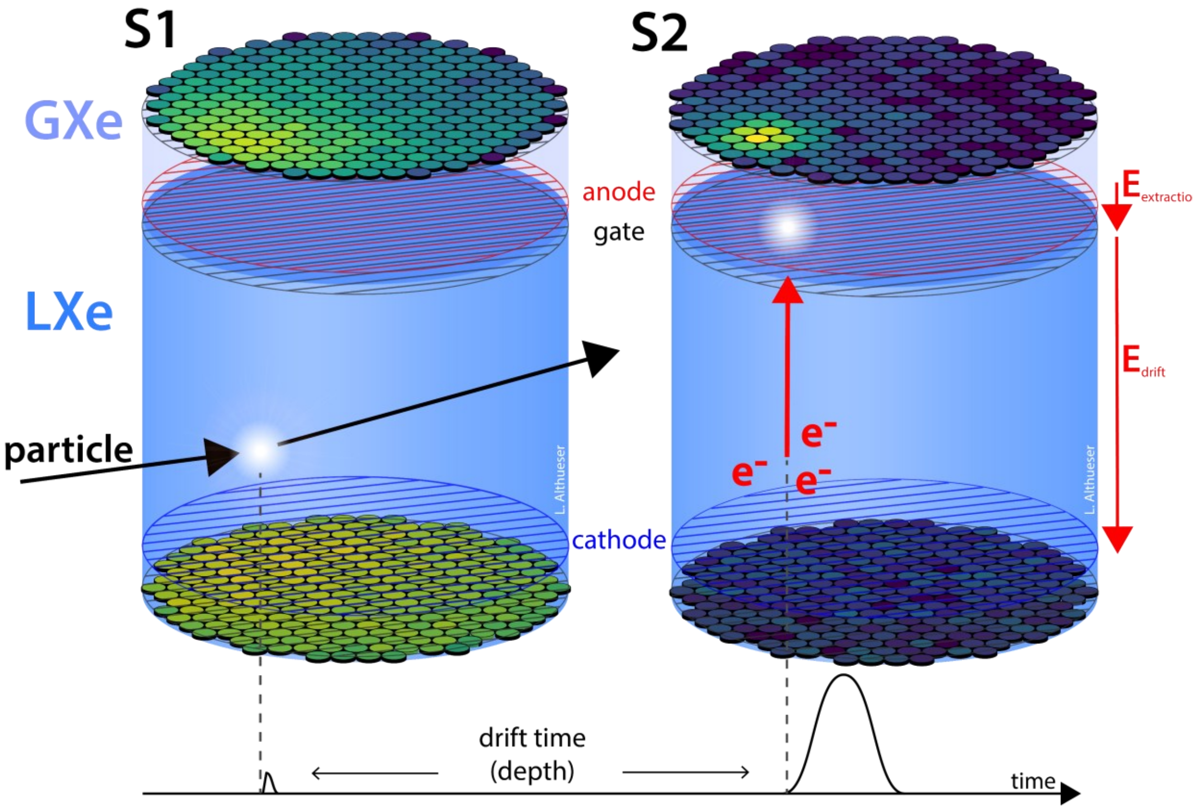
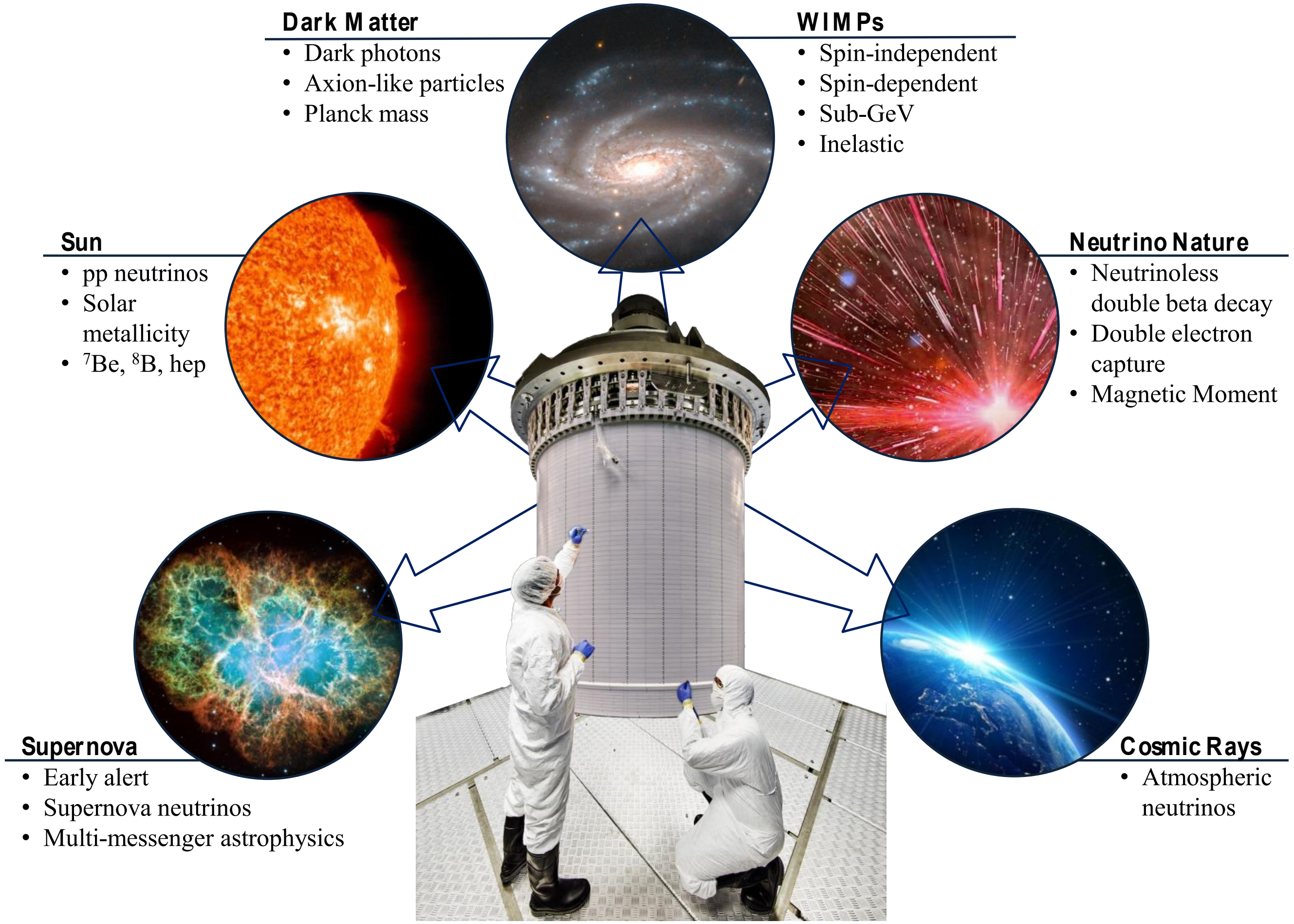
DARWIN – recent progress

