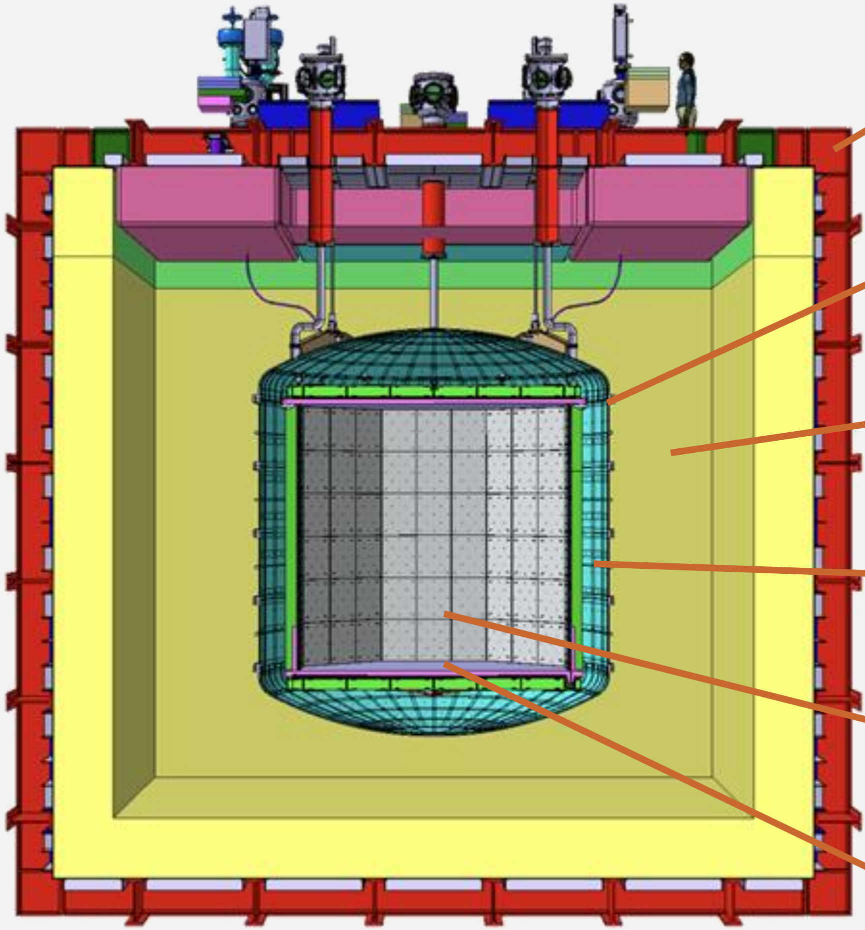
  Designed to catch cosmogenic neutrons by detecting the primary neutron – argon from atmospheric sources

- **Inner veto**

  Designed to tag radiogenic neutrons by detecting gammas from their capture – argon from underground sources

- **Dual-phase TPC**

  Designed to detect and reconstruct events – argon from underground sources



DarkSide-20k schematic - F. Acerbi et al 2025 JINST 20 P02016

ProtoDUNE-like membrane cryostat

Stainless steel cryostat

Atmospheric argon outer veto (~700 tonnes)

Underground argon inner veto (~32 tonnes)

Underground argon TPC (~20 tonnes fiducial volume)

Silicon Photomultipliers as photosensors

The Dual-phase Time Projection Chamber (TPC)

1. Dark matter particle enters the TPC
2. Interacts with the LAr to produce a scintillation flash (S1)
3. Electrons drift upwards

   Drift time can give z-positions
4. Electrons accelerate into gas phase

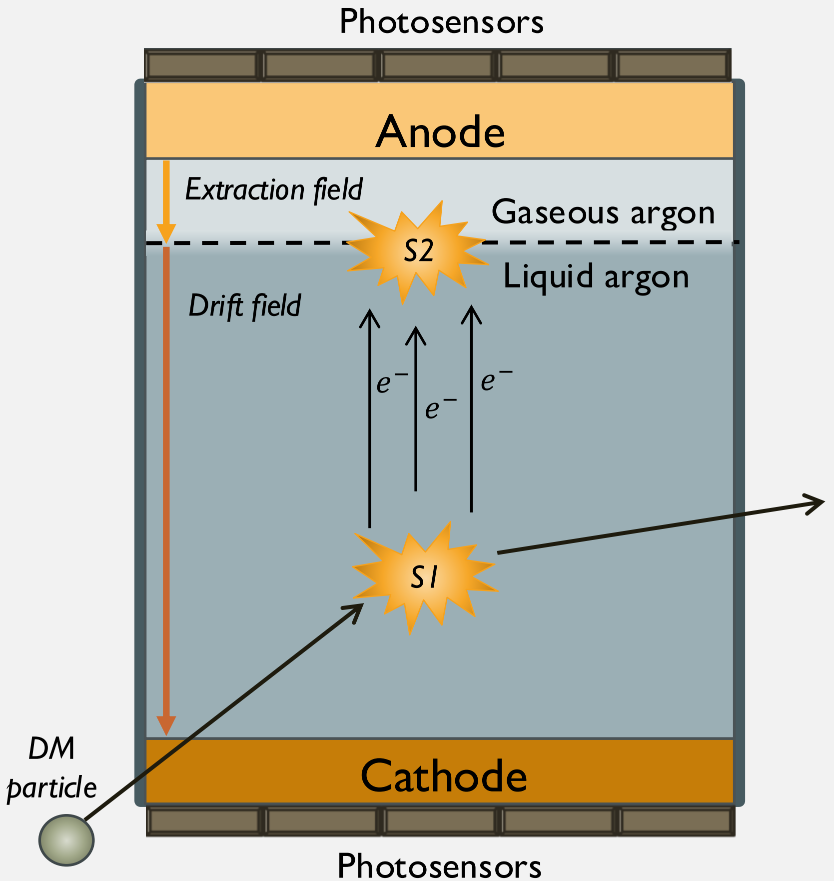
   Produces electroluminescence (S2)

S1 (prompt light) → energy and timing start.

S2 (delayed light) → position and charge.

Time difference between S2 and S1 gives depth.

Light pattern on sensors gives x-y position.



