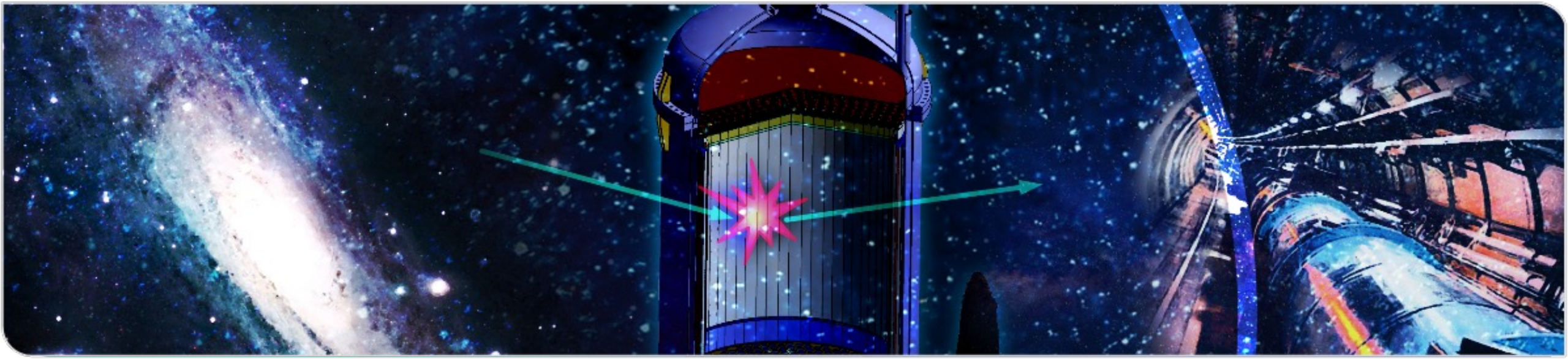
Karlsruhe Institute of Technology

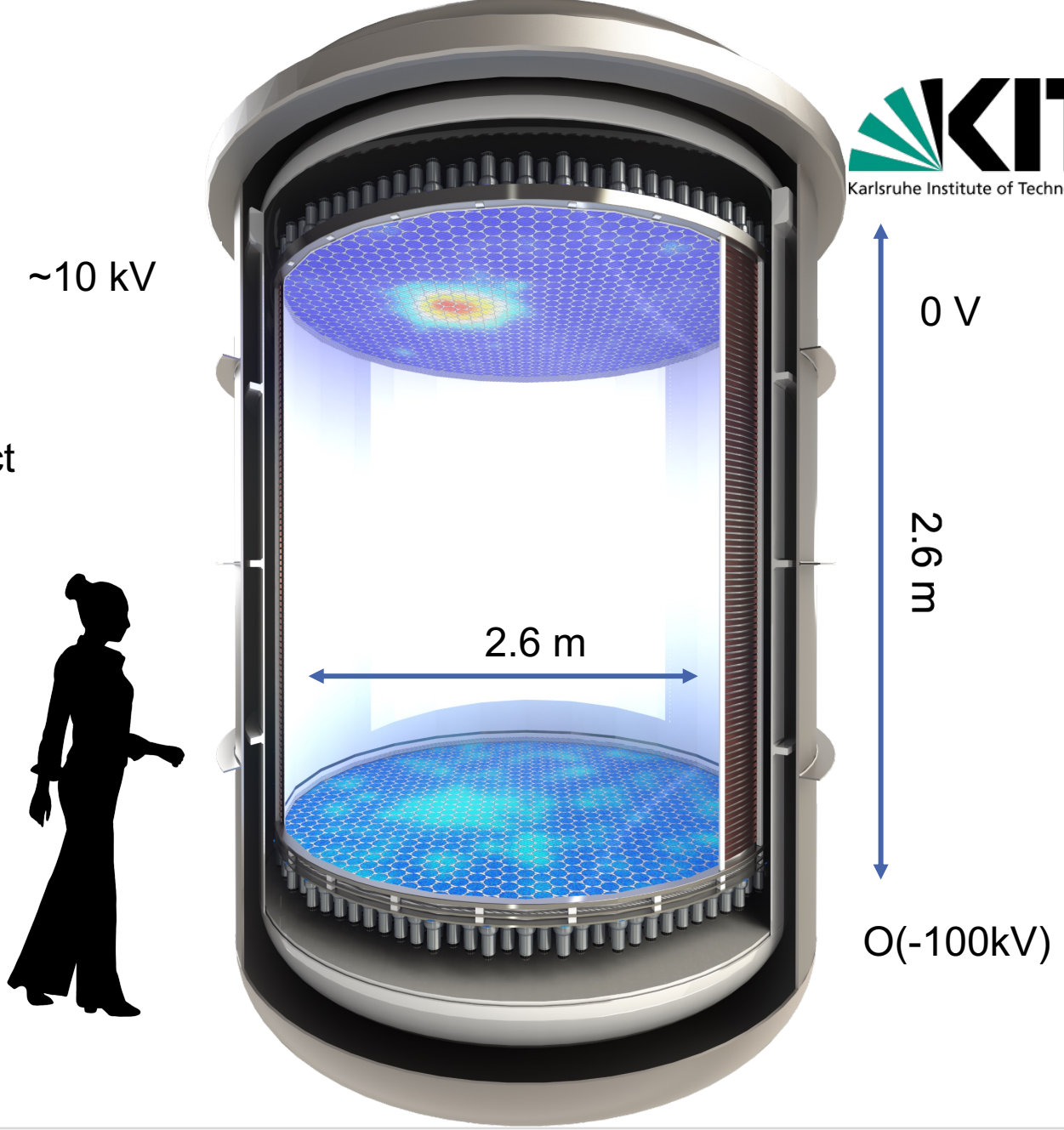
High voltage in large structures: challenges and progress

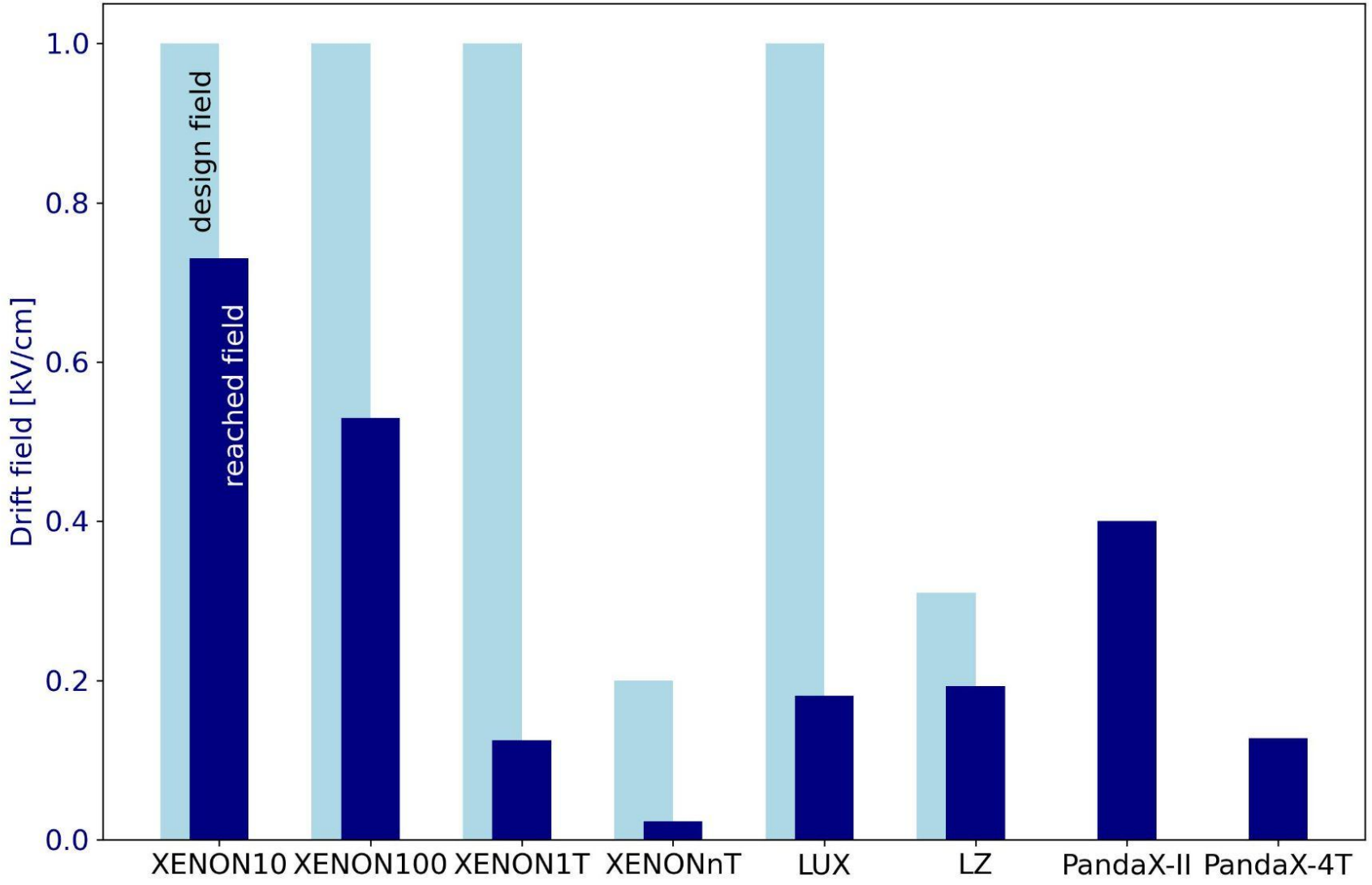
Yanina Biondi, Klaus Eitel, Alexey Elykov, Kathrin Valerius, Sebastian Vetter and Vera Hiu-Sze Wu



DARWIN baseline design

- Optimal drift field: very high voltage in the cathode
- The high field in the conductor can potentially affect the sensitive LXe in the detector
- HV (DC) require complex designs
- No off-shelf solutions (due to natural radioactivity)
- Sagging and defects on electrodes become more crucial

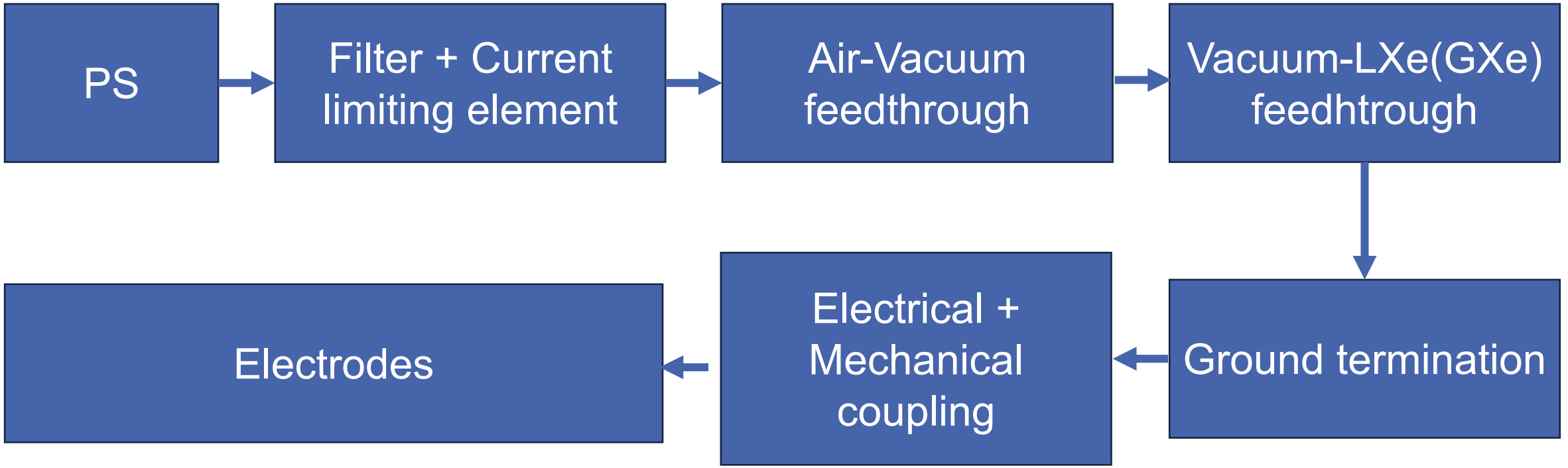




@Julia Müller

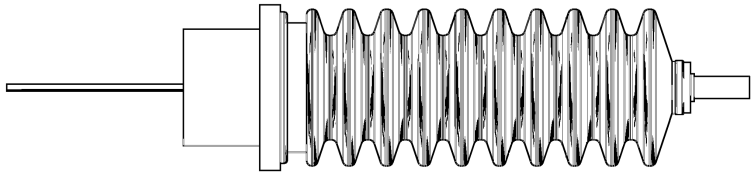
Need for a systematic approach on testing of HV elements

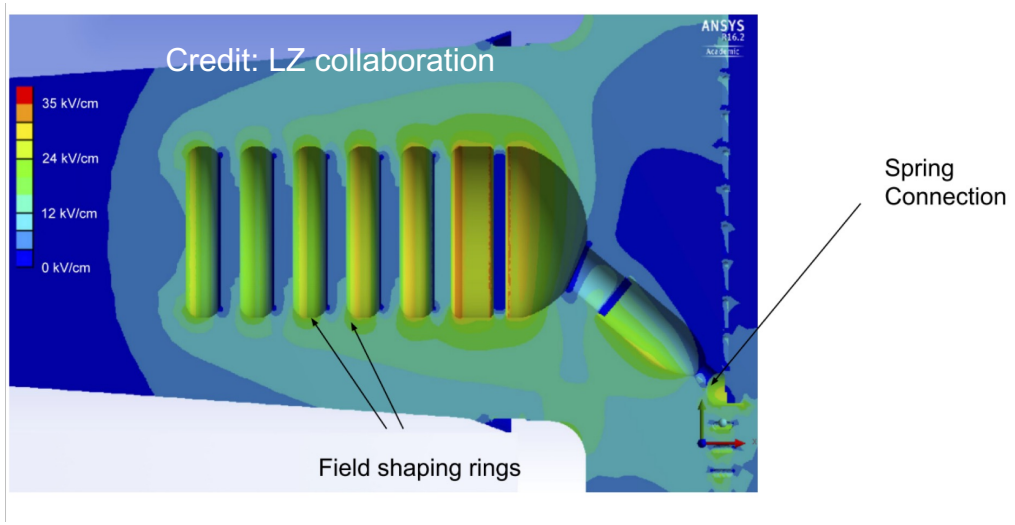
HV systems


PS
Filter + Current limiting element
Air-Vacuum feedthrough
Vacuum-LXe(GXe) feedhtrough
Ground termination
Electrical + Mechanical coupling
Electrodes