Yanina Biondi and Frédéric Girard on behalf of the DM groups at KIT, LPNHE and Subatech
Third DMLab meeting,
November 16, 2023

Liquid Xenon TPCs





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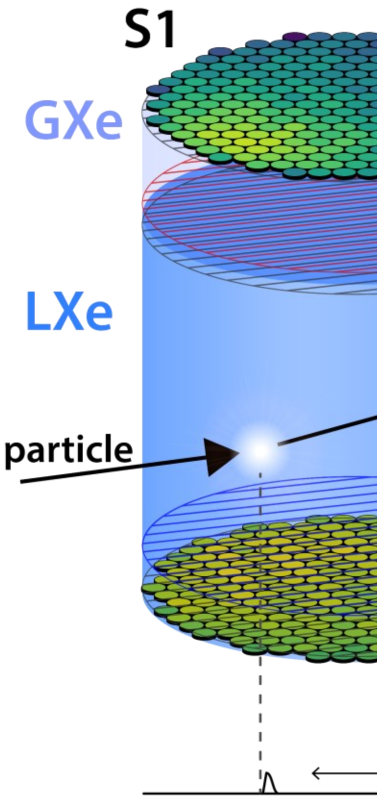
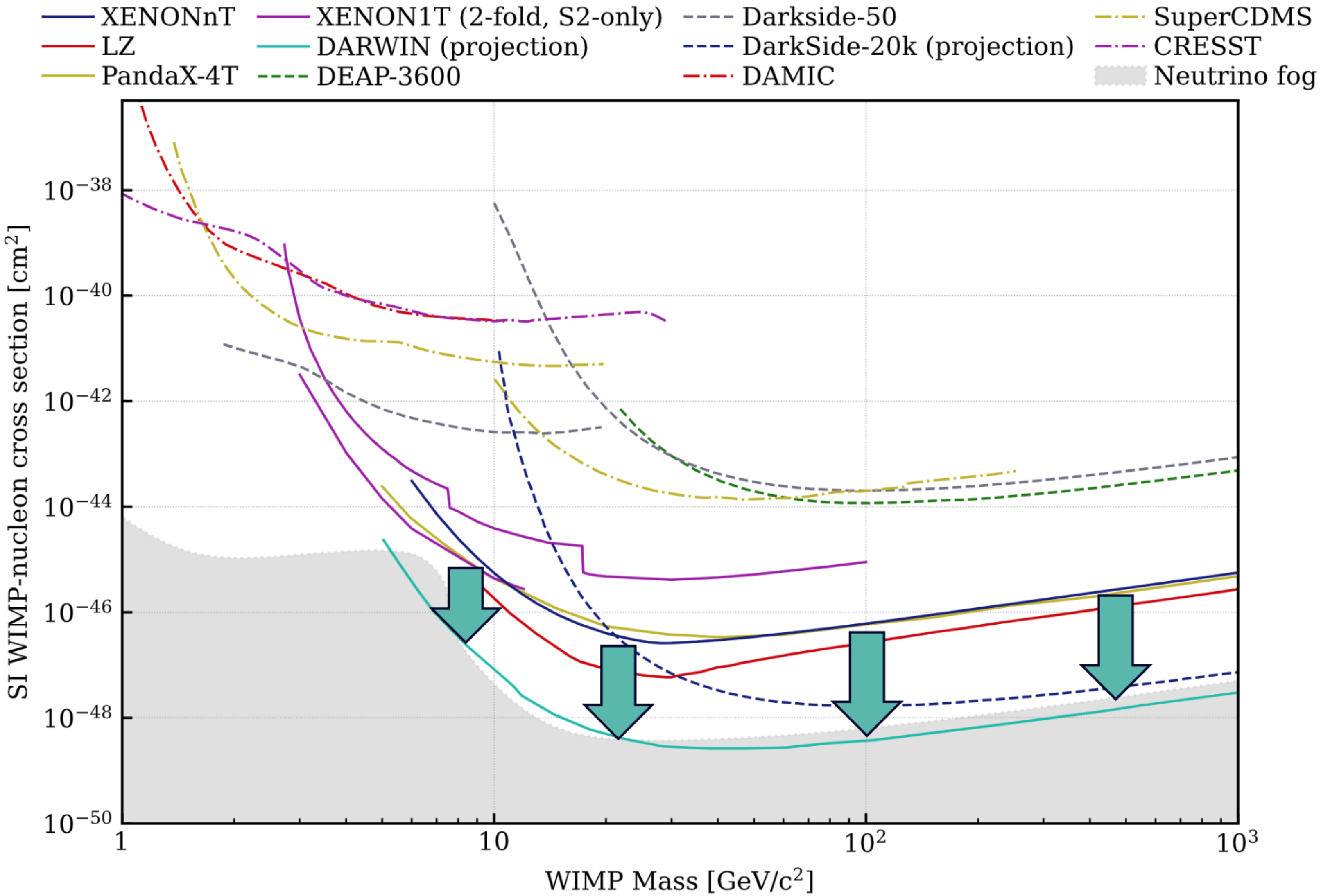
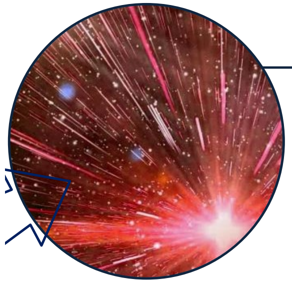
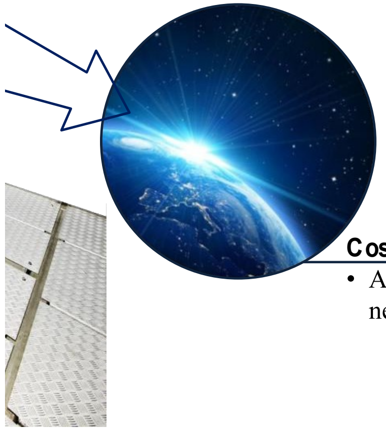