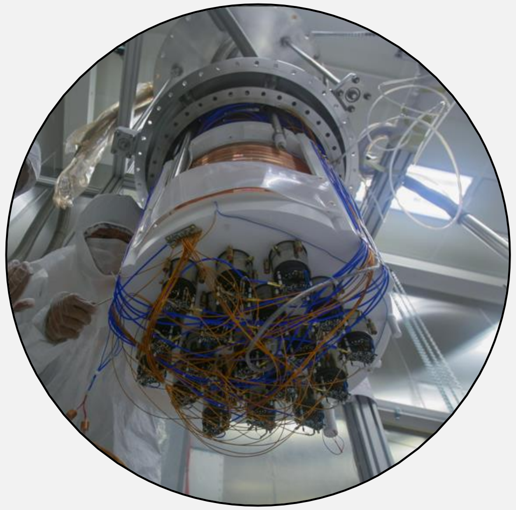
The Journey to DarkSide-20k

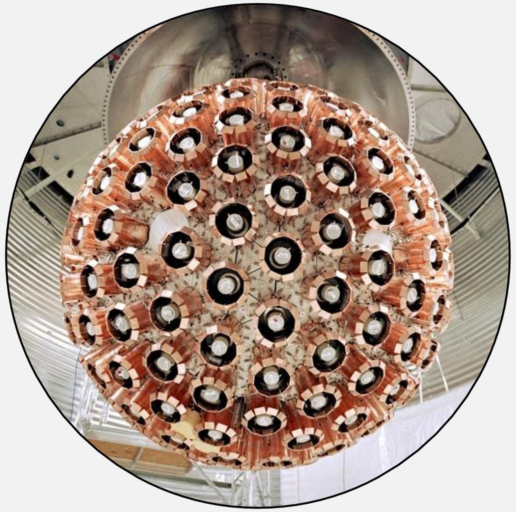
ArDM
- 1-tonne LAr
- Dual-phase TPC
- Exploration of technologies at tonne scale

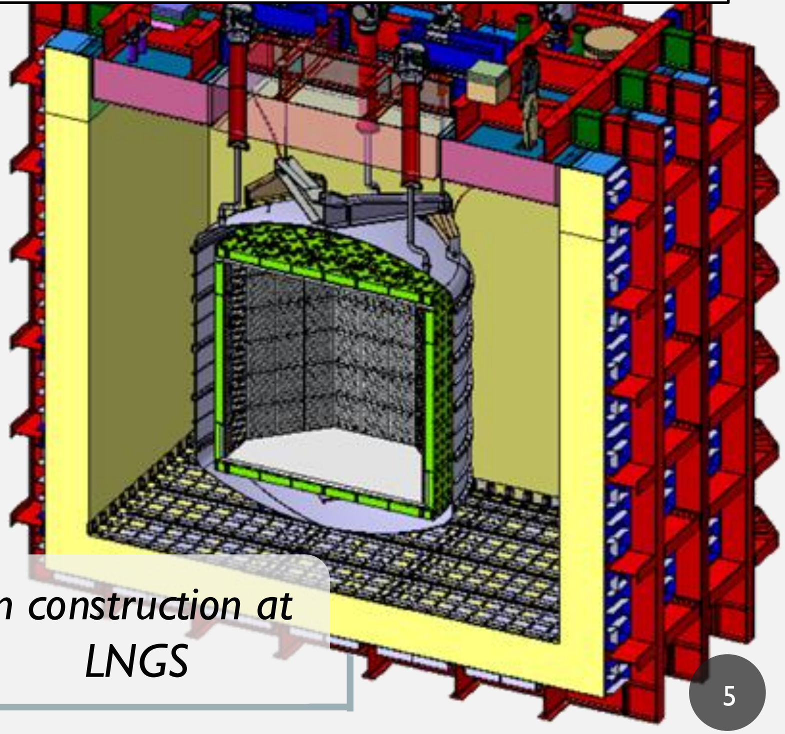
DarkSide-50
- 47 kg LAr
- Dual-phase TPC
- 3D event reconstruction

DEAP-3600
- 3.6-tonne LAr
- Single-phase liquid argon detector
- Pulse-shape discrimination

DarkSide-20k
- 50-tonne LAr (20T fiducial)
- Dual-phase TPC
- Unprecedented scale and sensitivity