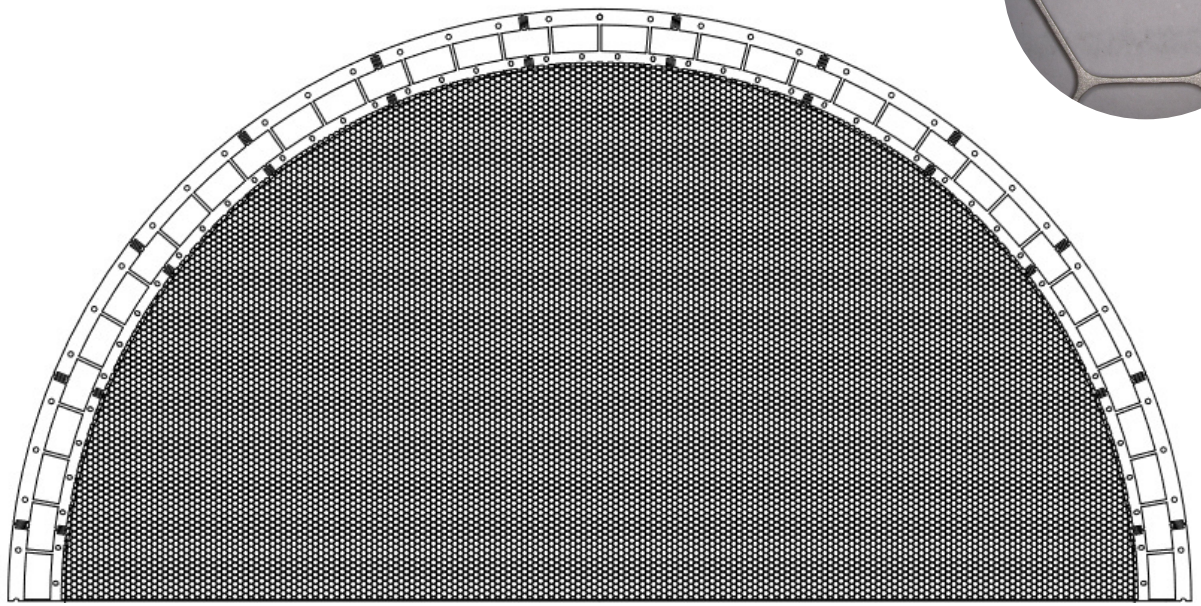
R&D task forces at KIT

- Very High Voltage (HV >100kV) delivery to electrodes through LXe





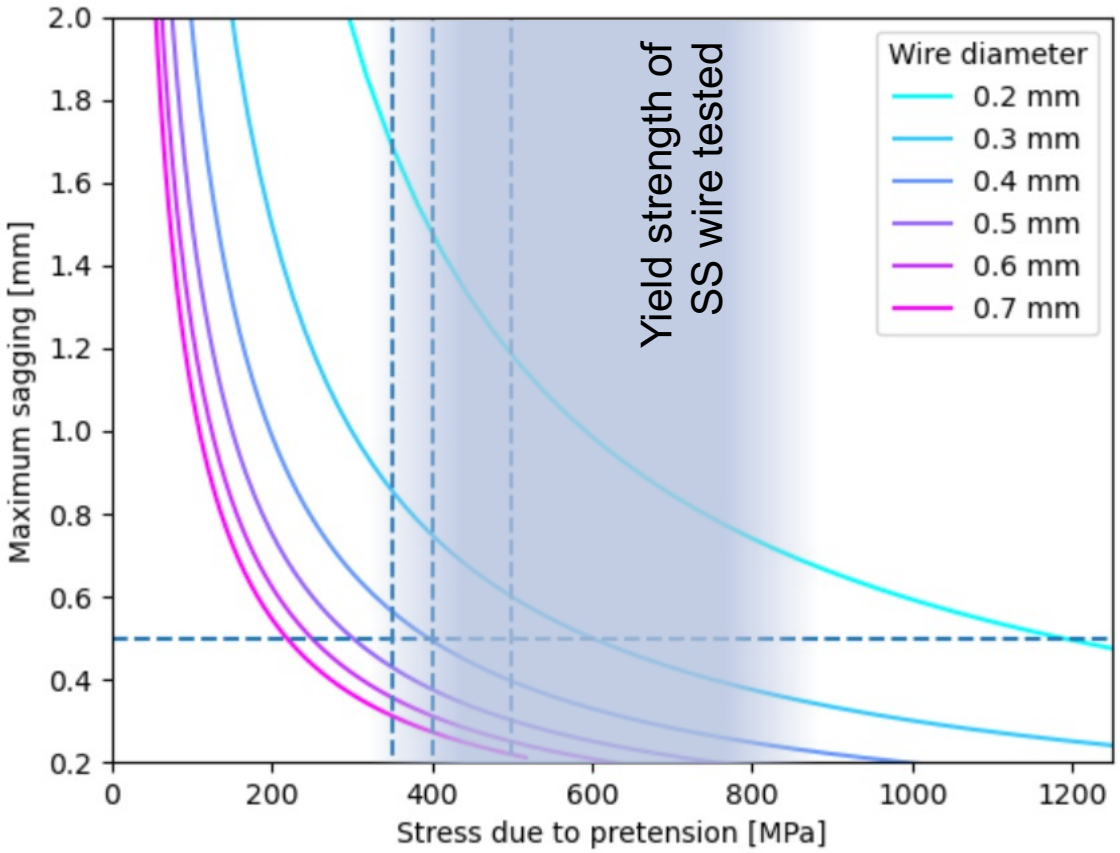
- Electrode design, production and quality testing



Electrode testing facilities

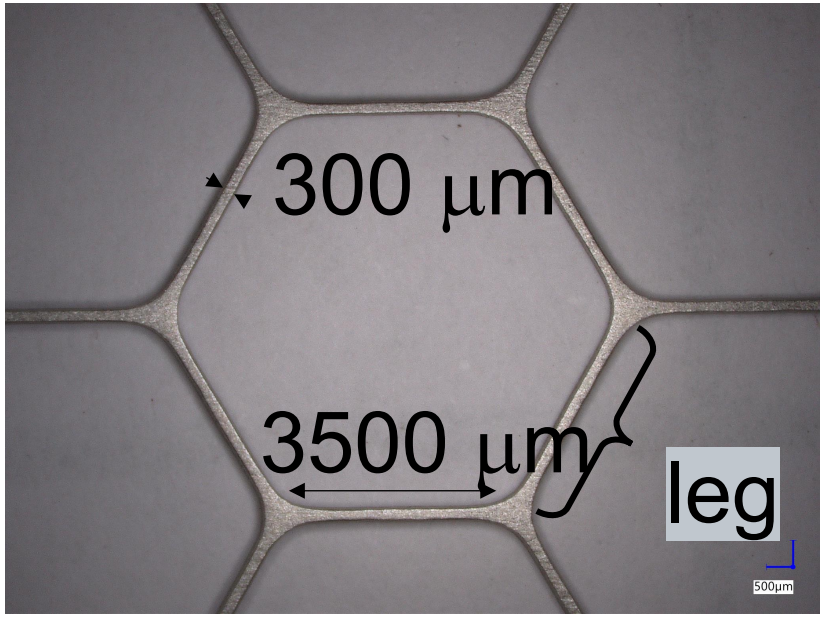
Electrode design

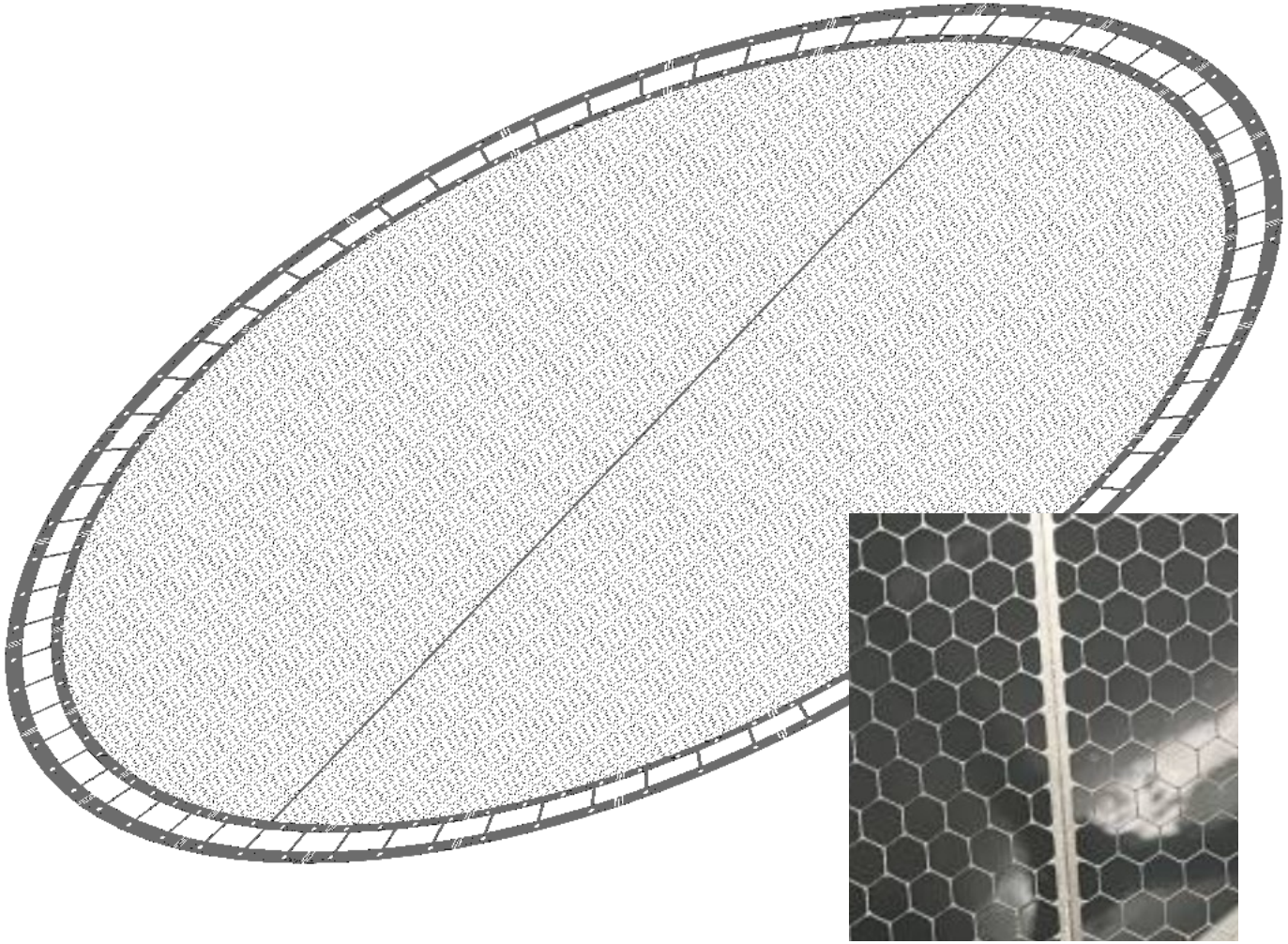
	Hexagonal Mesh	Parallel Wire
Stress	Lower ✅	Higher ❌
Sagging	Uniform ✅	Less uniform ❌
Fixation/assembly	Easy ✅	Difficult; error-prone ❌
Manufacturing	Mesh is too large to etch at once ❌	Ring might be hard to machine
Reparation before installation	Monolithic ➢ more difficult to repair ❌	Wires independent of each other ➢ easier to repair ✅



Etching of hex meshes

- For manufacturing, realistic to etch smaller sections
- **Cathode**: thicker line in middle of the mesh for laser welding





Electrode design

Variation of Geometrical Design Parameters:

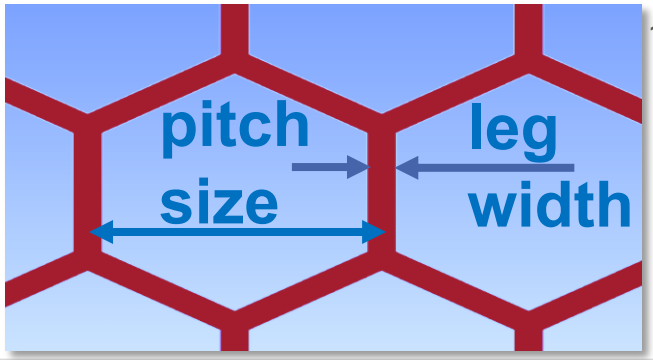
- pitch size (5 mm, 7.5 mm)
- leg width (0.3 mm, 0.5 mm, 1 mm)
- sheet thickness (0.3 mm, 0.5 mm, 1 mm)