WIMPs
- Spin-independent
- Spin-dependent
- Sub-GeV
- Inelastic



Neutrino Nature
- Neutrinoless double beta decay
- Double electron capture
- Magnetic Moment



Cosmic Rays
- Atmospheric neutrinos

The DARWIN Observatory

Baseline design:

- 2.6 m diameter x 2.6 m height
- 40-tonne LXe active target
- Two arrays of photosensors (1910 3” PMTs)
- 24 PTFE reflector walls
- Passive and active muon and neutron vetoes
- LoI submitted to LNGS for sitting

Ongoing design and sensitivity studies:

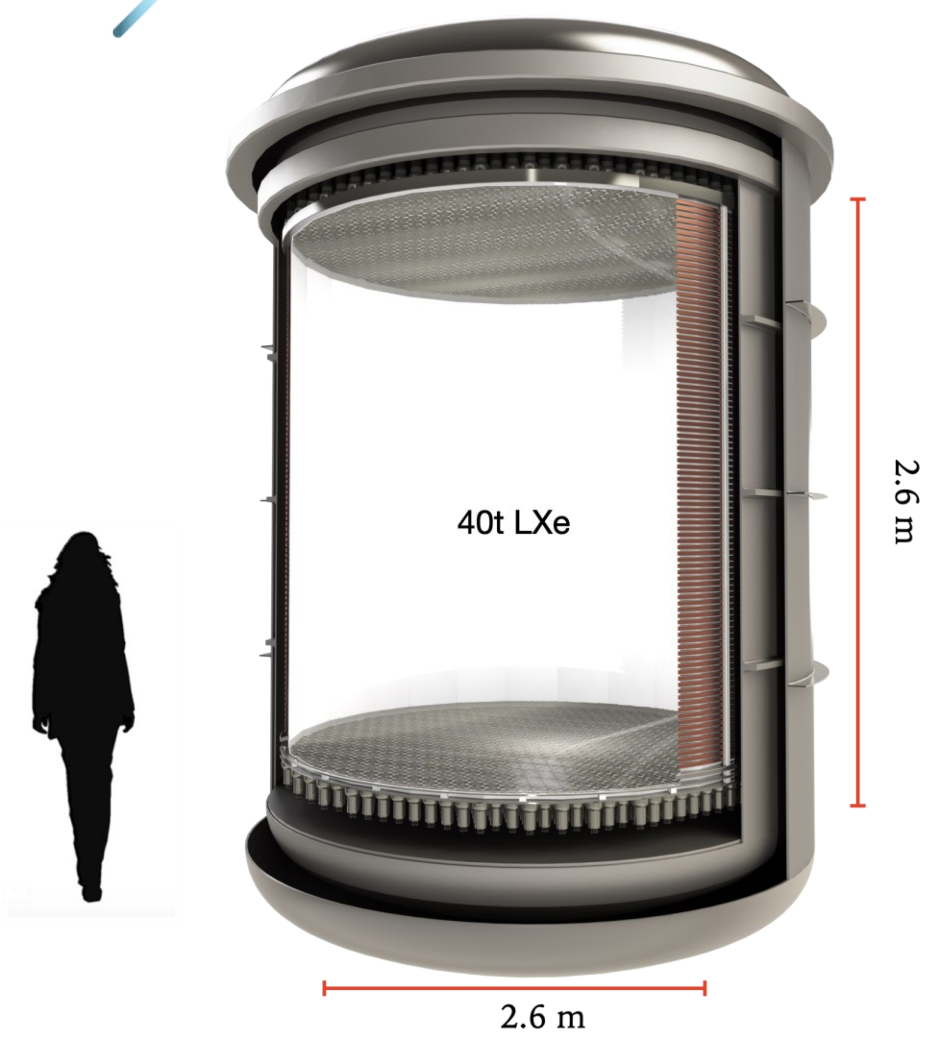
Cosmogenic background simulations for the DARWIN observatory at different underground locations