Year of first data-taking

2013

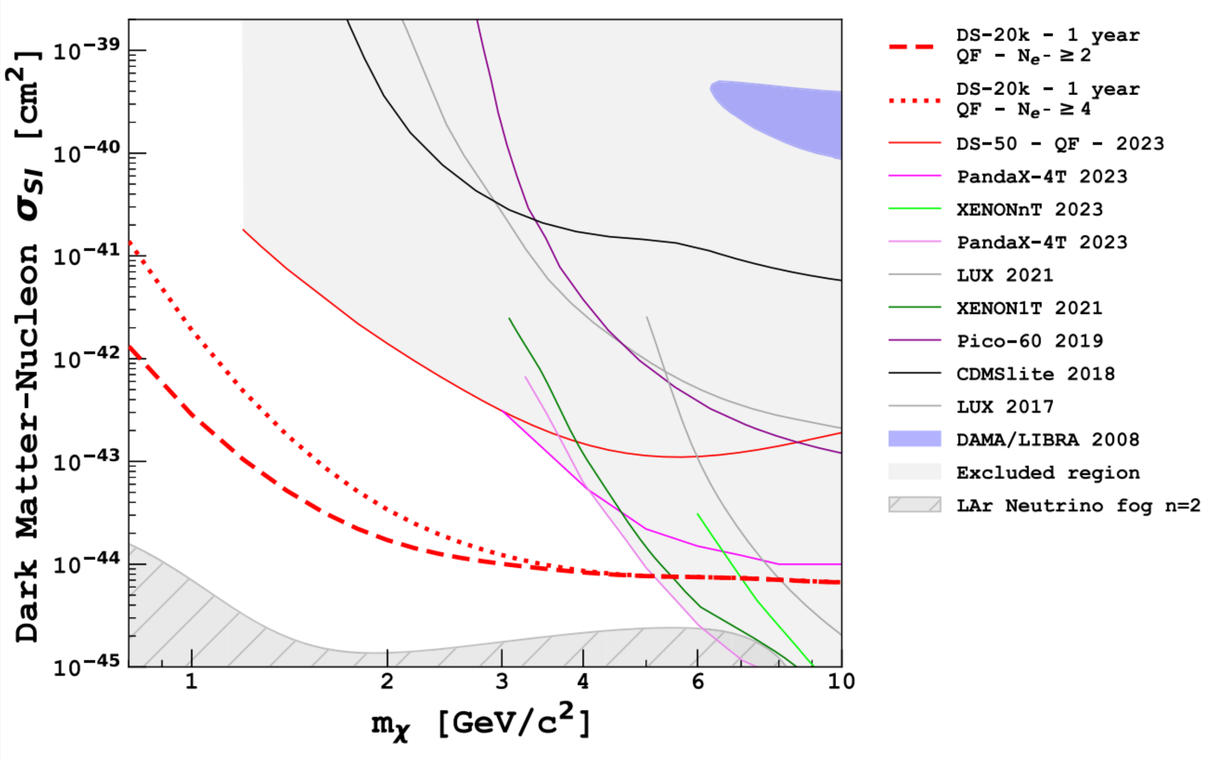
2015

2016

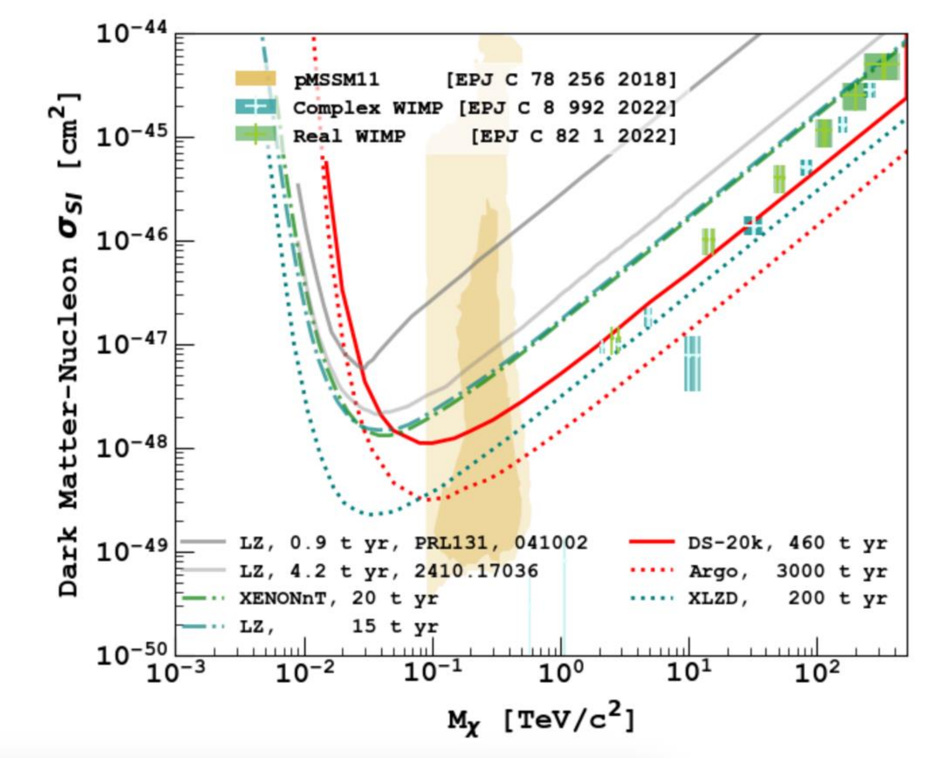
In construction at LNGS

DarkSide-20k Projected Sensitivity

Low Mass



High Mass



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Design and Goals of the Mockup

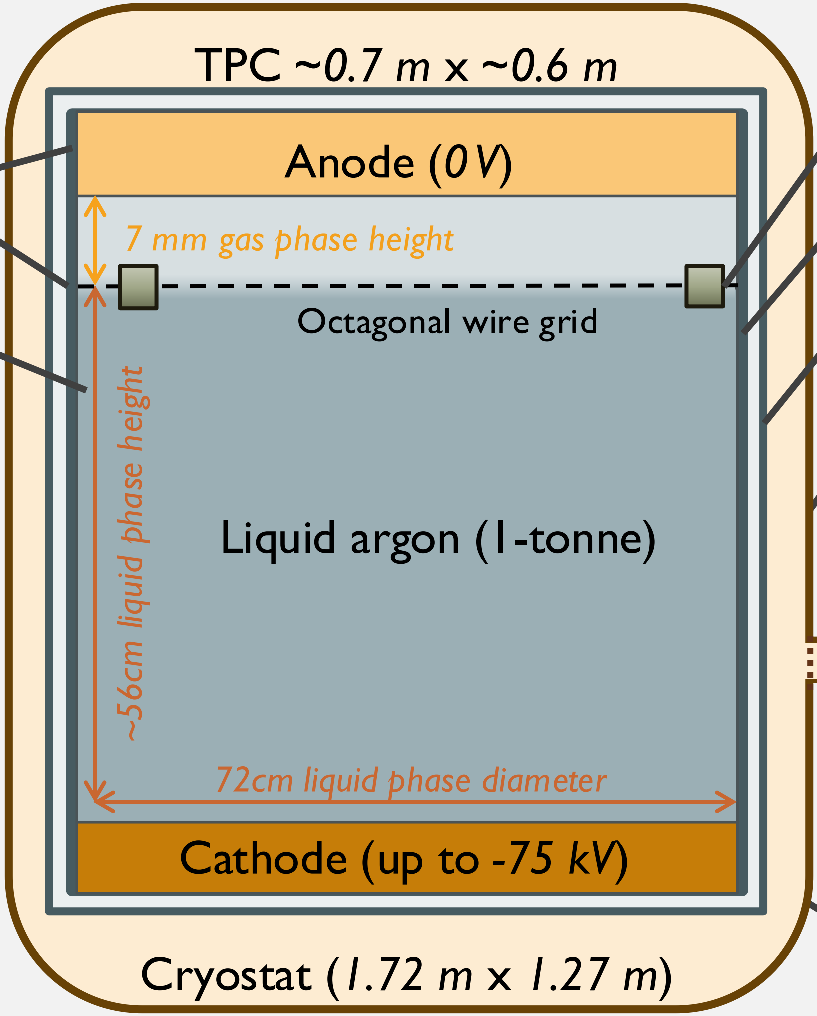
Challenge	Mockup approach
Mechanical stability of field cage	Octagonal acrylic TPC design, “dry-fit” and scanning for mechanical cross-check.
Thermal stability of acrylic	Thermal stability to be monitored extensively during cooldown and operation.
Field uniformity at HV and large scale	Clevios coating for field cage, stability and uniformity to be tested at intermediate scale.
HV delivery at large voltages	Monitor over 12-week period at DS-20k scale, including ramping up and down.
Grid planarity at large scale	Planarity to be measured with 3D scanner and optical methods at intermediate scale.
Cryogenic stability over time	Monitor over 12-week period at 1-tonne scale.
Gas pocket formation	Test use of bubbler and direct argon feed for gas pocket formation.
Gas pocket stability	Monitor over 7-day period at 1-tonne scale.