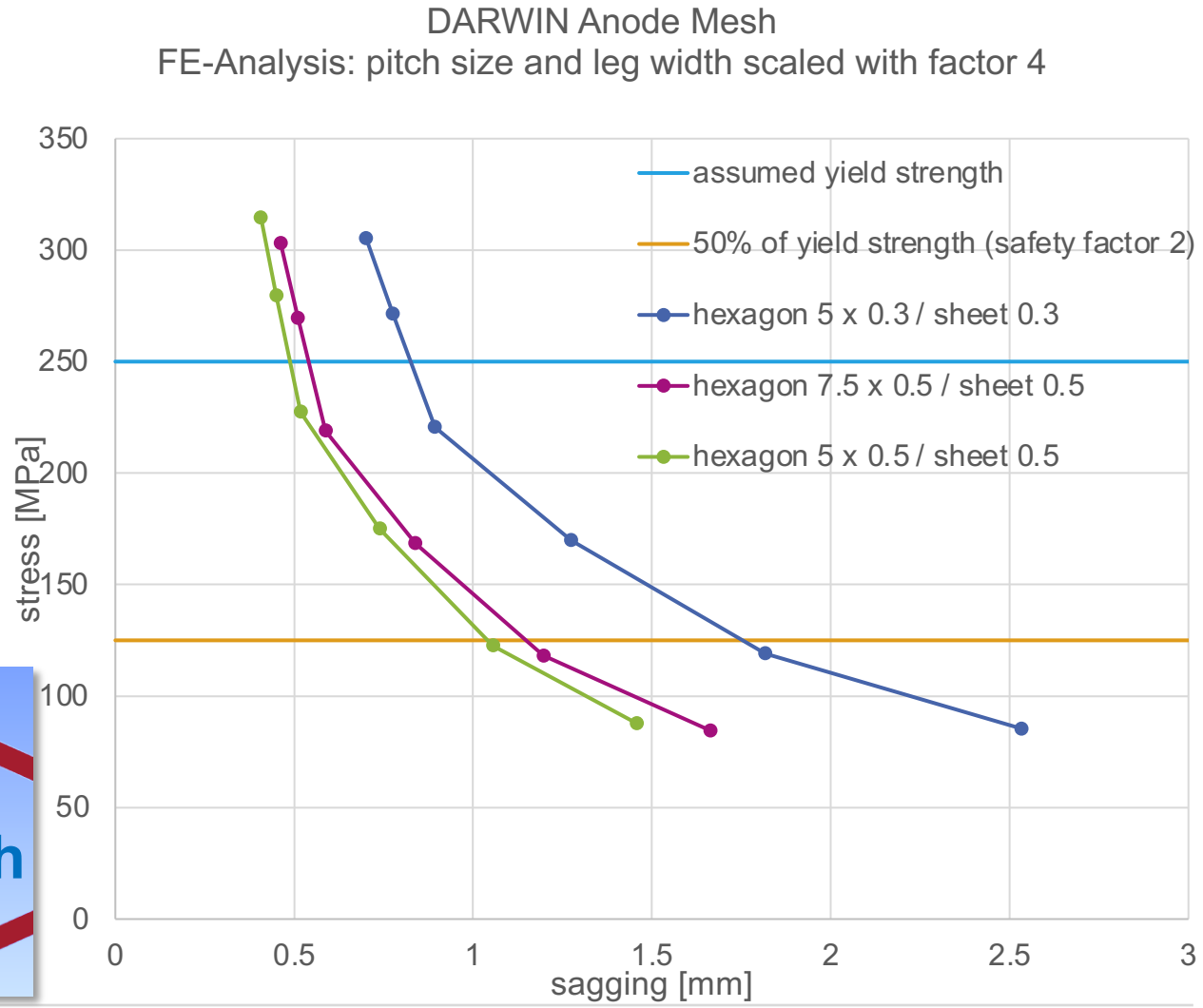
Calculation of

- sagging (aim: 0.5 mm)
- Stress (aim: 0.5 x yield strength)

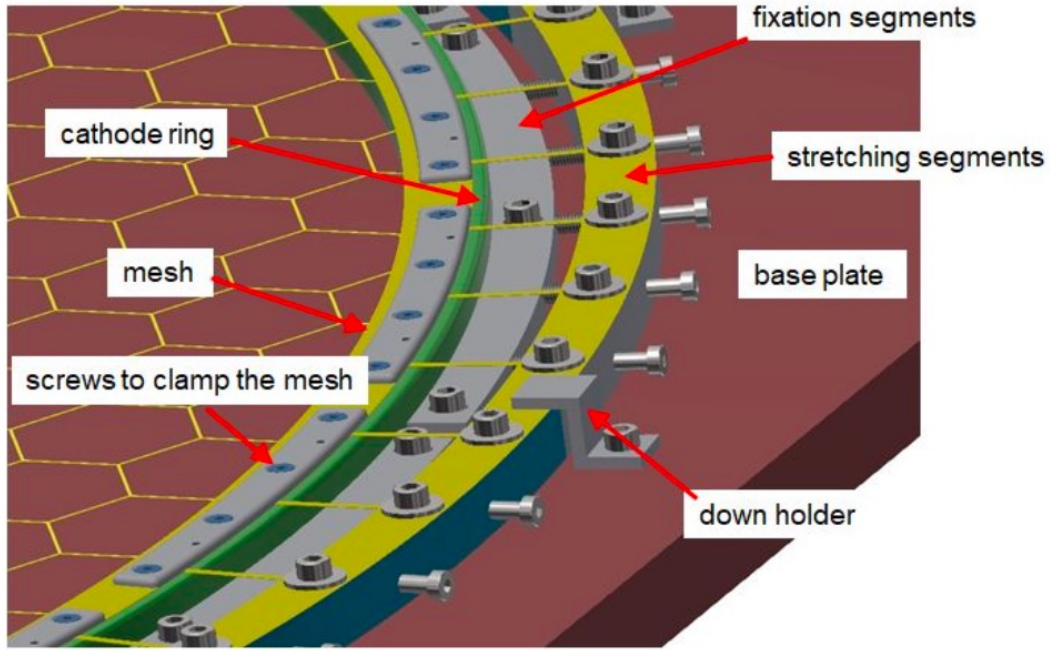
Loads on mesh:

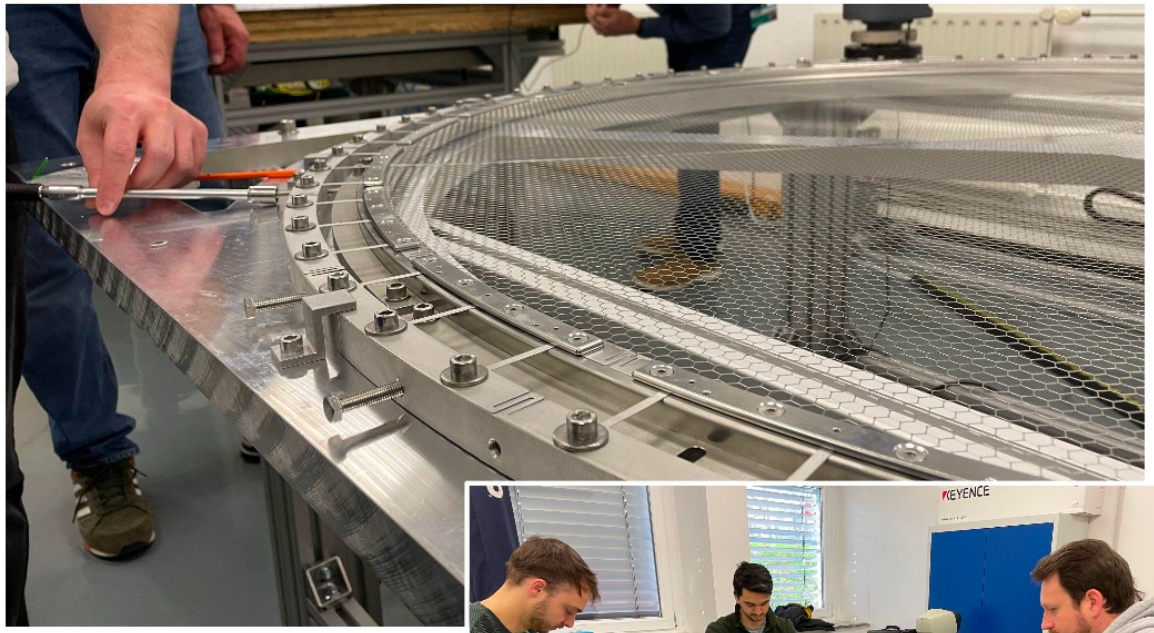
- gravity
- electrostatic force

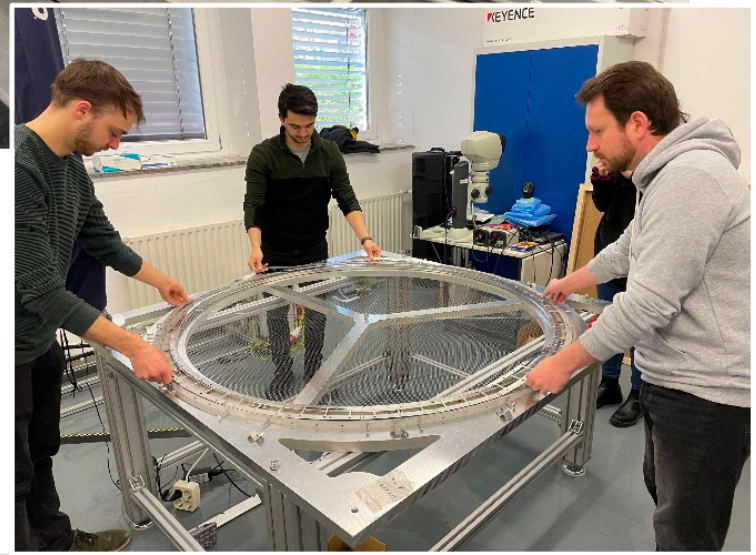




Mesh electrodes design and testing

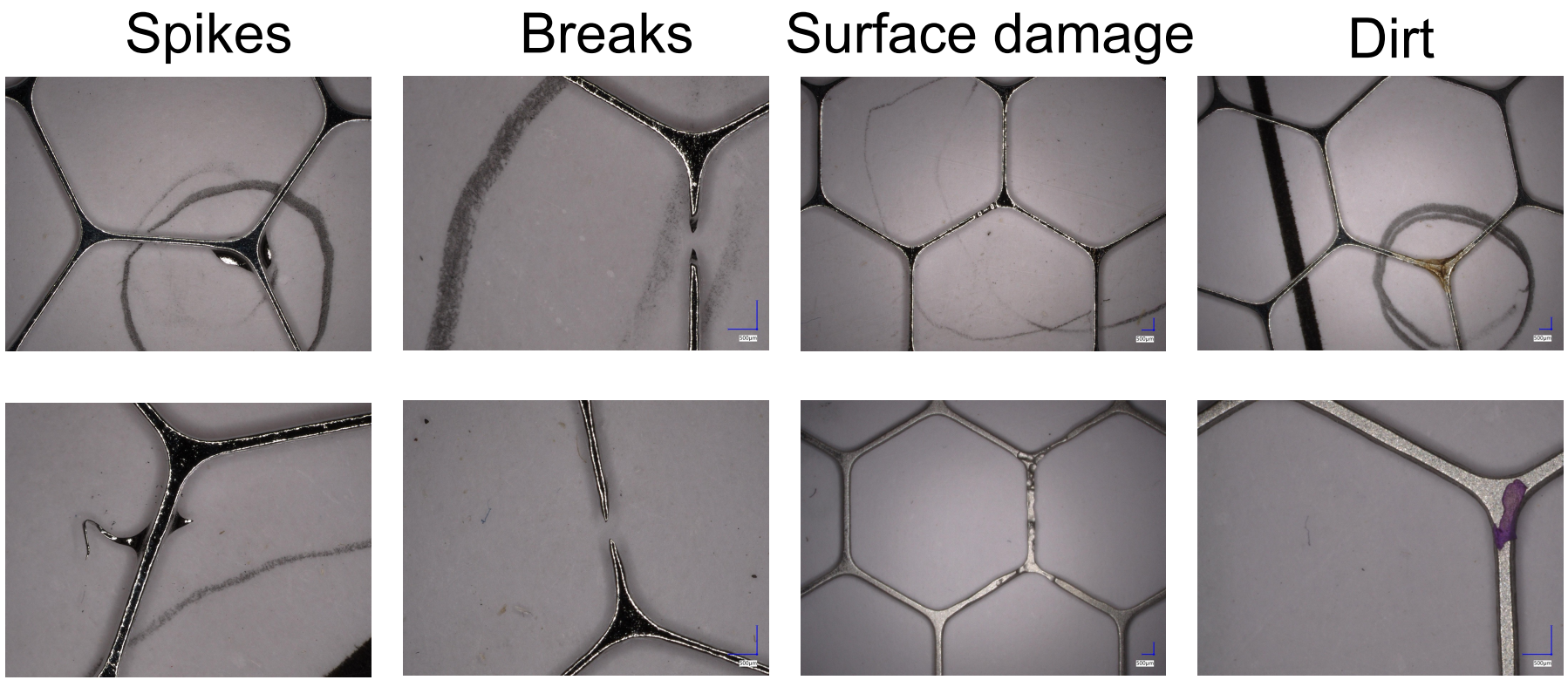






- Assembly and stretching procedure tested
- Flatness and sagging of mesh controlled