GPU-based optical simulation of the DARWIN detector

Solar neutrino detection sensitivity in DARWIN via electron scattering

Sensitivity of the DARWIN observatory to the neutrinoless double beta decay of 136Xe

DARWIN: towards the ultimate dark matter detector



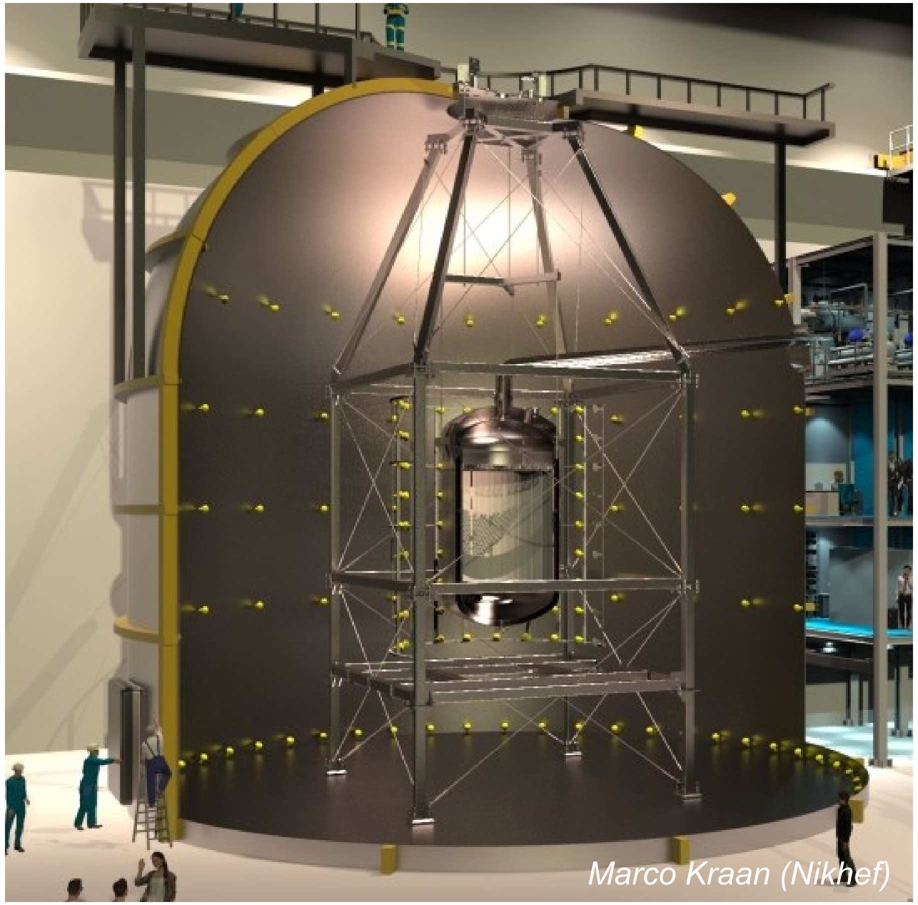
Credit: Frédéric Girard

XZLD Consortium

MoU between XENON, LZ and DARWIN to join efforts for the ultimate LXe TPC

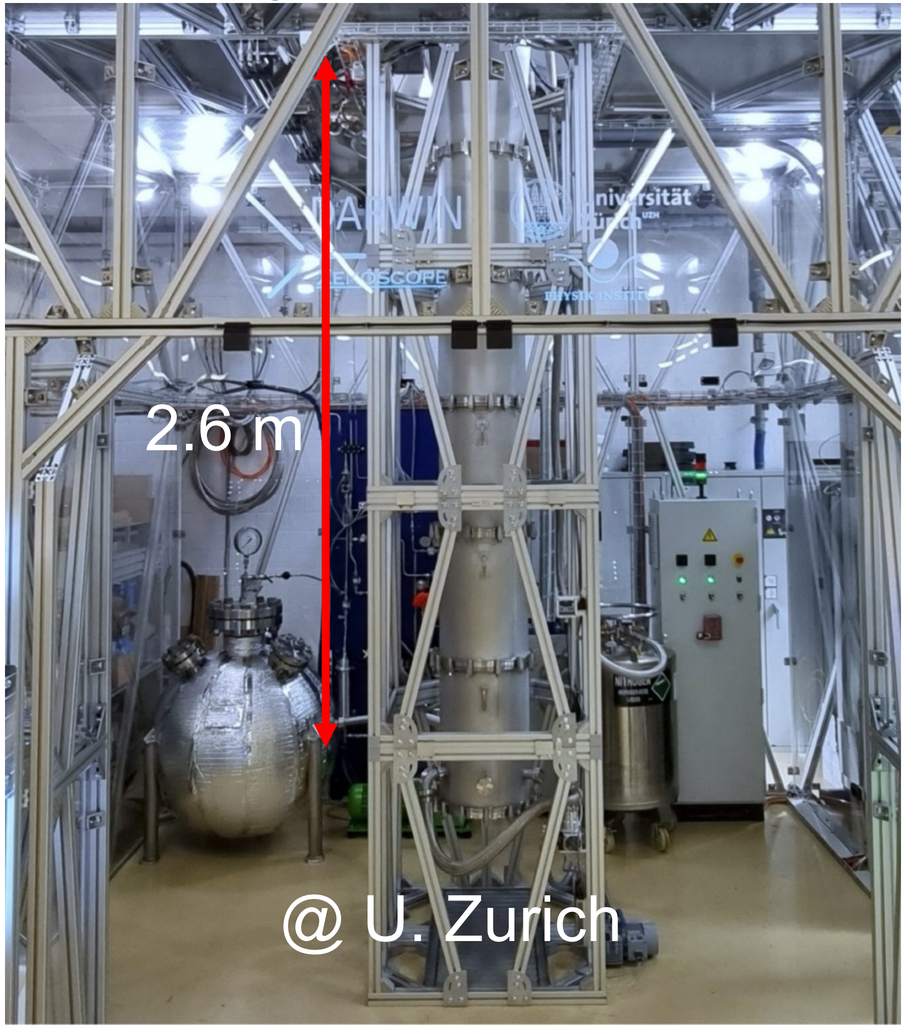
"A next-generation liquid xenon observatory for dark matter and neutrino physics." *Journal of Physics G: Nuclear and Particle Physics* 50.1 (2022): 013001.