Design and Goals of the Mockup

Wire grid and anode (dual phase region)

1-tonne of liquid argon

- Acrylic TPC and resistive Clevios field cage
- Test HV system and feedthrough up to full -75 kV
- Realistic grid and extraction system
- Gas pocket formation system
- Cryogenic platform and cooling/filling
- Precision level sensing and slow control



Level meters at interface

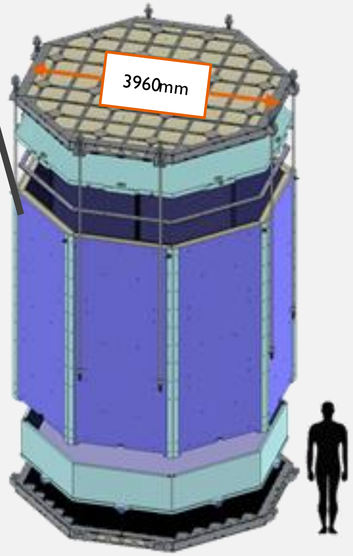
Clevios-coated field cage

Octagonal acrylic TPC

Cryostat and cryogenics

External cryogenic system

HV system and feedthrough

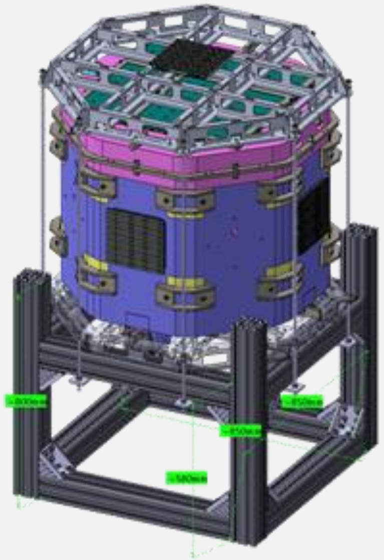


Darkside-20k inner detector

The Dry Fit

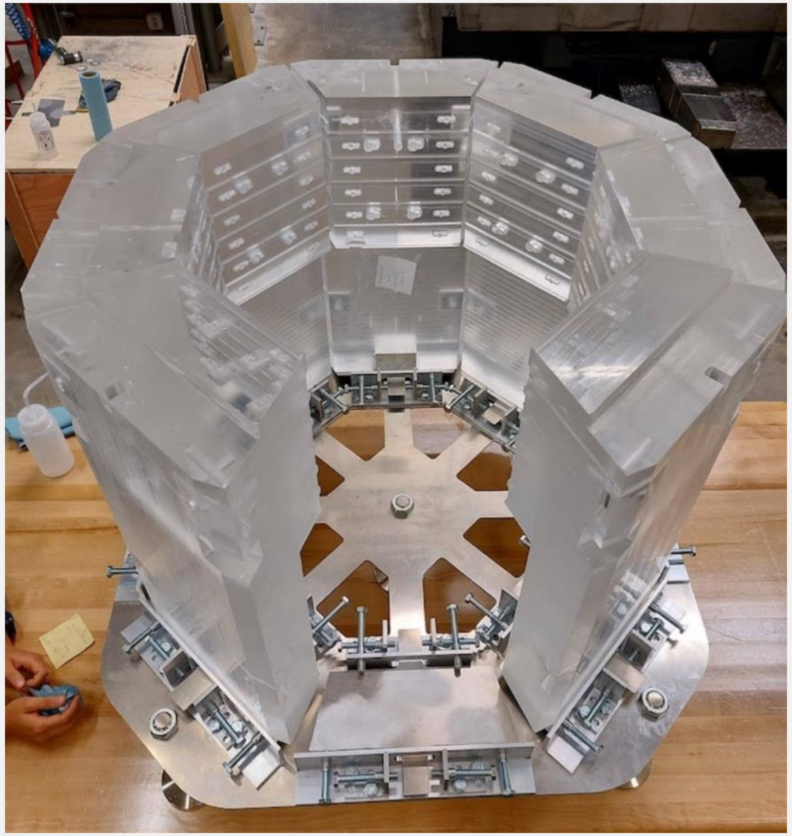
Preliminary hand-fitting of TPC components after machining

- Test mechanical stability and alignment
- Assess flatness (required within 100 µm)



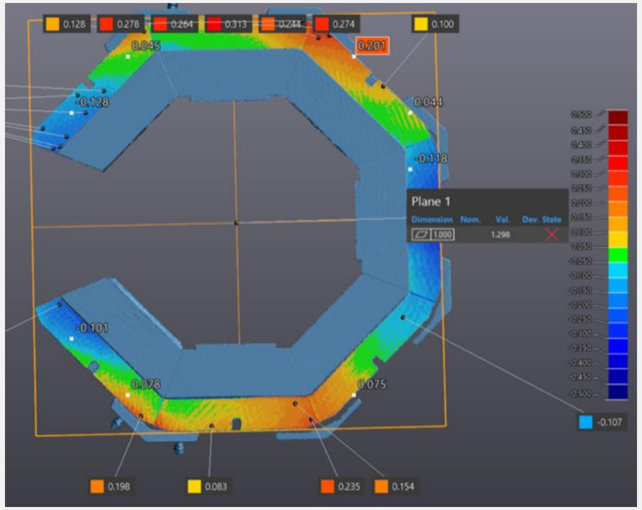
Mockup barrel and frame

Use of Creaform 3D scanner to assess flatness (image from final alignment)



TPC panels and alignment frame

The Dry Fit – Flatness

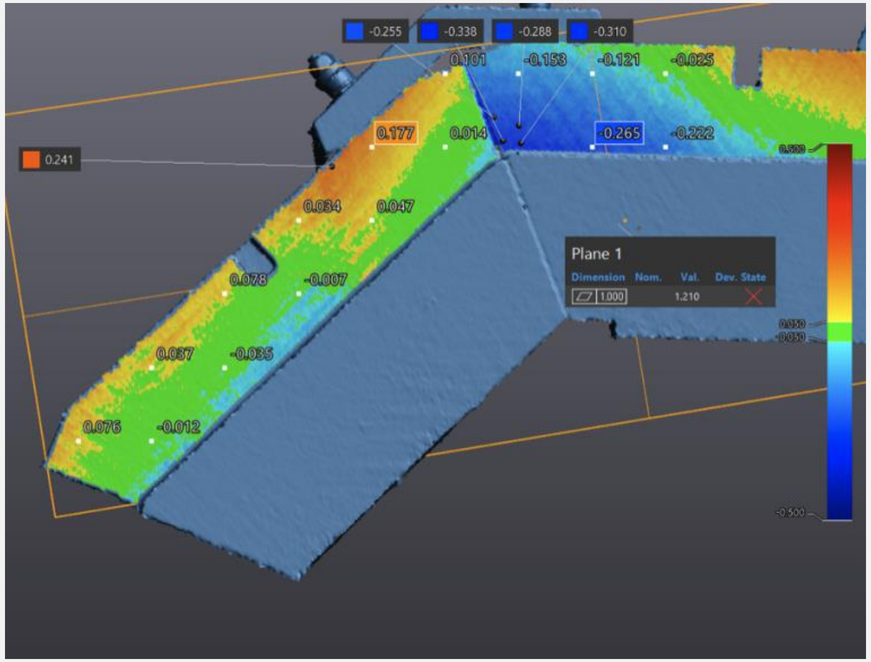


Creaform MetraSCAN 3D in Scan of panel top flatness

Method

- Used Creaform 3D scanner to assess flatness (µm resolution)
- Corrected flatness with steel shims – switched to full alignment frame
- Developed plastic spacers to improve alignment
- Corrected and re-scanned incrementally

A scan of a single panel, where planarity was achieved by placing shim foils beneath it and separating it from the adjacent panel.