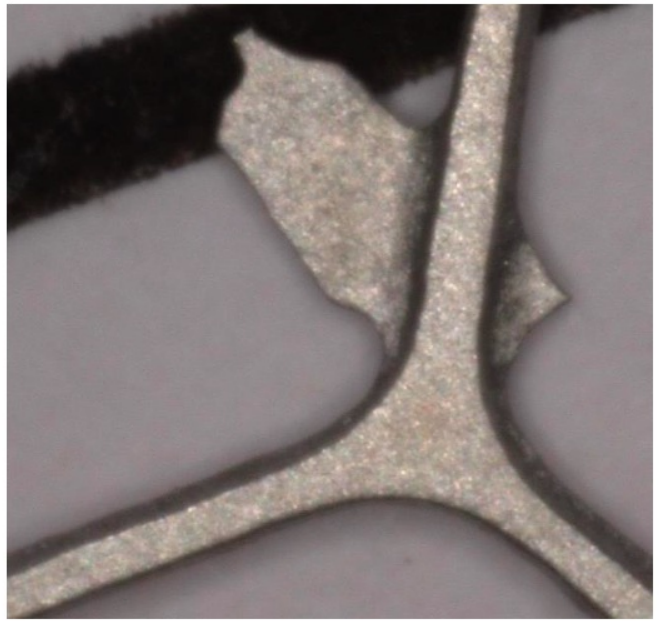
Electrode quality control



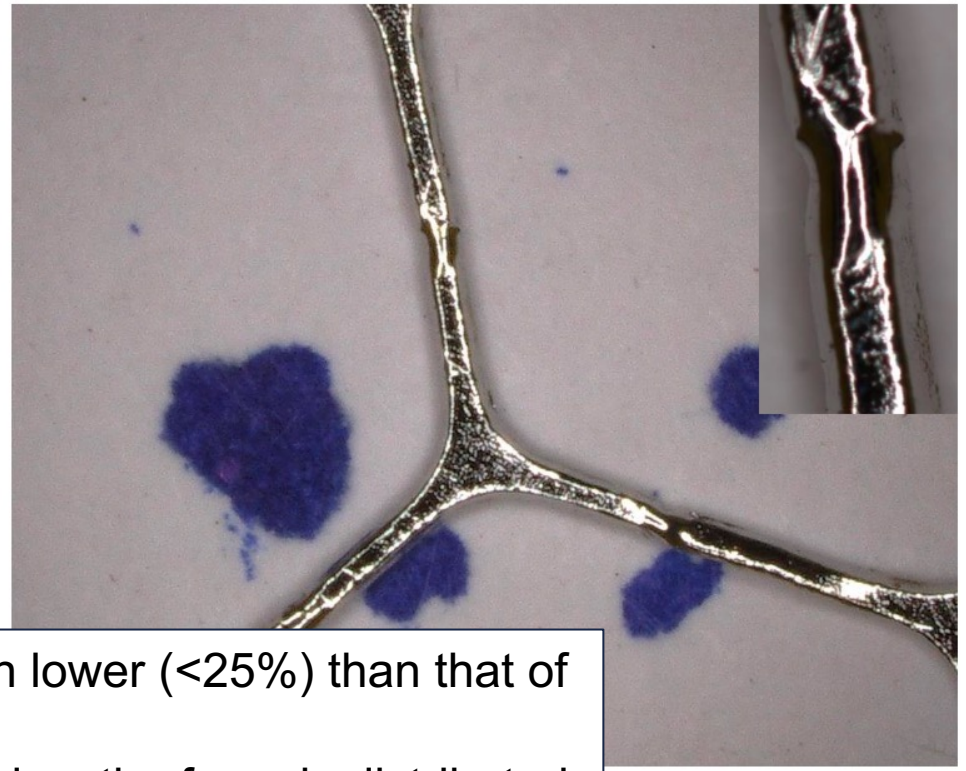
- 300µm (+ electropolishing) hexagons → susceptible to damage
- Defects identified by eye and with ML

Repair with Laser Welding

Before treatment



After laser welding
& electropolishing



- The ultimate tensile strength lower (<25%) than that of a leg without welding point
- Still well above the threshold as the force is distributed in different directions

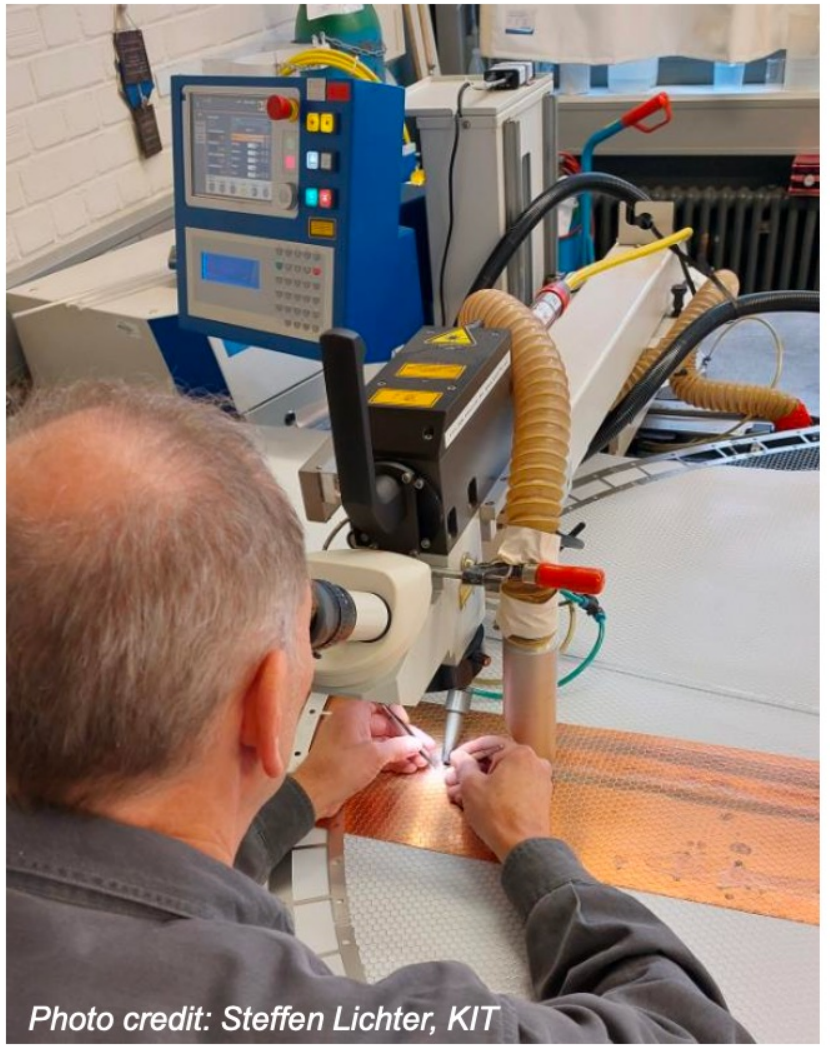


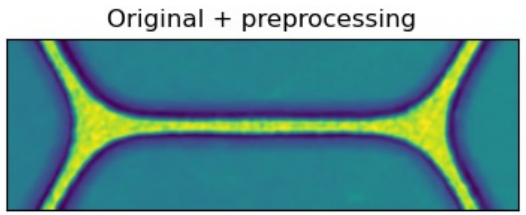
Photo credit: Steffen Lichter, KIT

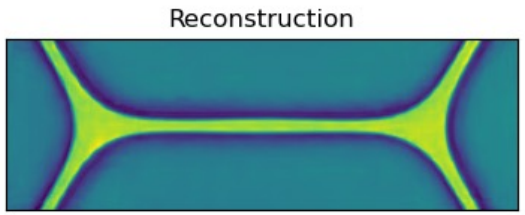
Electrode quality control: ML

General idea $X \rightarrow$  $\rightarrow X'$

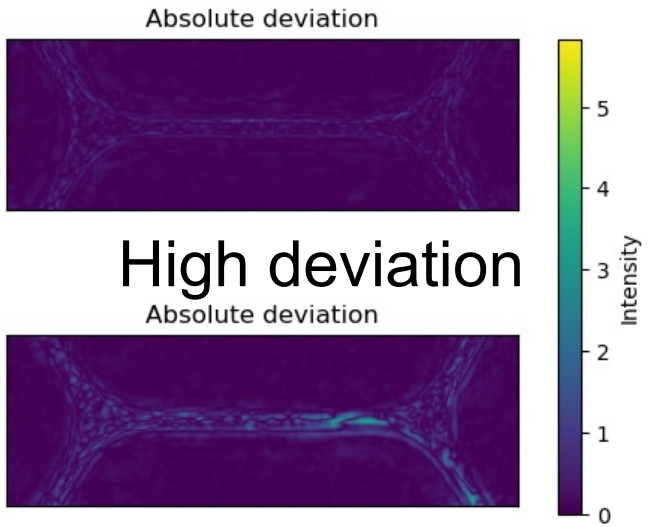
X X' $|X - X'|$

Clean image

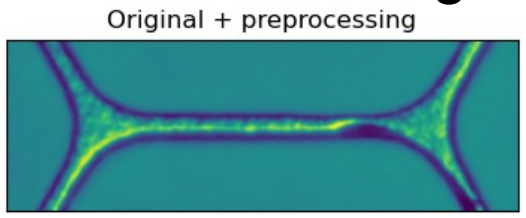


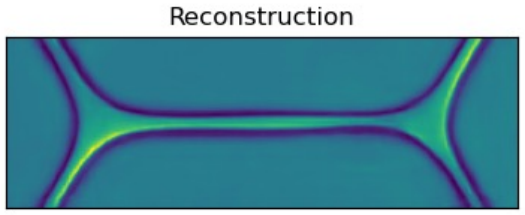


Low deviation

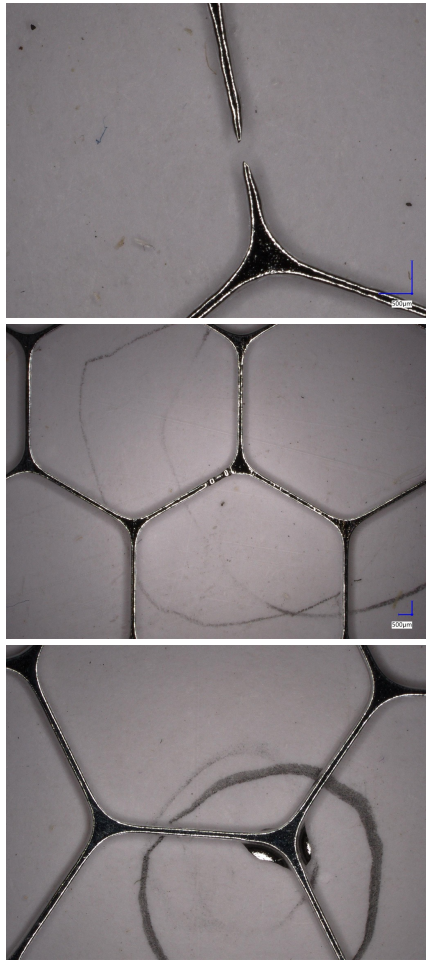


Defect image



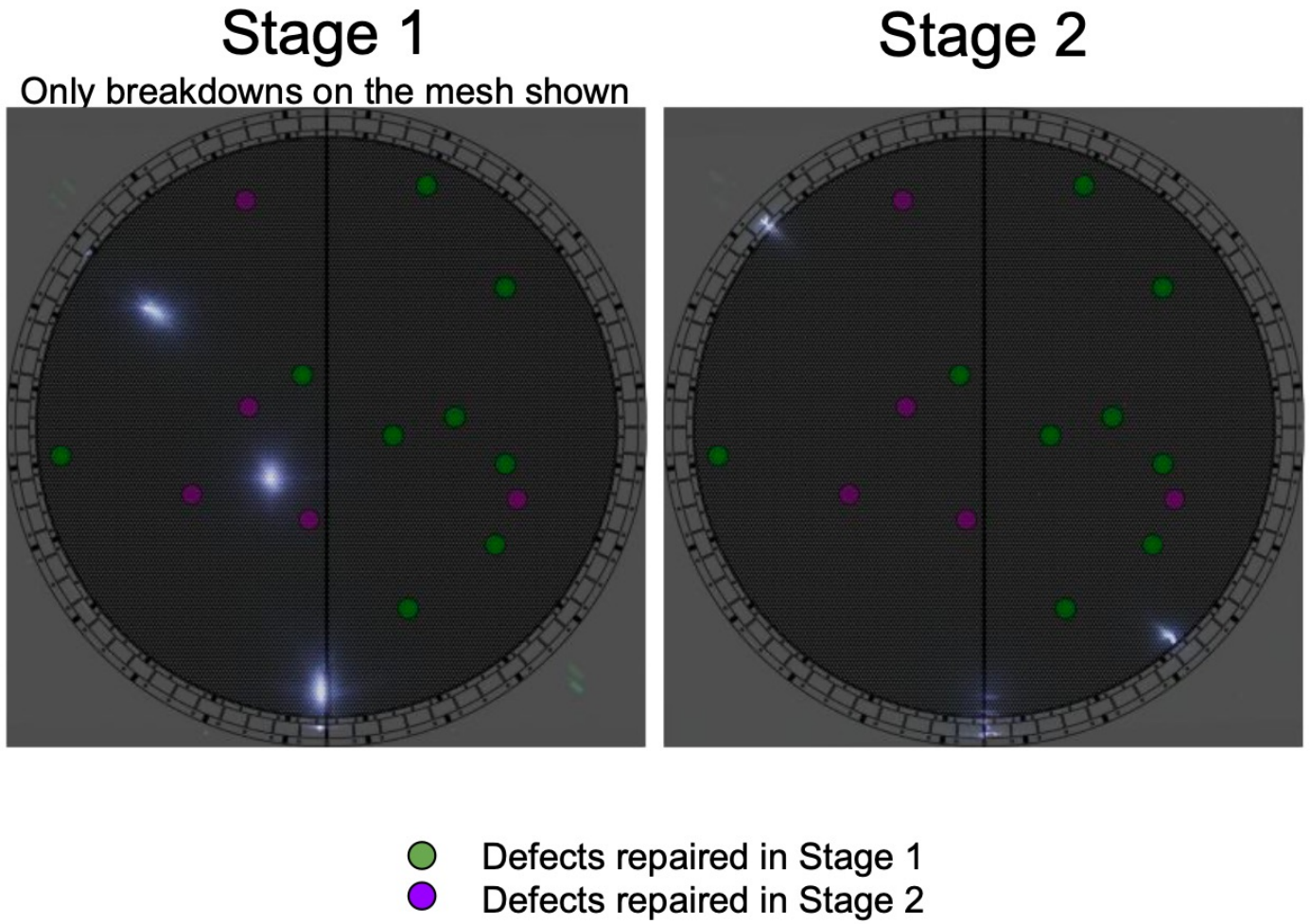


High deviation



High Voltage Test on 1.3 m Electrode

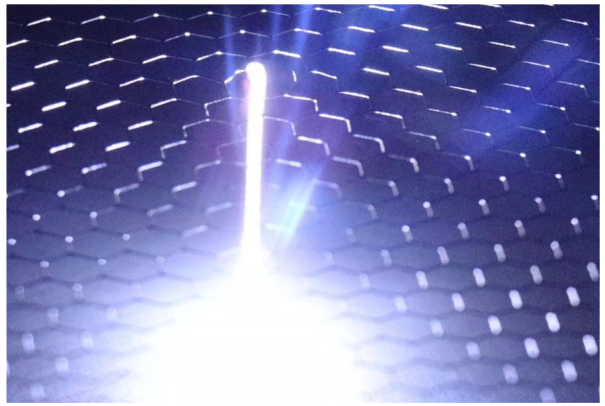
- Detect glow in gAr indicating defects in mesh - **diagnostics**: optical imaging
- Establish HV stability/reliability - **diagnostics**: HV breakdowns, peaks in supply current/voltage
- No discharges in known defects