Upscaling challenges



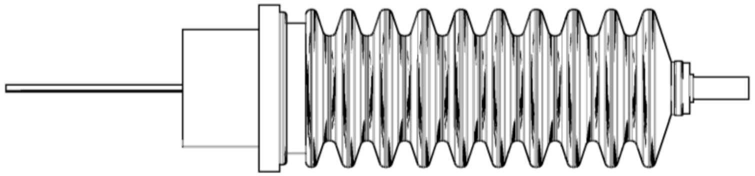
- Liquid xenon purity
- High-voltage delivery
- Electrodes design and construction at 2.6 m
- Electric field homogeneity
- Light collection efficiency throughout the TPC
- Background mitigation
- Photosensor performance

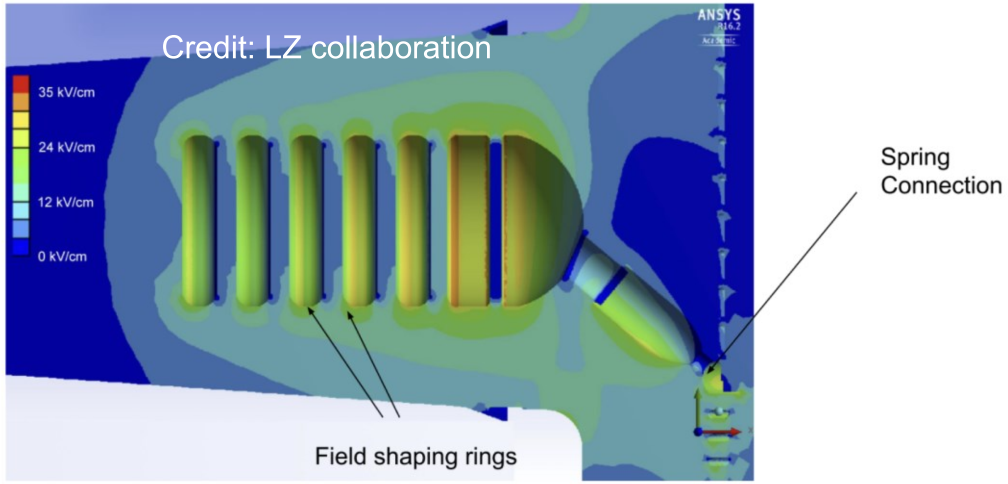
DARWIN large-scale Demonstrators



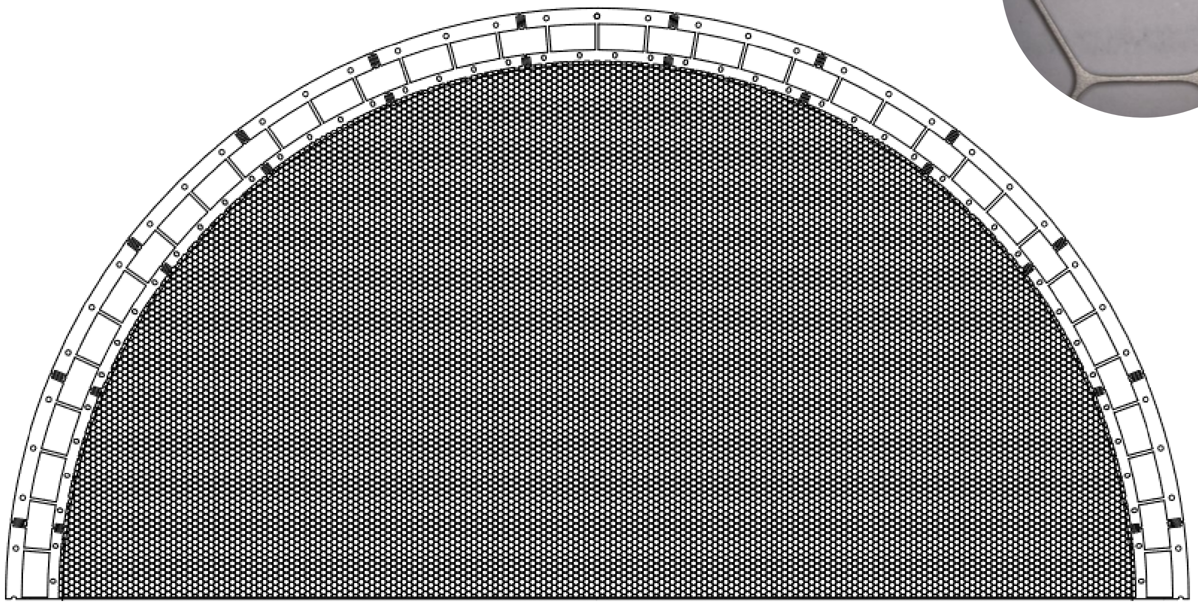
R&D task forces at KIT

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