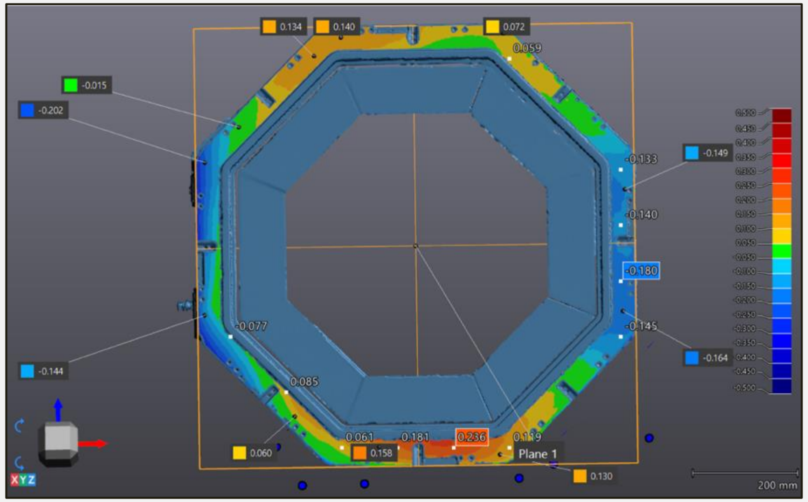


Results

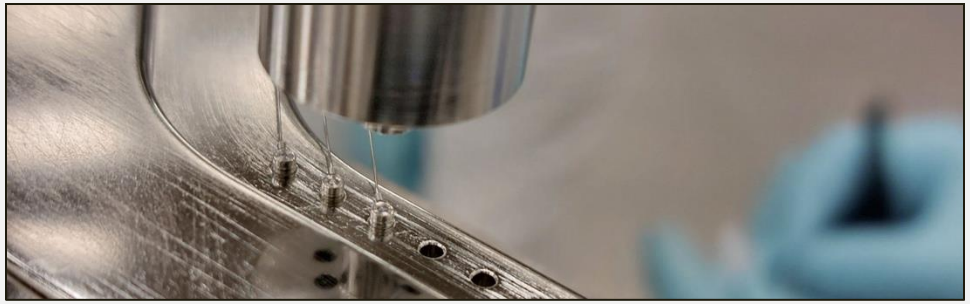
- Impractical to have panels in contact – introduce spacing
- Built and validated support structure and realignment mechanism
- Scanner valid for assessment of flatness – **100 µm flatness achieved!**

Wire Grid Planarity

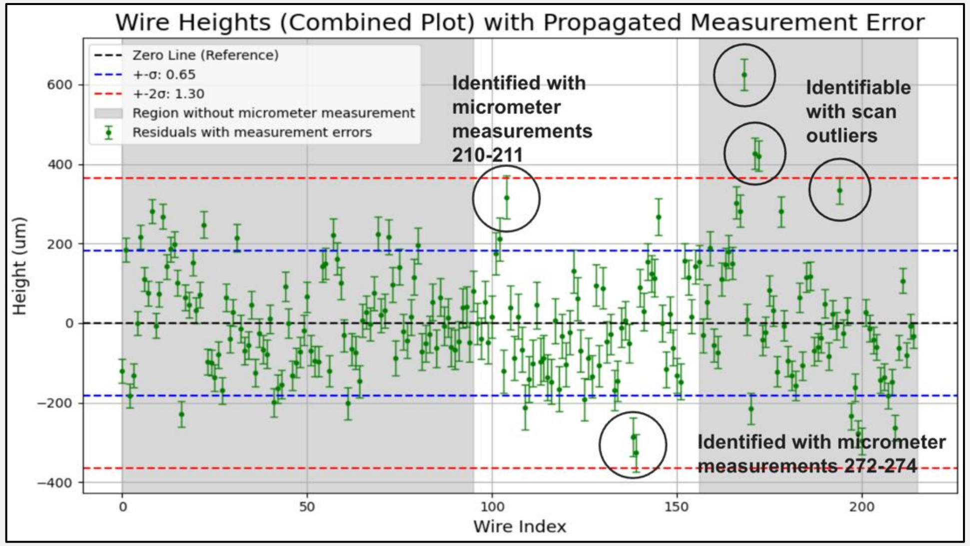
- The wire grid separates the drift and extraction fields
- It is a plane of parallel current-carrying wires attached to a frame by pins
- Require flatness within 100 μm
- Measured using the 3D scanner – could not resolve individual wires
- Developed optical method for wire height measurement
- Heights not within 100 μm – **redesigned grid for DS-20k**



Scan of grid frame – individual wires not visible



(Top) Pin attachment mechanism (Bottom) Wire heights from optical measurement, identified with scan and micrometer results



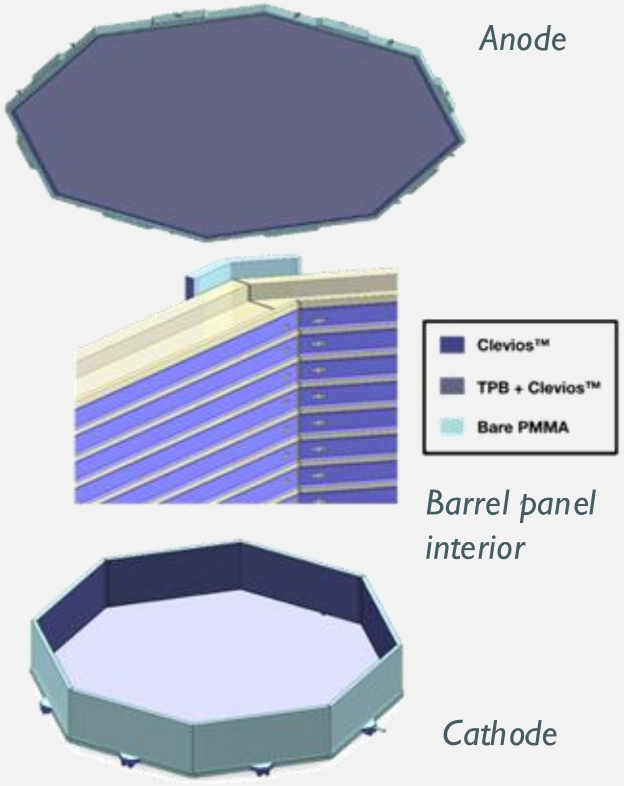
Validation of Clevios (Resistive Field Cage)