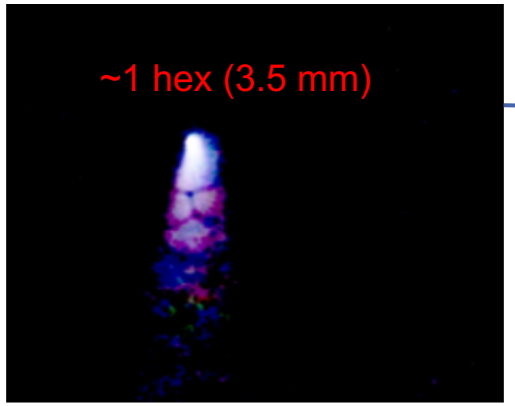
High Voltage Test on 1.3 m Electrode

Video:

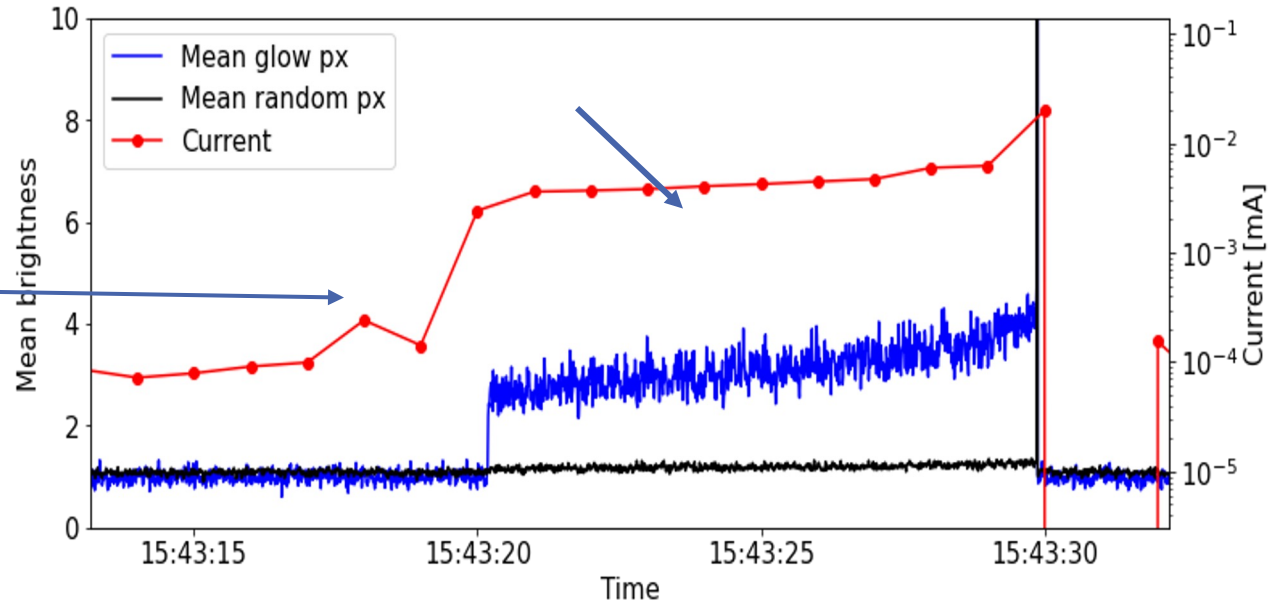
- Zoom-in on known defect
- Glow-up visible:
  - Current increases ~10 seconds before breakdown
  - Brightness of pxs in the defect area increases at same time