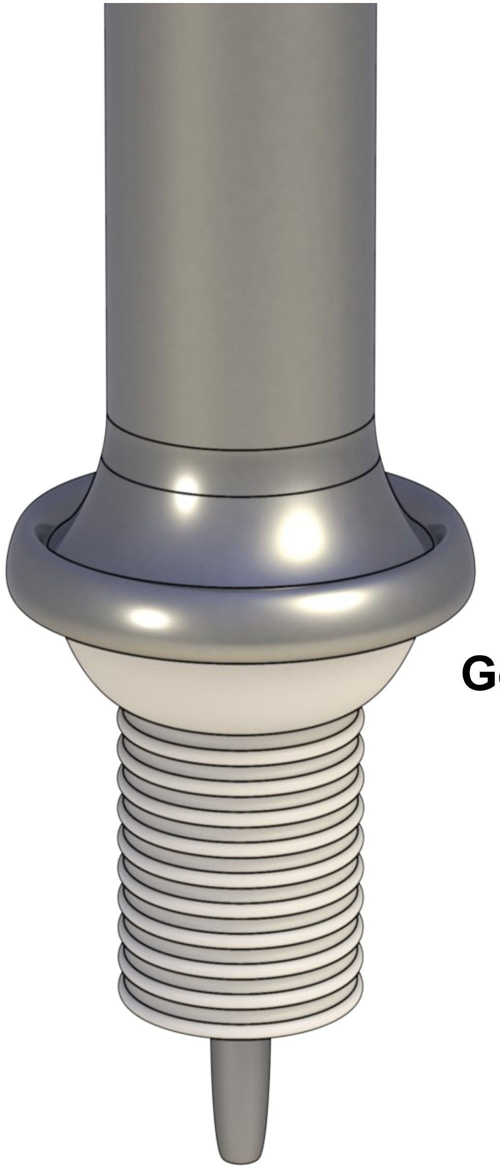


- Electrode design, production and quality testing



HV feedthroughs

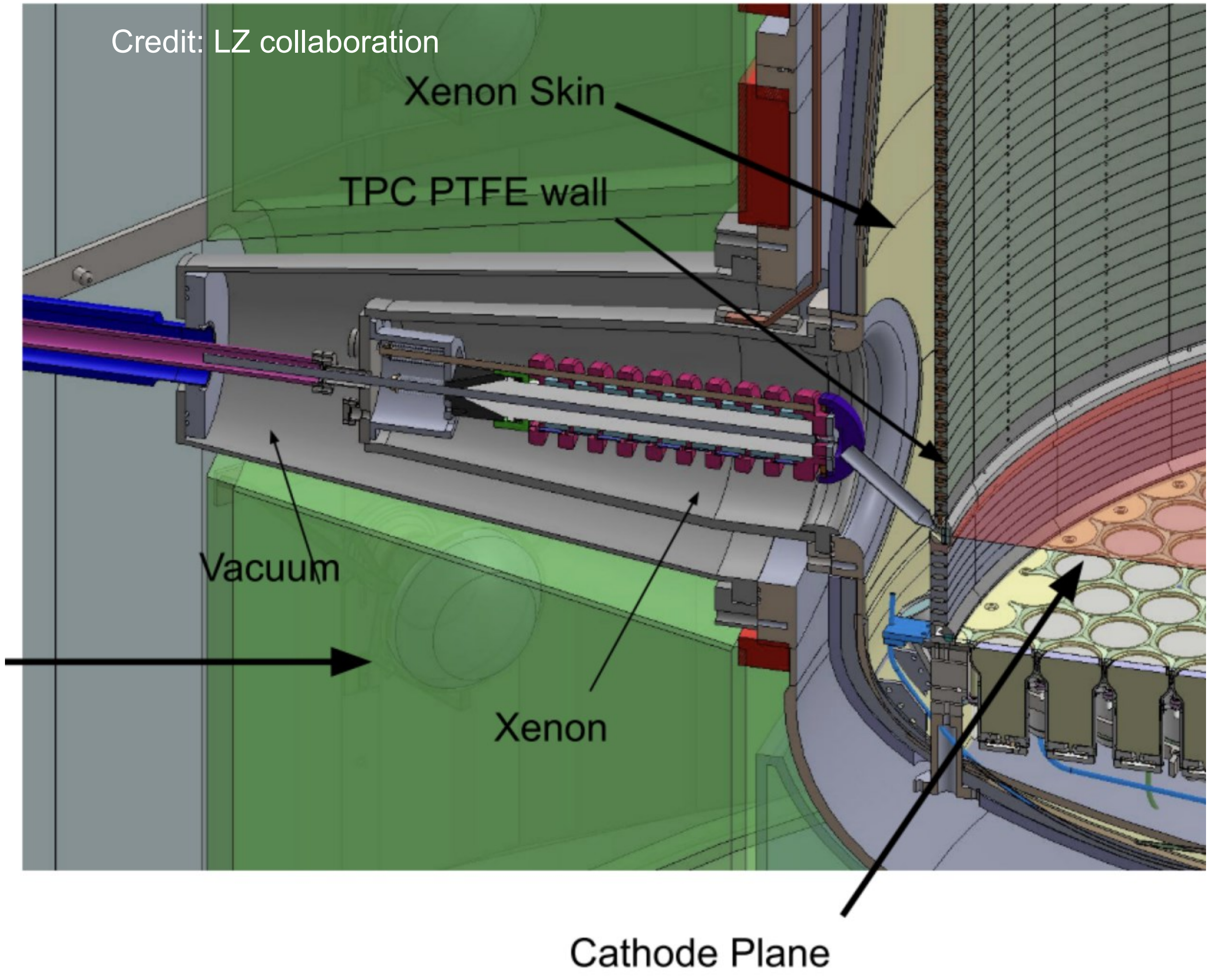
- Optimal drift field: very high voltage in the cathode
- Challenging components in noble liquids
- The high field in the conductor can potentially affect the sensitive LXe in the detector
- The source of discharges is not completely understood
- HVDC terminations (end of the coax termination for a shielded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