Design

- Interior of TPC barrels, anode, and cathode sprayed with a conductive Clevios coating
- Forms a continuous resistive divider

Specs

- This created a total field cage resistance of *6.5 GΩ*
- With ~*116 MΩ/cm*
- Allowed for electrical continuity across panels



Results

- Electrical continuity achieved
  - Cage behaves as a single resistive element with no breaks or discontinuities
- Resistivity within specs
- Coatings sensitive to handling/thermal cycles
  - Required re-coating after damage
- **Scalable method is viable**

High Voltage Validation

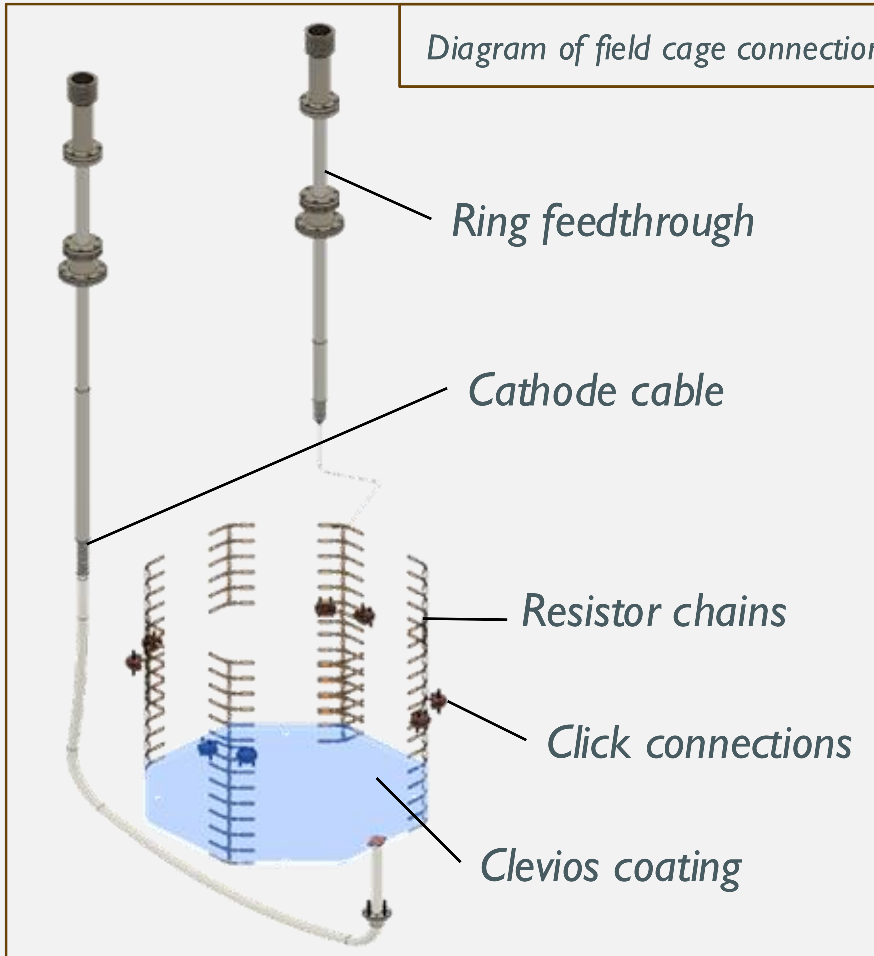
Design

- Cathode up to *-75 kV*
- Grid and top ring biased via resistor chain
- Semi-resistive HV cable

Tests

- Controlled ramping at *10 V/s*
- Long-term stability runs at DarkSide voltage (*-75 kV*) and higher (up to *-100 kV*)

Diagram of field cage connections



Results

- Electrical continuity achieved
- Ran at *-75 kV* in dual phase for 3 days
- Ramped up to *-100 kV* and maintained for 24 hours
- **Method is viable for DS-20k field requirements**

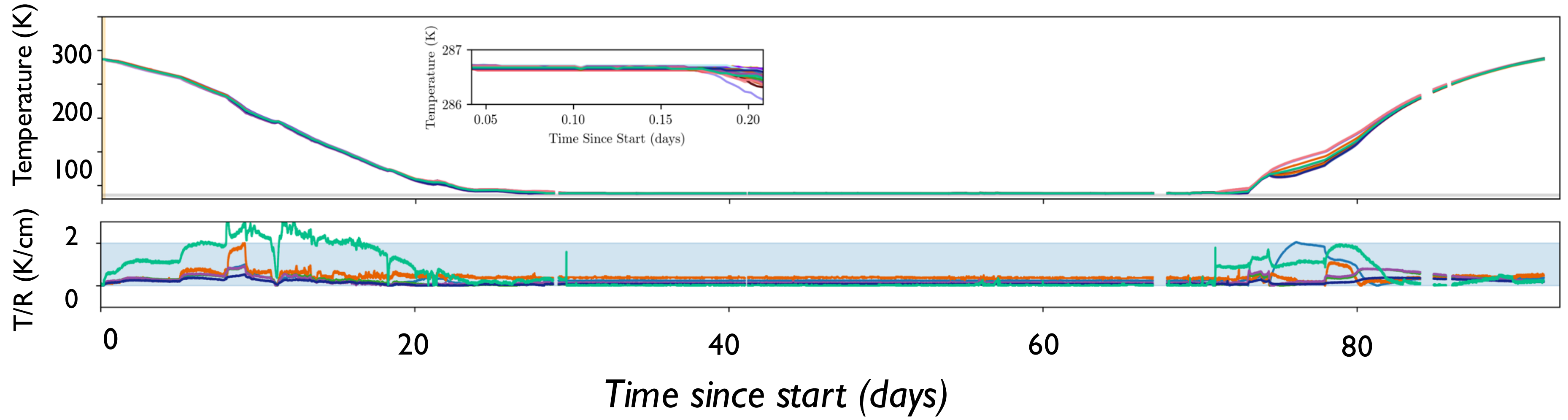
Cryogenic System Validation

Requirements

- Fill cryostat with LAr while keeping temperature gradient in PMMA <2 *K/cm*
- Requires 2.5-week steady cooling period down to *110 K*

Results

- Stable cooling over 3.5 weeks
- Stable warming over 2 weeks
- Temperature gradients within specs
- **Method is viable for DS-20k field requirements**