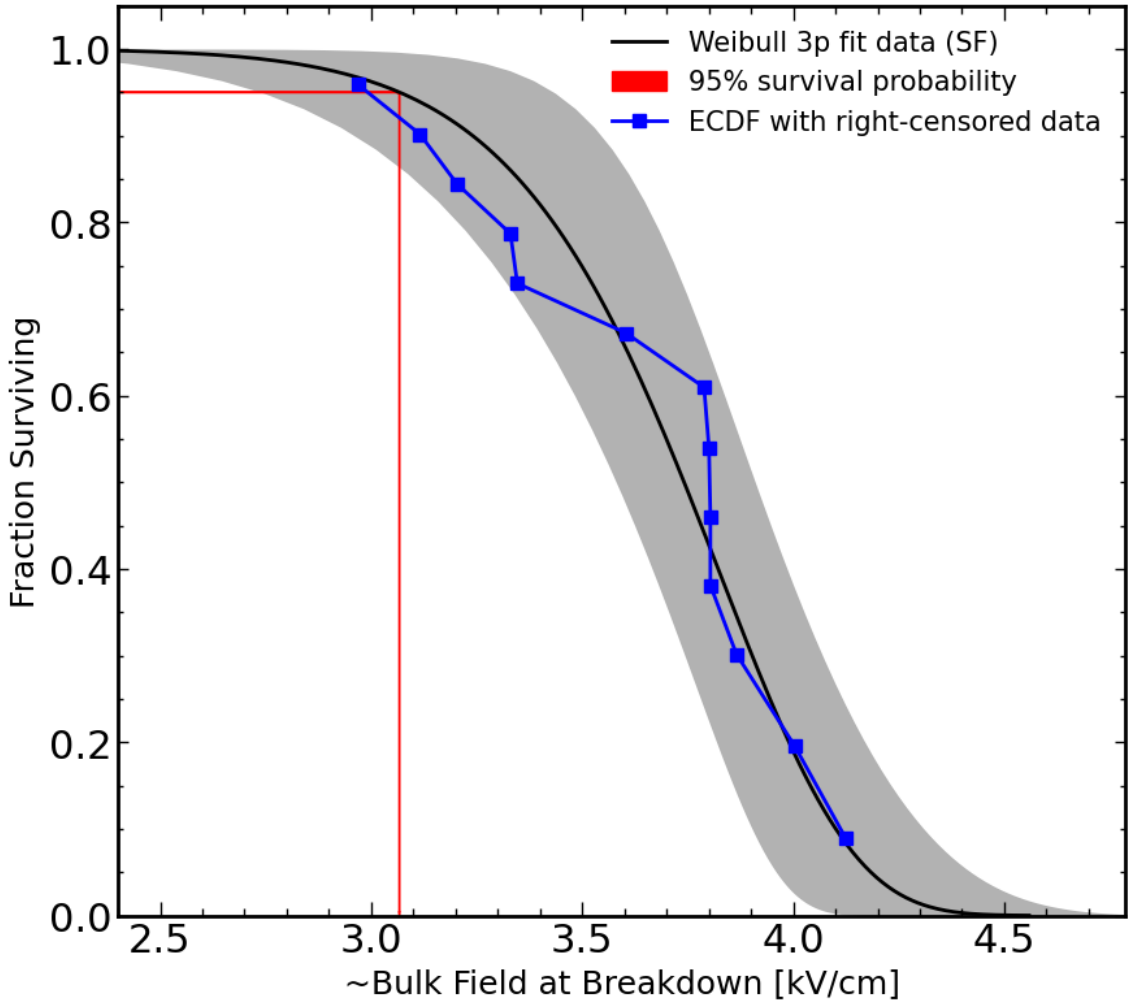
Zoom-in breakdown single frame

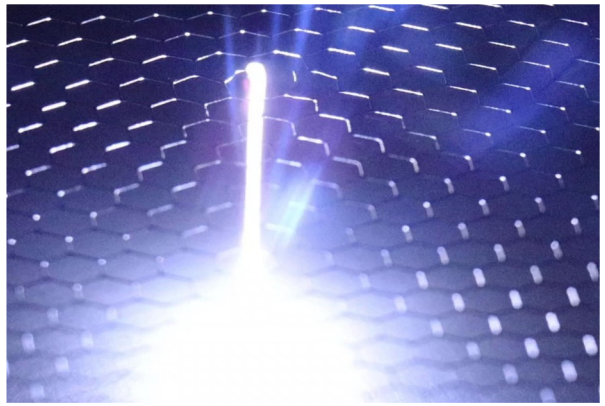


Zoom-in a - pre-breakdown

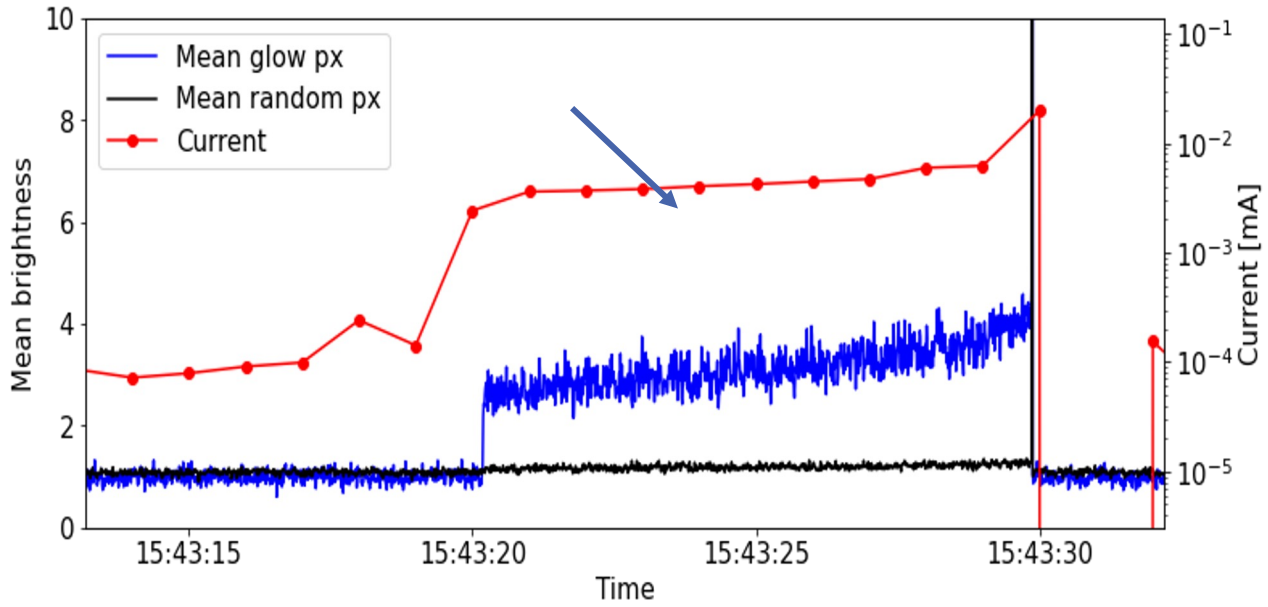


High Voltage Test on 1.3 m Electrode



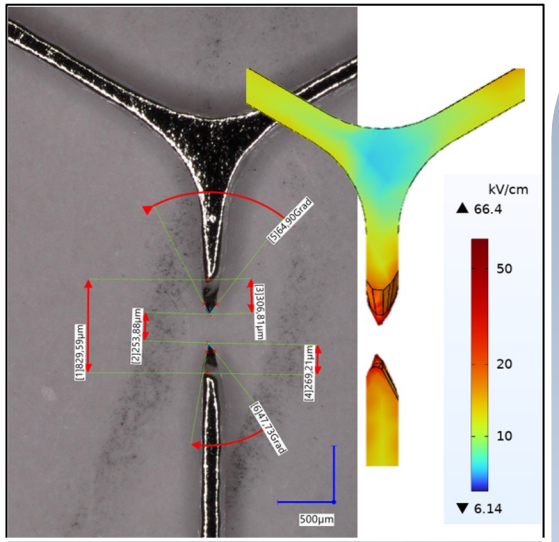


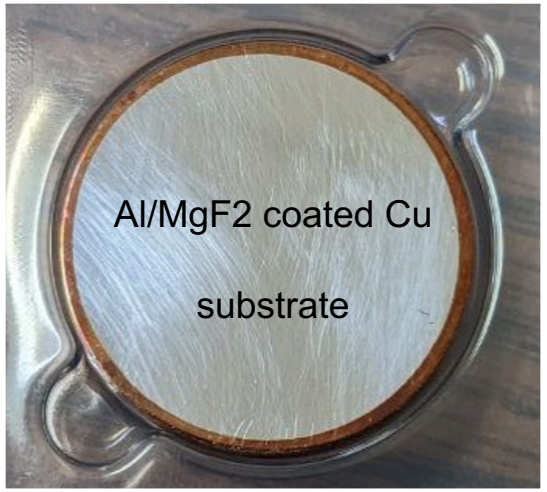
Zoom-in breakdown single frame

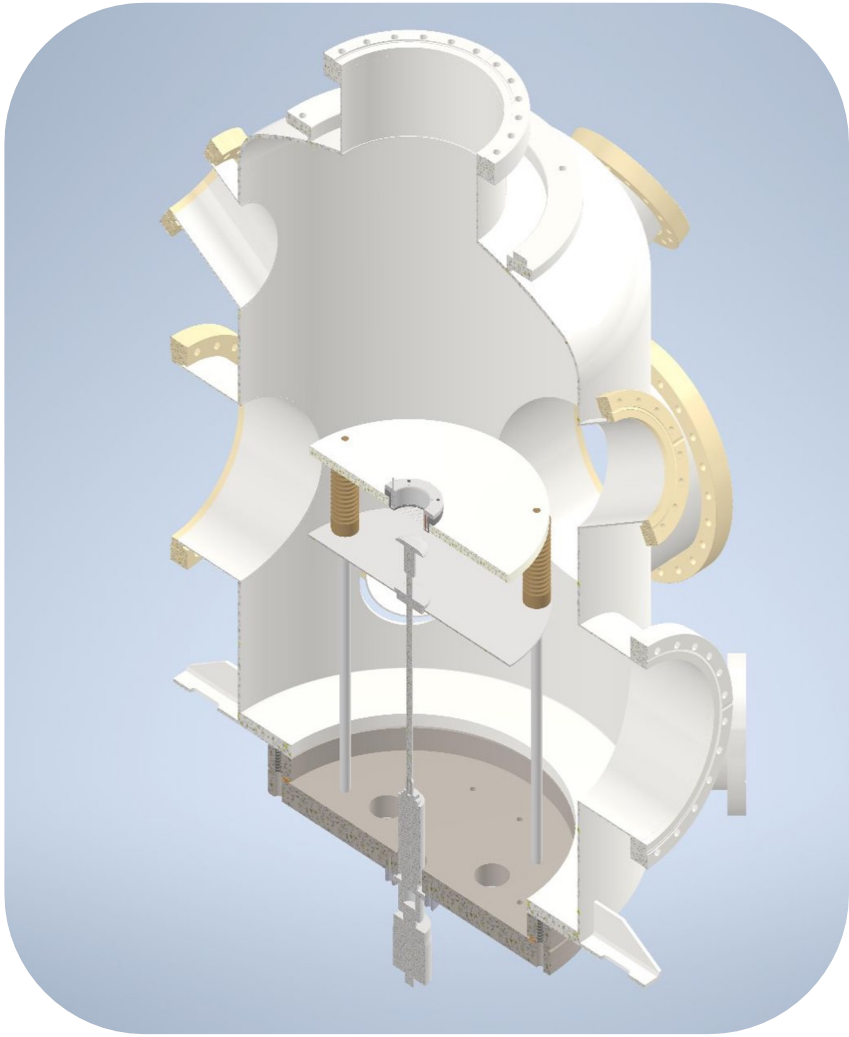


Electrode coating BHiVE

- Study electron and photon emission from electrode samples
- Electrode surface treatment and coating
- Study electrode surfaces with optical & electron microscopy
- Versatile sample holder design; substrates, mesh electrodes
- Imaging with external high-res cameras, X-Y reconstruction

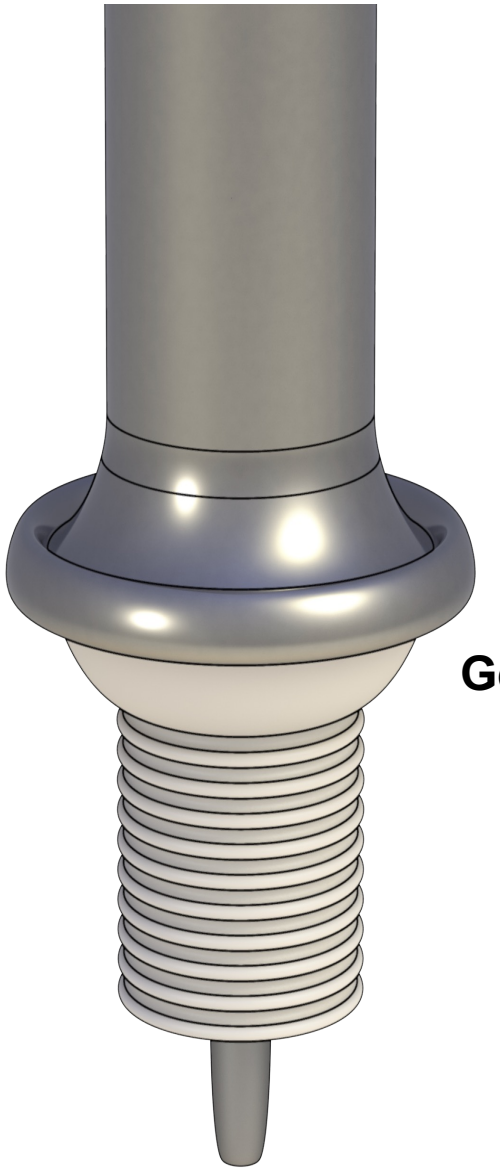






HV feedthroughs

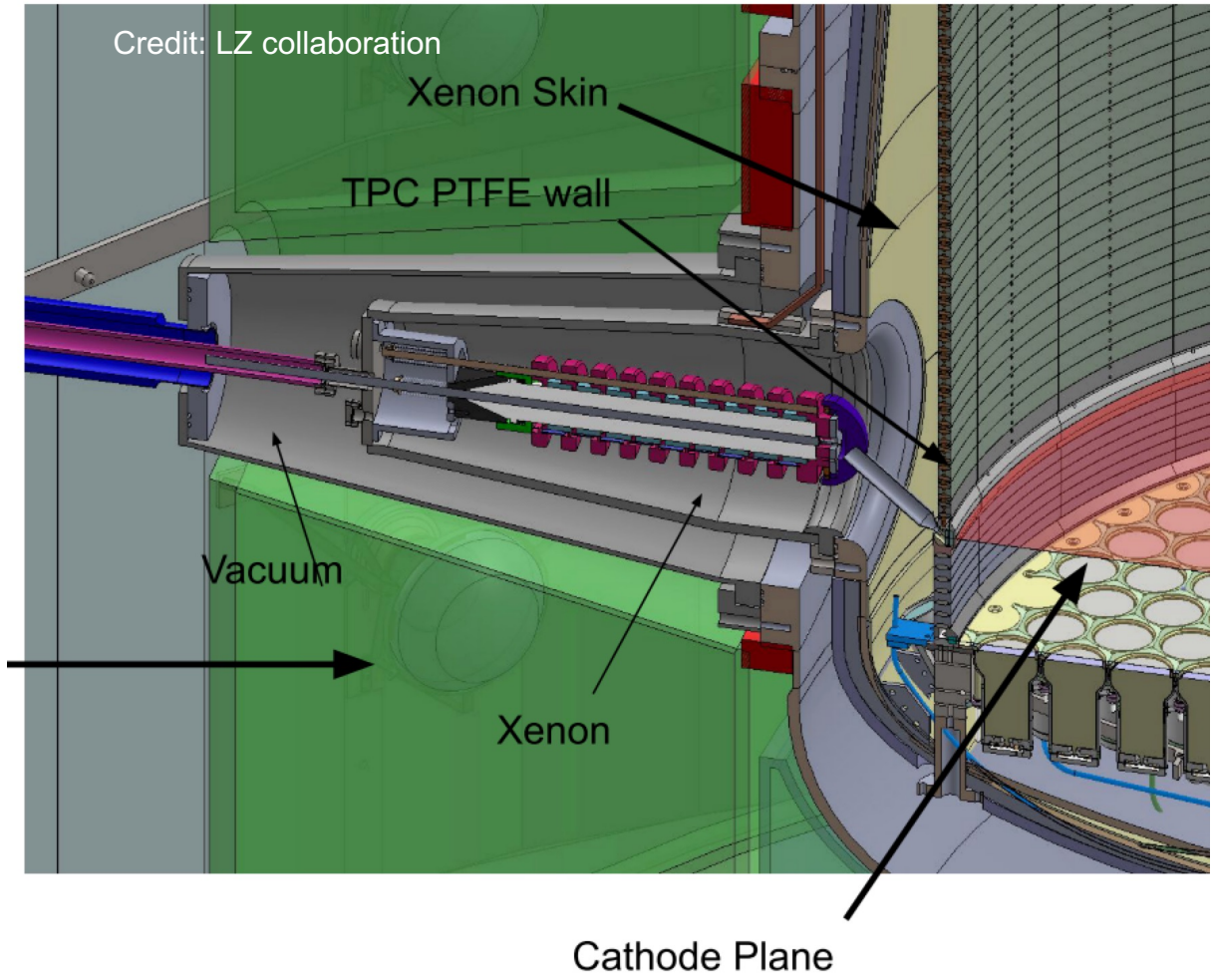
- Optimal drift field: very high voltage in the cathode
- Challenging components in noble liquids
- The high field in the conductor can potentially affect the sensitive LXe in the detector
- The source of discharges is not completely understood
- HVDC terminations (end of the coax termination for a shielded cable) require different and complex designs
- No off-shelf solutions (due to natural radioactivity)

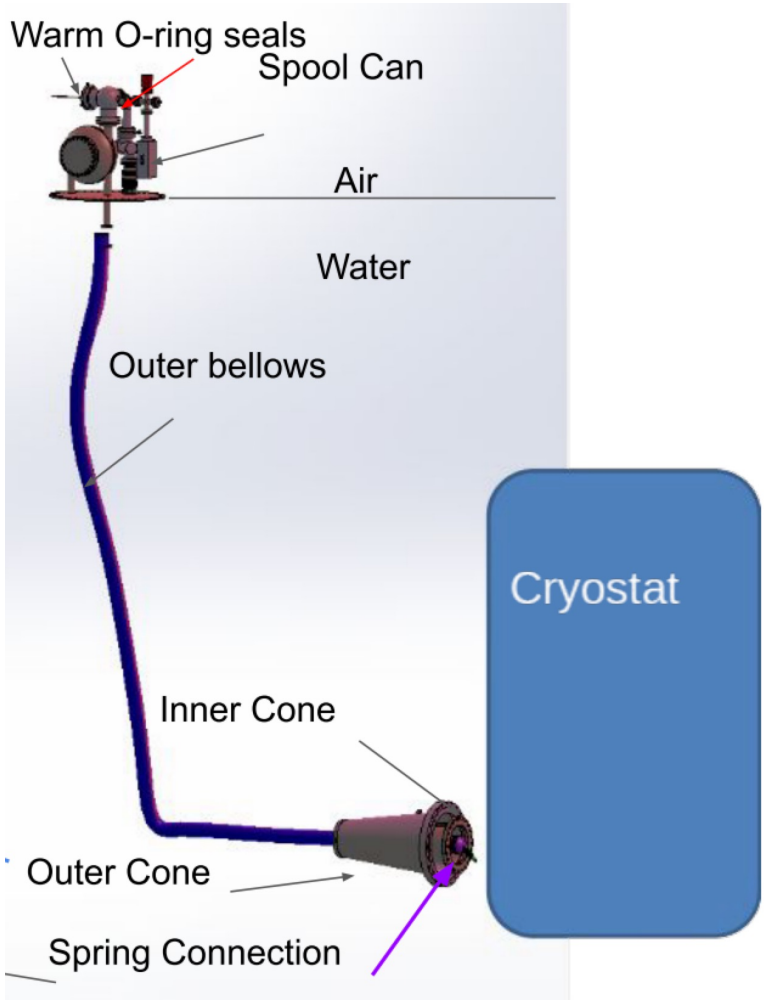


Geometrical field grading

HV feedthroughs

Resistive field grading

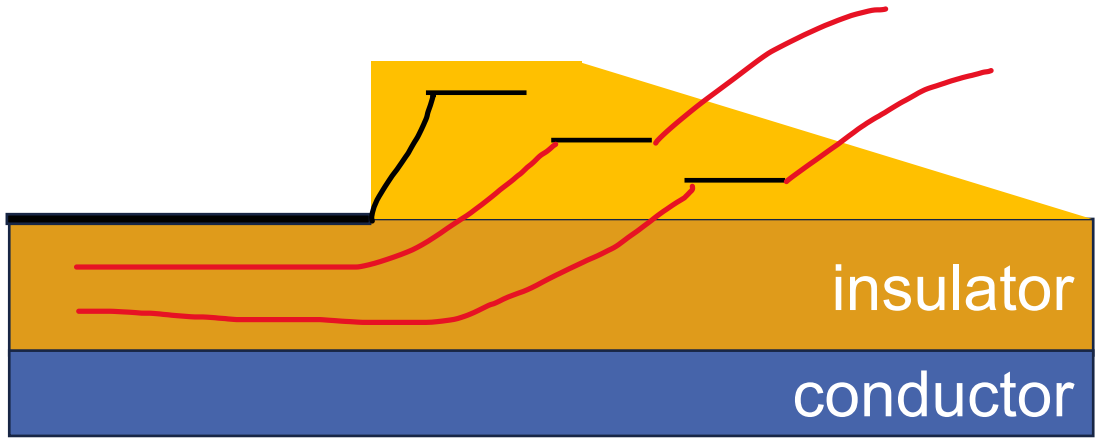




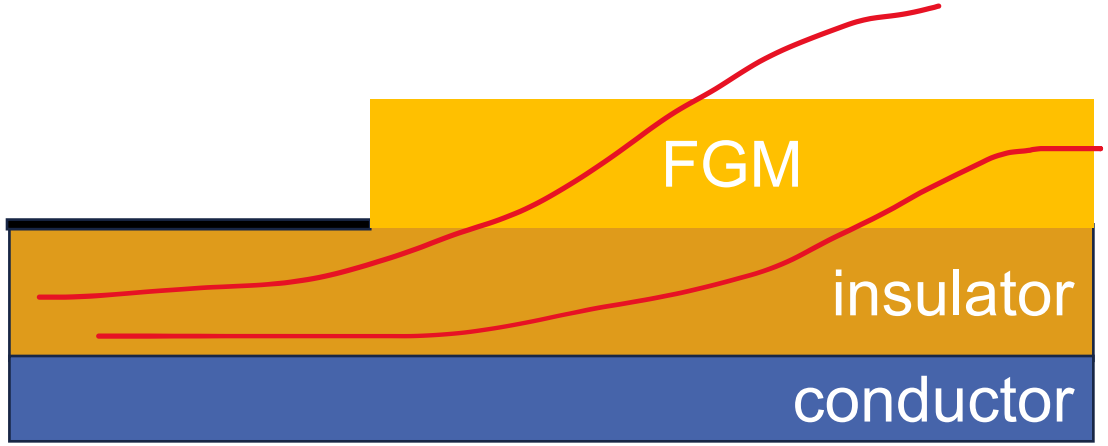
HVDC terminations

- Explore solutions given in industry and other research areas to minimize radioactivity, complexity and material