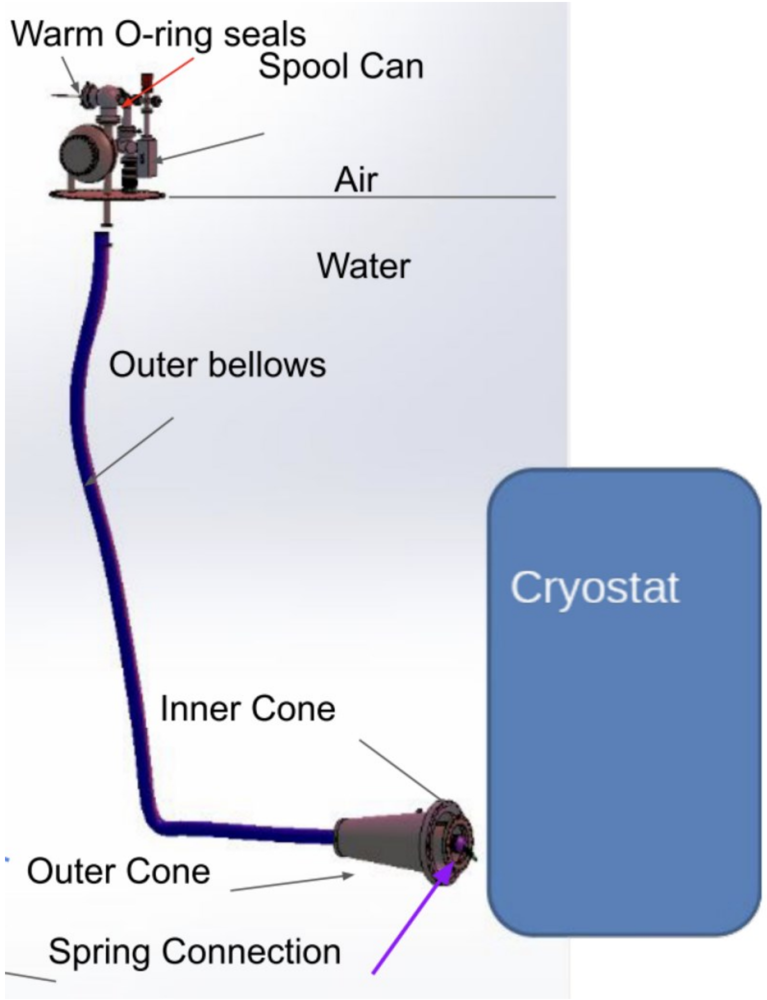


Geometrical field grading

HV feedthroughs

Resistive field grading

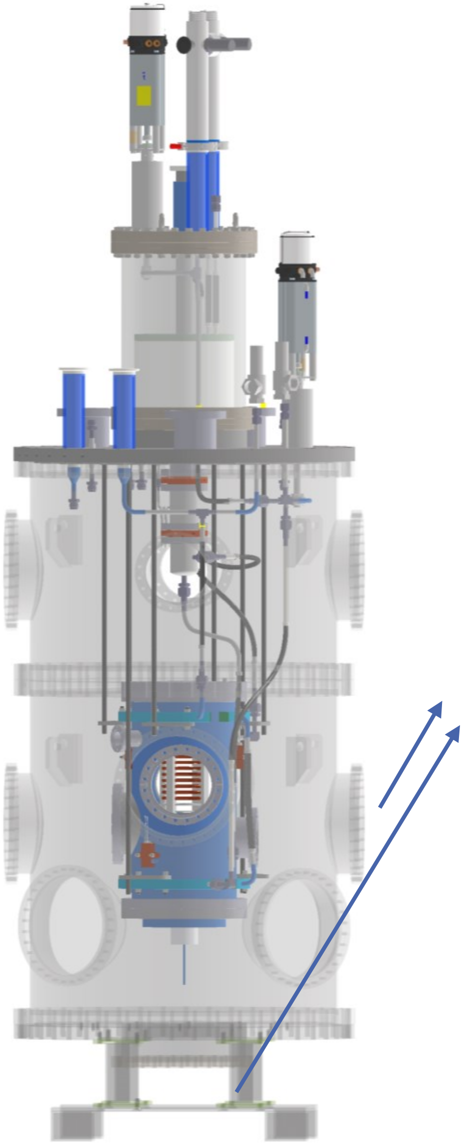




HV TPC: MOTION

Goal: Safe and stable high voltage (-100 kV) delivery to the cathode without disturbing the drift field in the detector, made from radio-pure materials

- Up to 100 kg LXe TPC with current, purity, and light readout
- Test capacitor, permittivity, resistor and non-linear resistor terminations
- Characterise treatment of electrodes in an LXe environment
- Test hypothesis for discharge events: bubble streamers, electroluminescence,…
- Mechanical and electrical design that can sustain thermal shocks vibrations or low-magnitude earthquakes