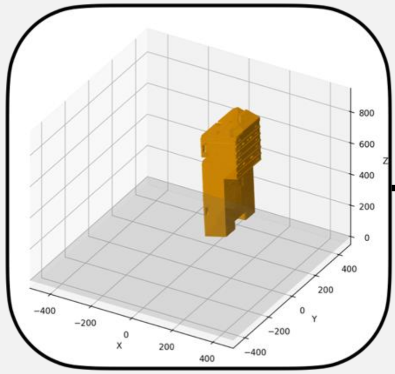


Temperature sensor data over full run. Each colour indicates a different PMMA position. Blue regions indicate required specs

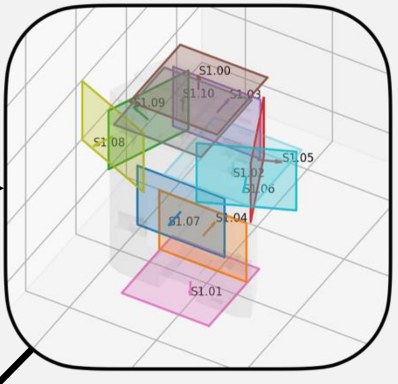
Virtual Alignment for DarkSide-20k

Goal: Use results from the Mockup to develop a robust tool for virtual alignment of the Darkside-20k TPC

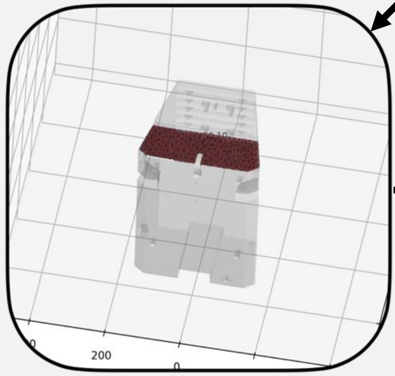
For each component:



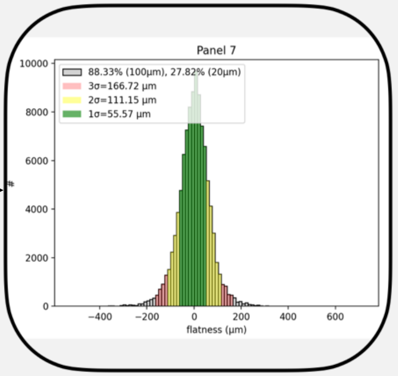
Load component



Find surfaces

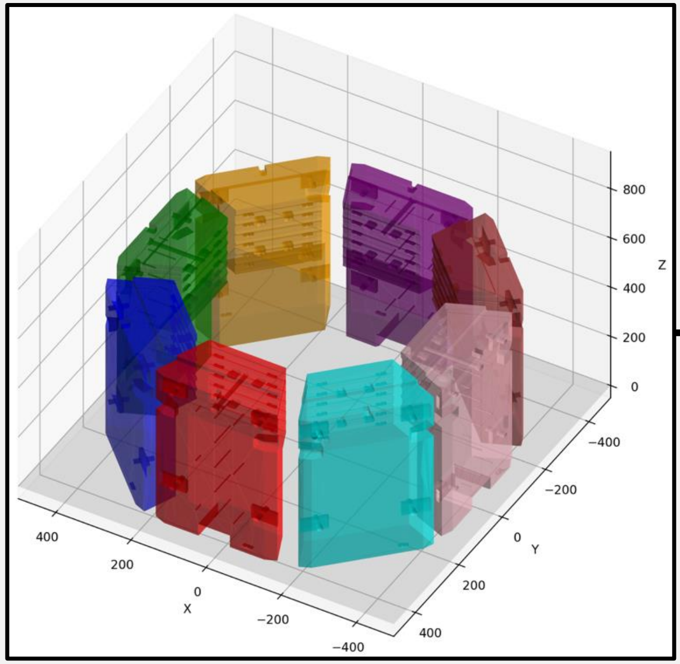


Identify relevant surfaces



Calculate flatness

Place and align components



Use analytical and statistical methods to check for collisions

Conclusion

- The Mockup was designed to validate new technologies for DS-20k at the 1-tonne scale
- The Mockup was able to test:
  - *The dry fit – improved method for PMMA alignment*
  - *Planarity of PMMA and grid – PMMA successful, grid redesigned*
  - *Clevios, field cage, and HV system – validated scalable systems for DS-20k*
  - *Cryogenic system – validated system for DS-20k*
- Mockup data is being used to develop tools for the virtual alignment of the DS-20k TPC

References

DarkSide-20k Collaboration, *"DarkSide-20k sensitivity to light dark matter particles,"*

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A. Jamil, *"The DarkSide-20k Experiment and the Search for Dark Matter with Underground Argon,"*

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Global Argon Dark Matter Collaboration (DarkSide-20k), presentation materials (DocDB 5872)

DarkSide-20k Collaboration, *"Design, Installation and Operation of the DarkSide-20k Inner Detector TPC Mockup,"*

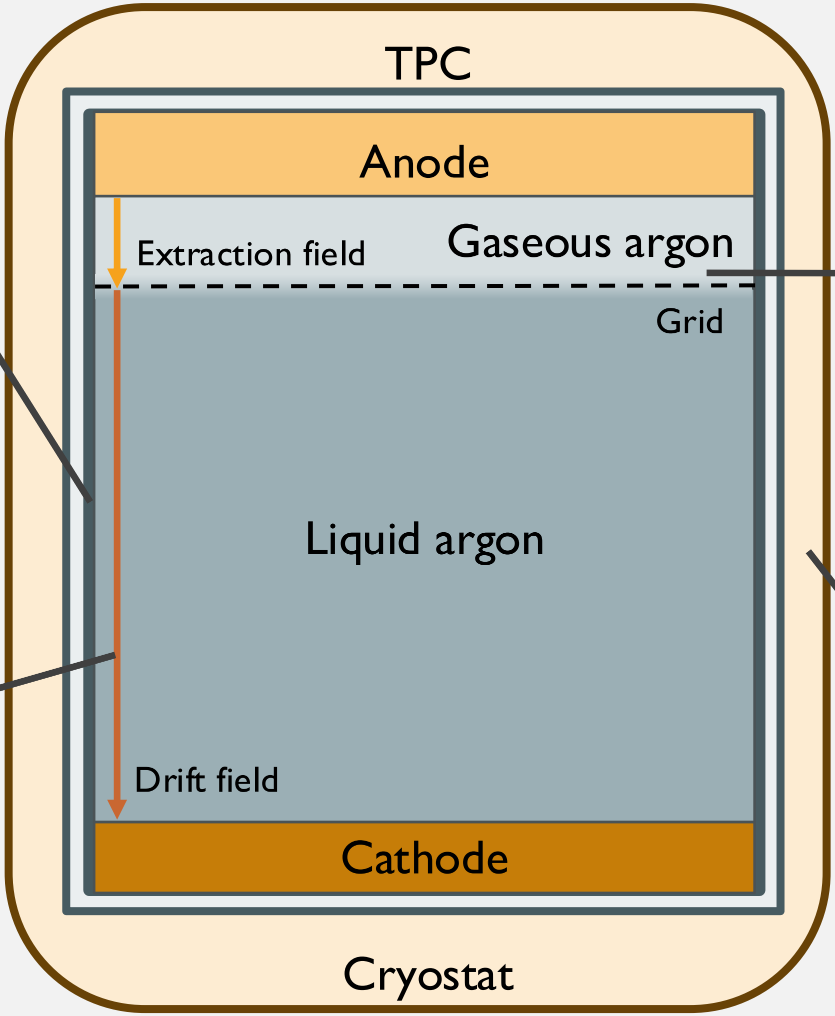
Technical Note, Version 1.1, March 2026.
Internal DarkSide-20k documentation (DS-20k Mockup Project)