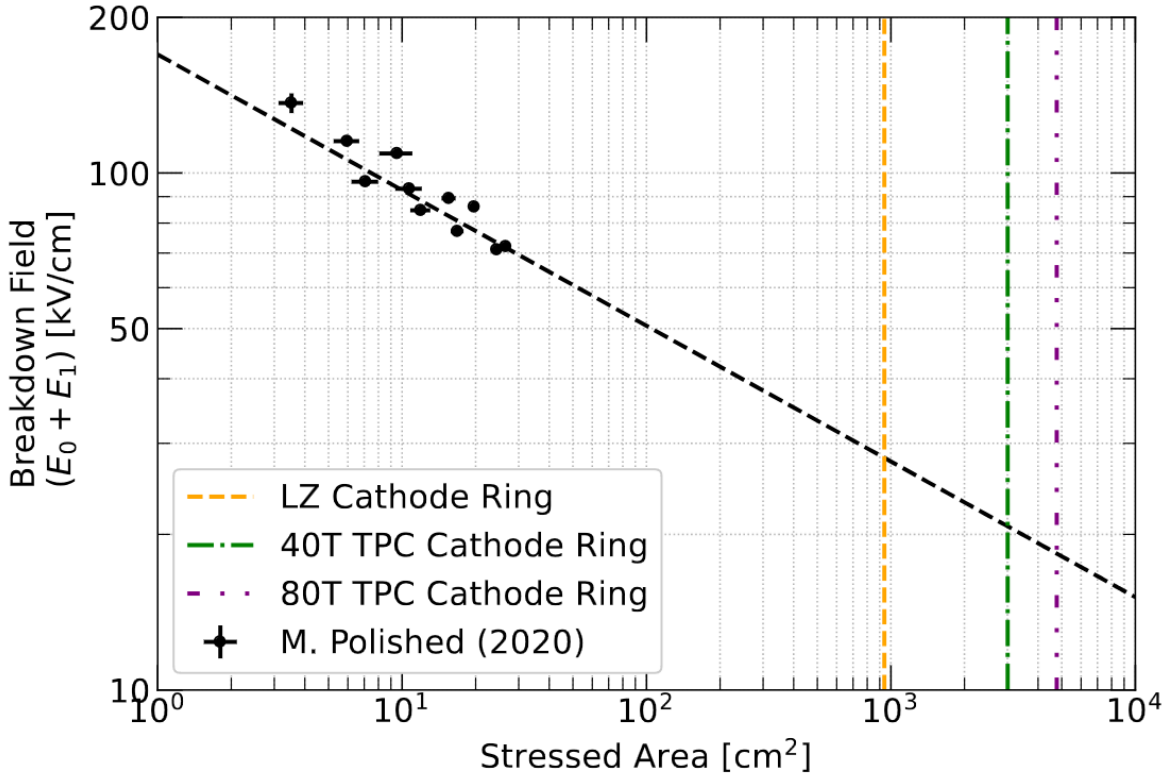
Condenser field grading

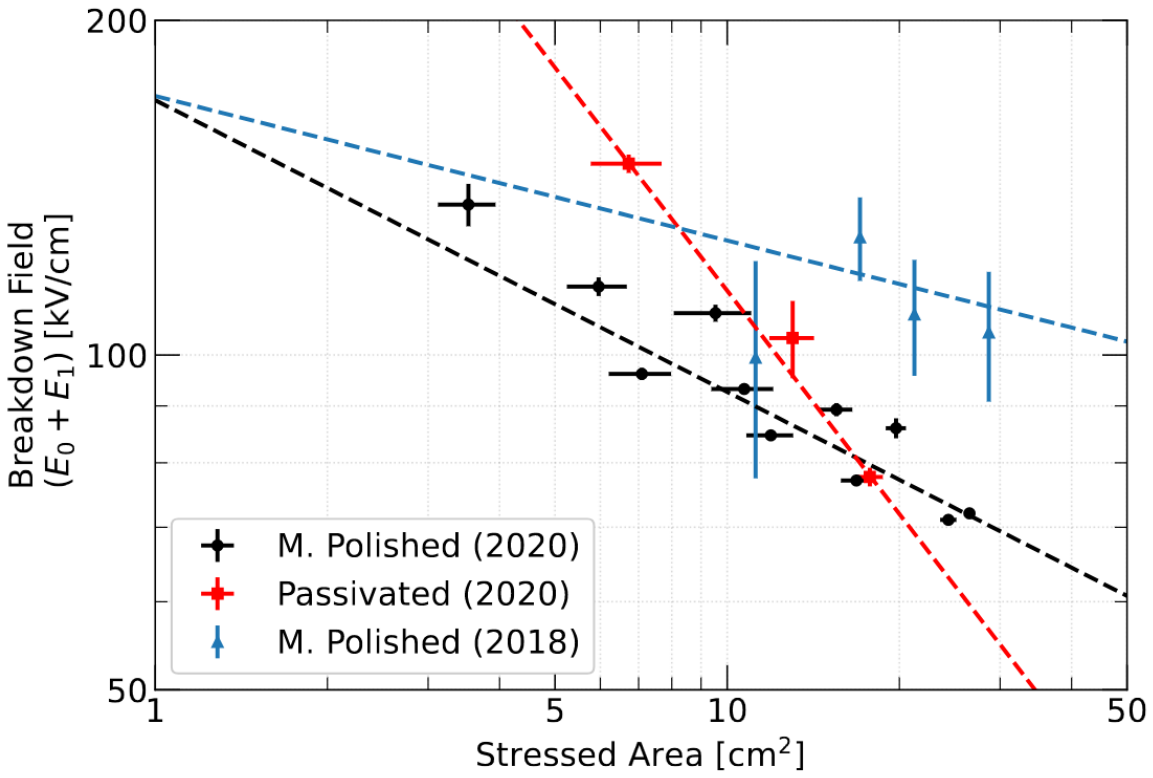


Non-linear grading



Dielectric strength of LXe





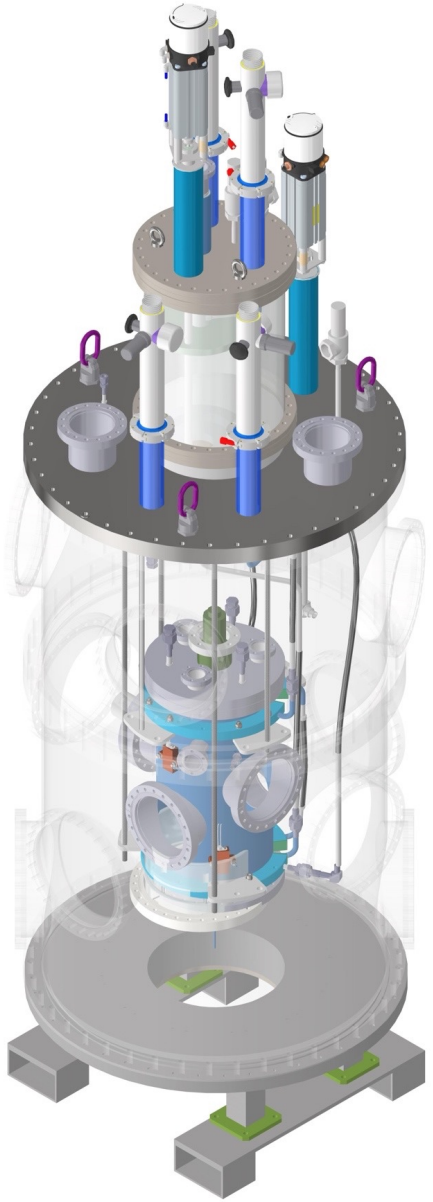
Watson et al: 10.1063/5.0107082

HV TPC: MOTION (experiMent for develOpmenT of technologies in liquld xenON)

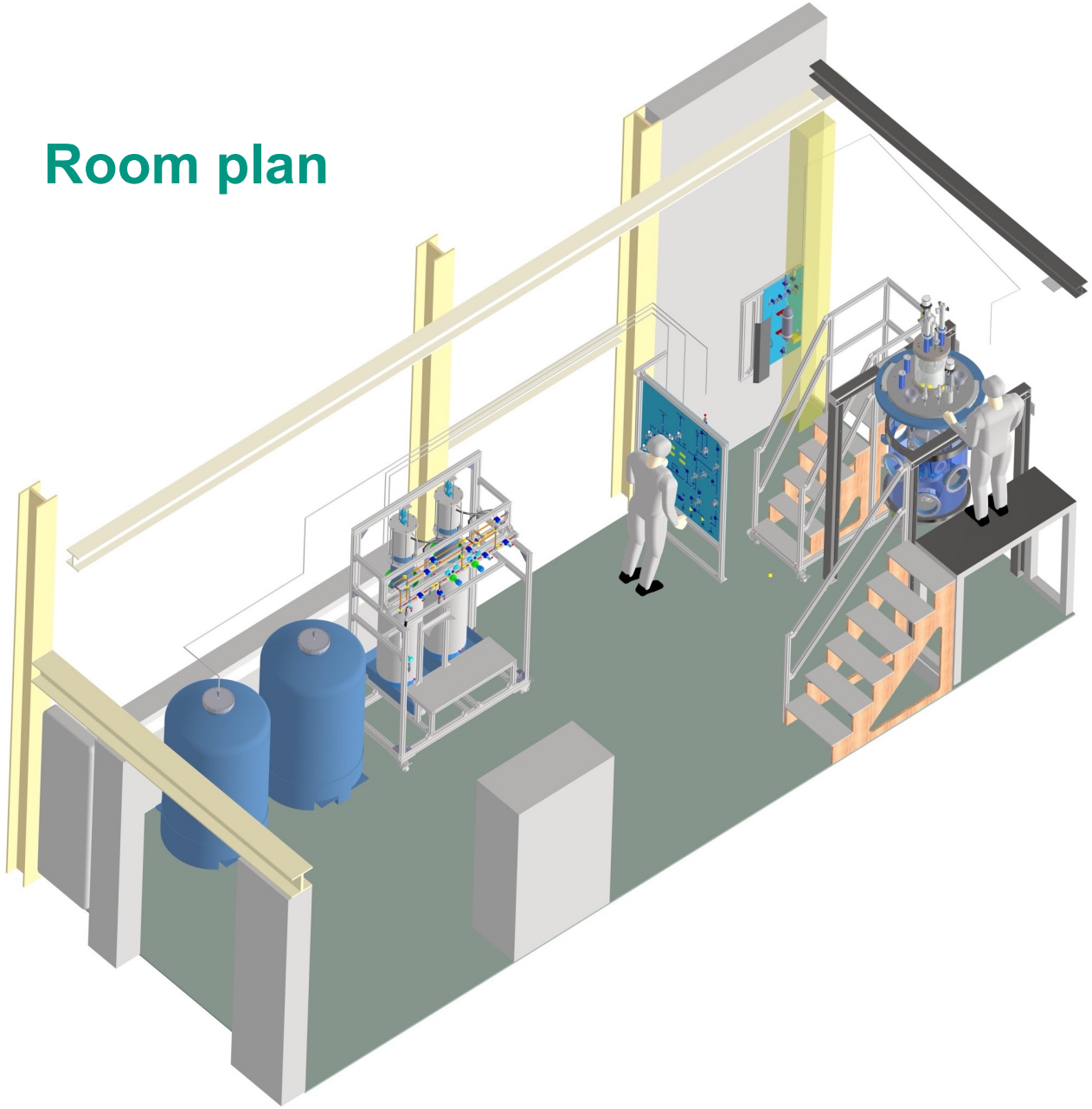
Goal: Safe and stable high voltage (up to -200 kV) delivery to the cathode without disturbing the drift field in the detector, made from radio-pure materials

Additional plans:

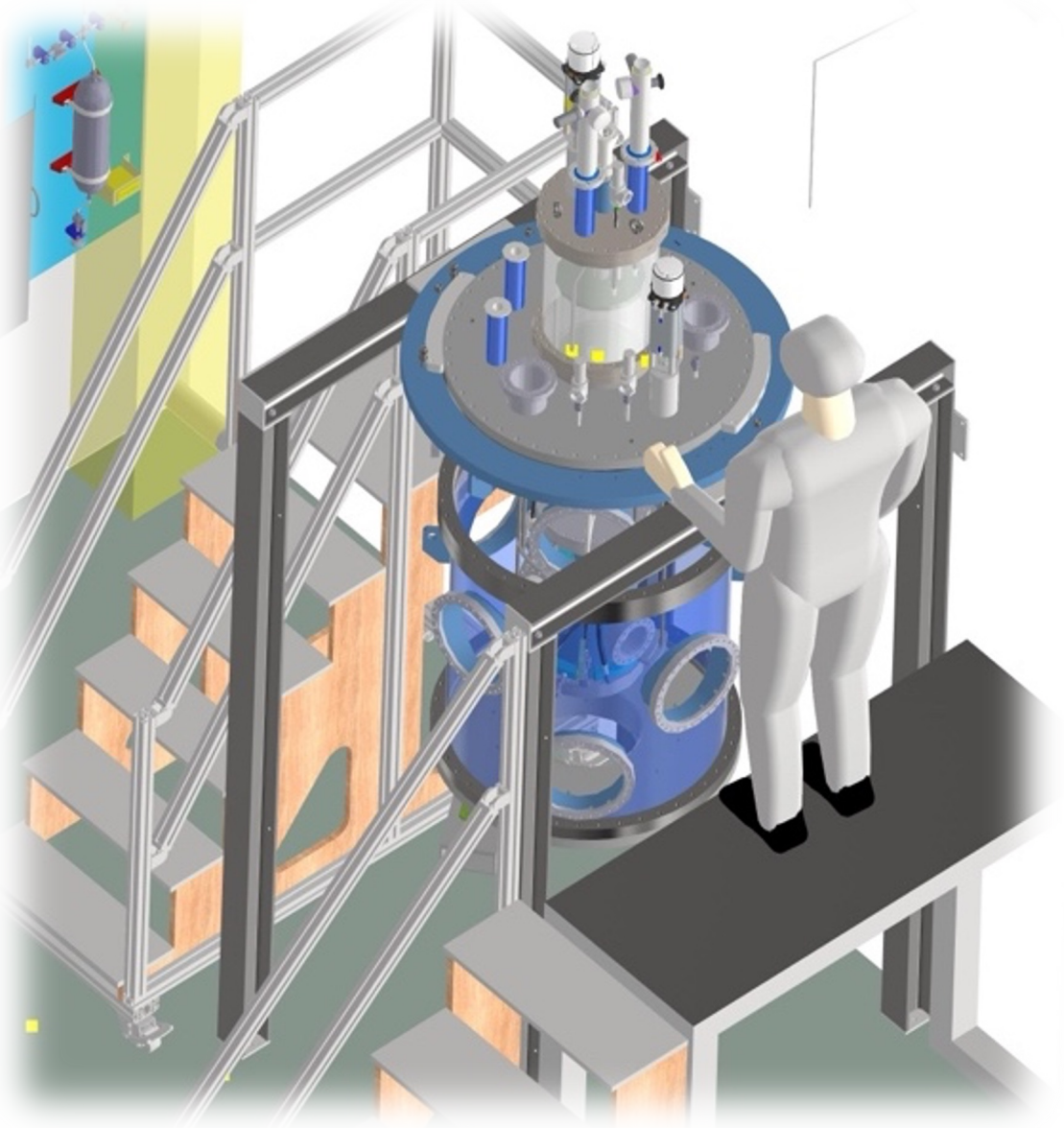
- LXe dual-phase TPC with light and charge readout
- Test of treated electrodes (single electron emission, electroluminescence and dielectric strength)
- Electrically stressed area of surfaces vs dielectric strength
- Tritium calibration
- Xe gas bubbler to study bubbles as initiators of discharges
- Plastic scintillators to study cosmic rays as initiators of discharges
- Oxygen ampule to study hypothesis of decreasing dielectric strength with decrease of electronegative impurities



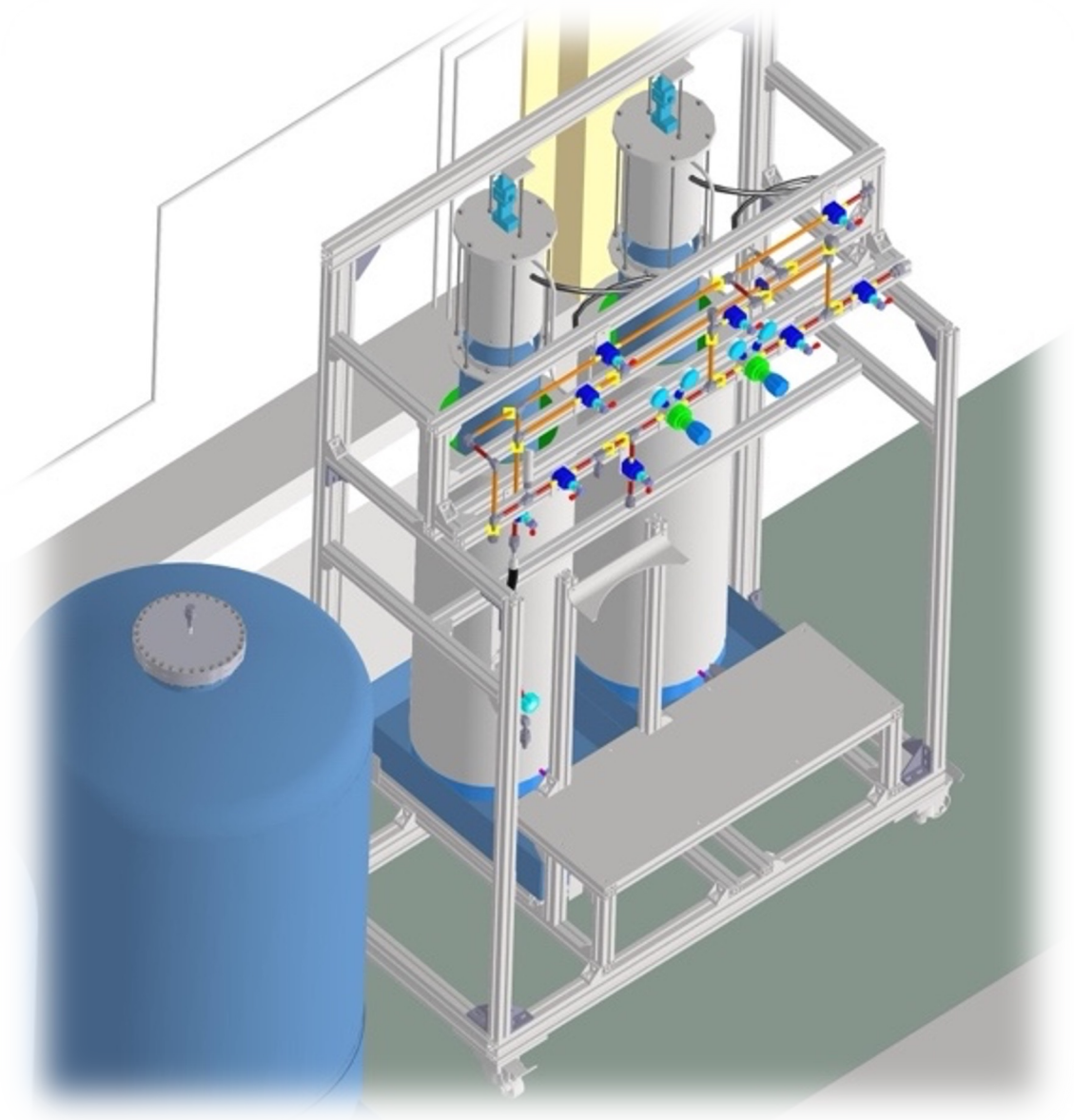
Room plan



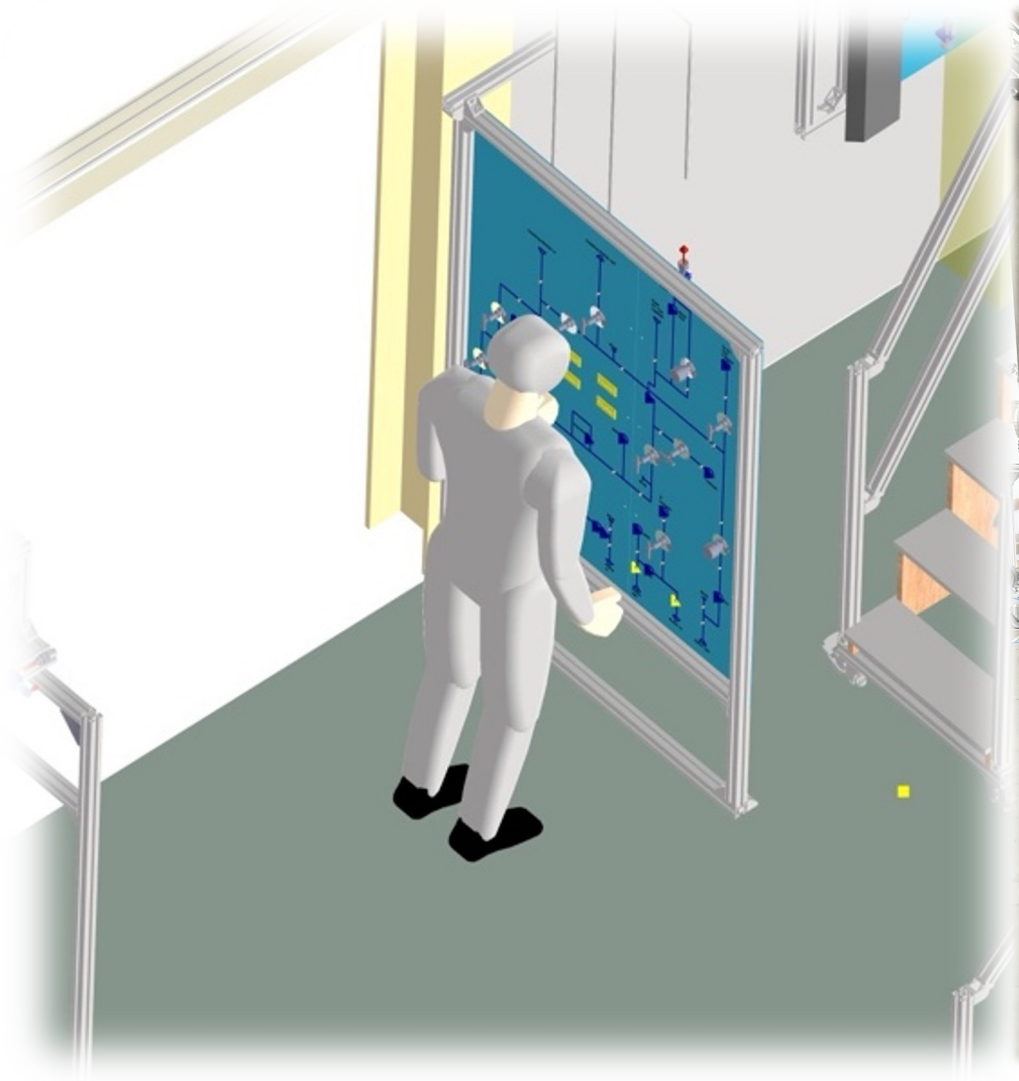
The cryostat



Xenon storage

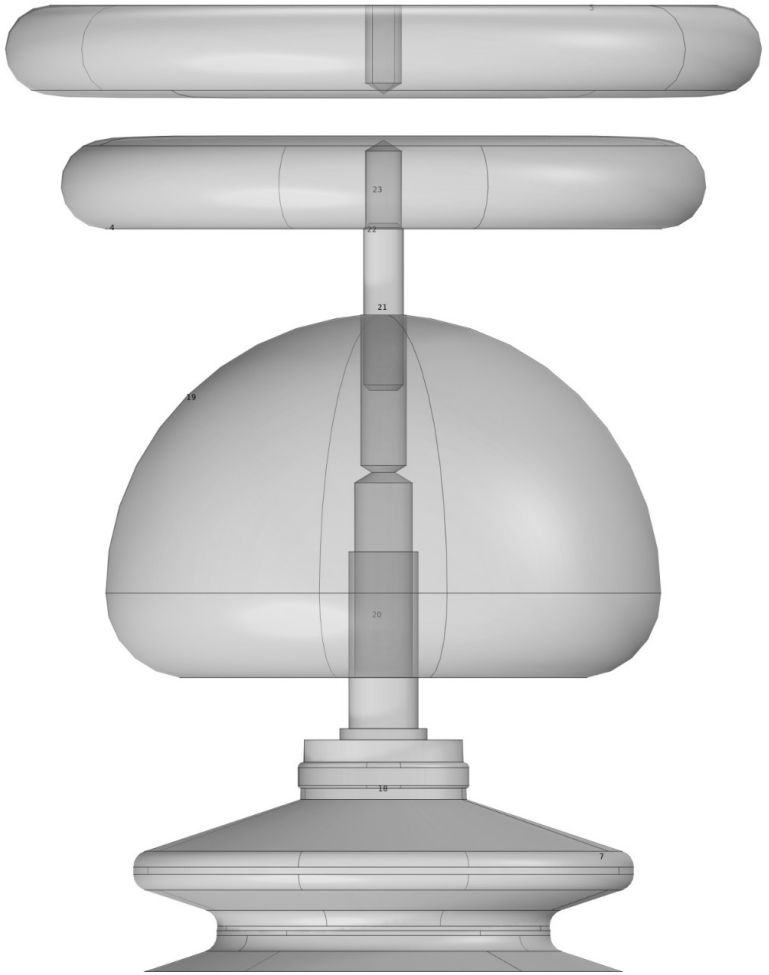


Xenon gas control and process panel



Next steps 2024

- Commissioning of the outer and inner vessel soon
- Commissioning of gas panel
- First tests with argon gas
- First tests on liquefaction of xenon gas
- Commissioning of very high voltage system
- First test with electrode configuration
- Upgrade to a TPC with dual-phase readout



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Conclusions

- Need of systematic testing of HV elements in conditions similar to the operation ones!
- Extensive R&D program at KIT on electrode design, manufacturing, conditioning and testing
- Developed image methods and testing procedures for quality control of electrodes
- Developed reparation techniques for meshes
- Developing the necessary expertise for the next generation detectors
- R&D program on HVDC feedthroughs that can fulfil the requirements of DARWIN/XLZD

Looking for collaborators inside XLZD to tackle this challenge!

Feel free to ask me questions in the coffee breaks as well ☺