BONUS SLIDES

The Challenges of Scale

- Mechanical challenges
  - Field cage must remain mechanically stable
  - Thermal contraction can cause stresses and warping

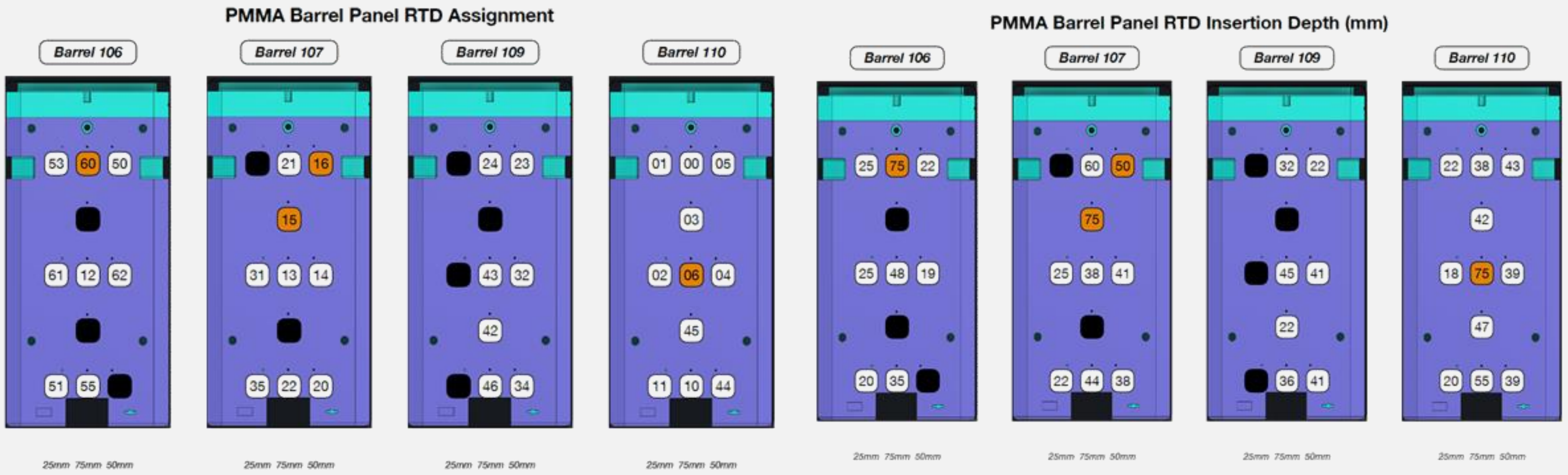
- High-voltage challenges
  - The larger volume requires a higher voltage (~75kV) to maintain the drift field



- Gas pocket challenges
  - A larger phase interface (~4m diameter) is more susceptible to ripples, convection, boiling etc.

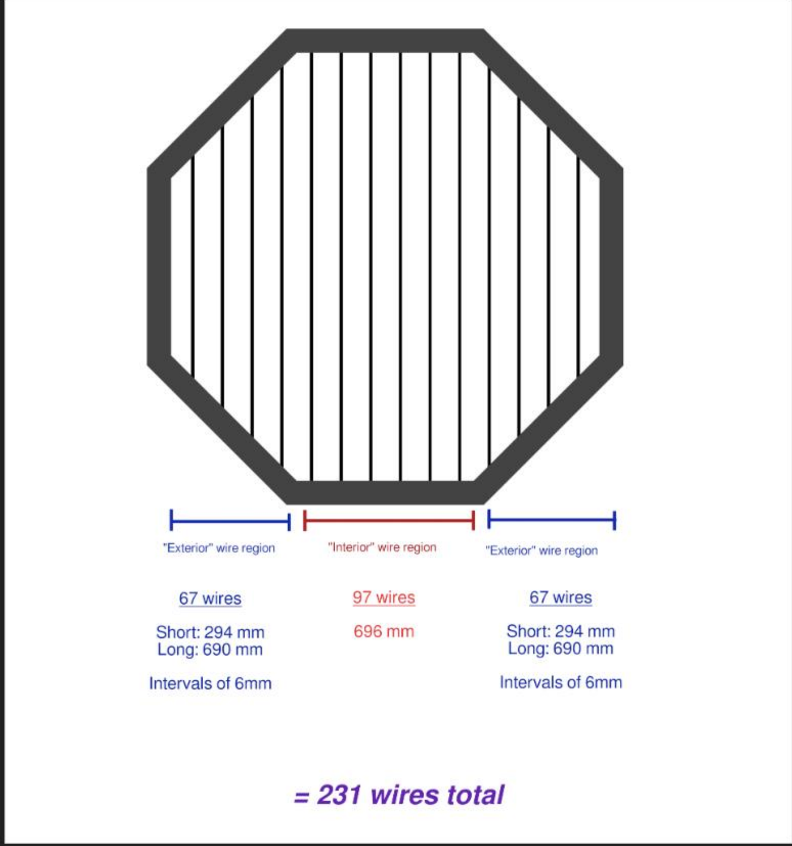
- Cryogenic challenges
  - Large volume of cryogenic liquid requires constant maintenance for mK-level stability

Temperature Sensor Positions in TPC



WIRE GRID

Design and Purpose of the Grid



- Wires are strung across a rigid octagonal frame
- The whole assembly is sandwiched between the top of the barrel panels and the bottom rim of the anode
  - SS-316 frame and wires
  - 200 μm diameter wire
  - 3N tension on each wire (nominally)
  - Wires all lie in same plane (nominally)