Ports on the side and bottom of the TPC for HV delivery

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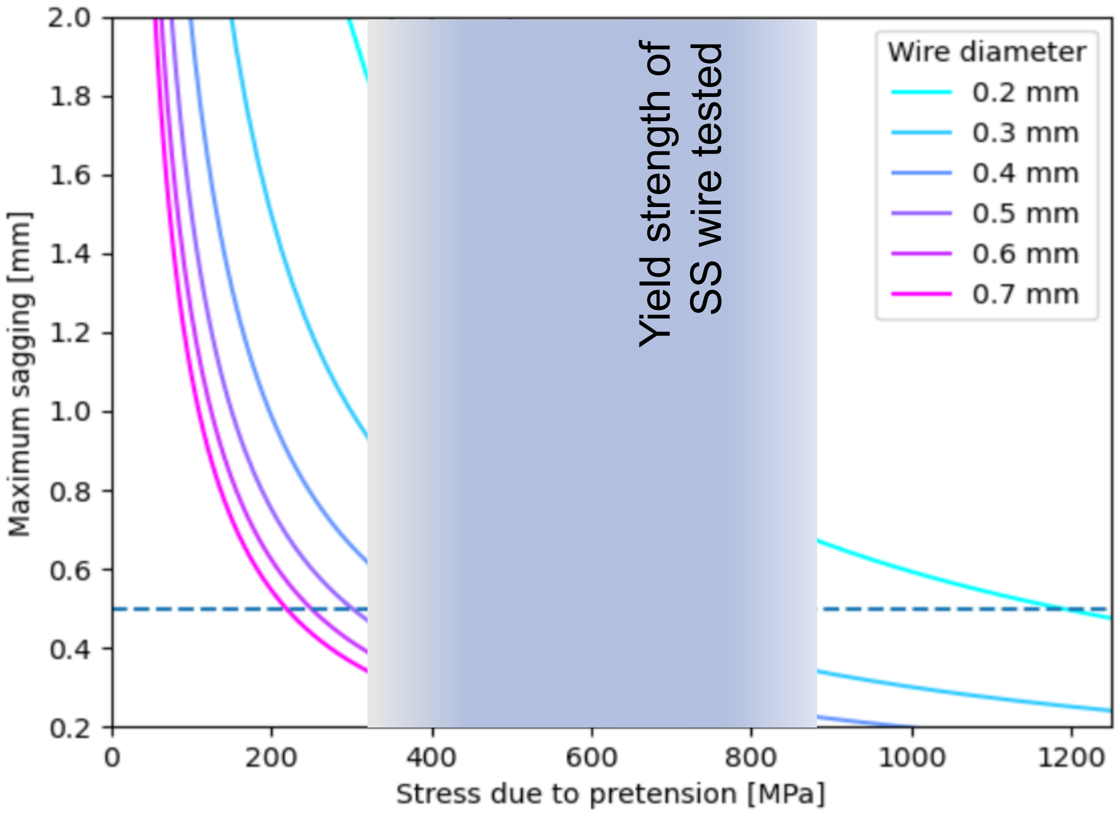
Electrode design

Karlsruhe Institute of Technology

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 too large, difficult for CNC to drill all wire holes ✕
Reparation before installation	Monolithic ➢ more difficult to repair ✕	Wires independent of each other ➢ easier to repair ☑



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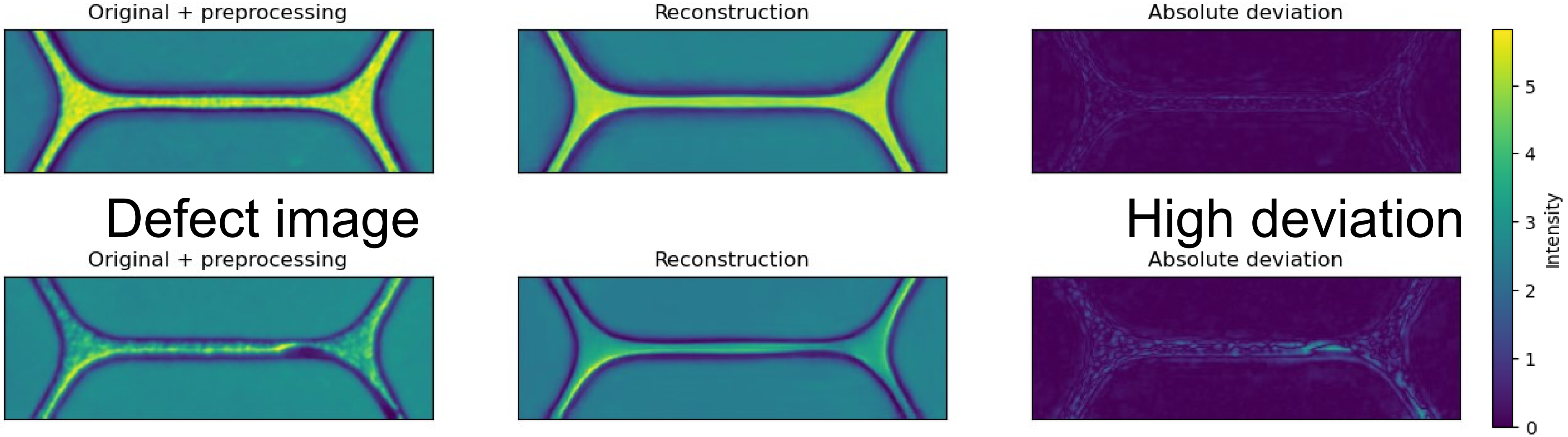
Electrode quality control: ML

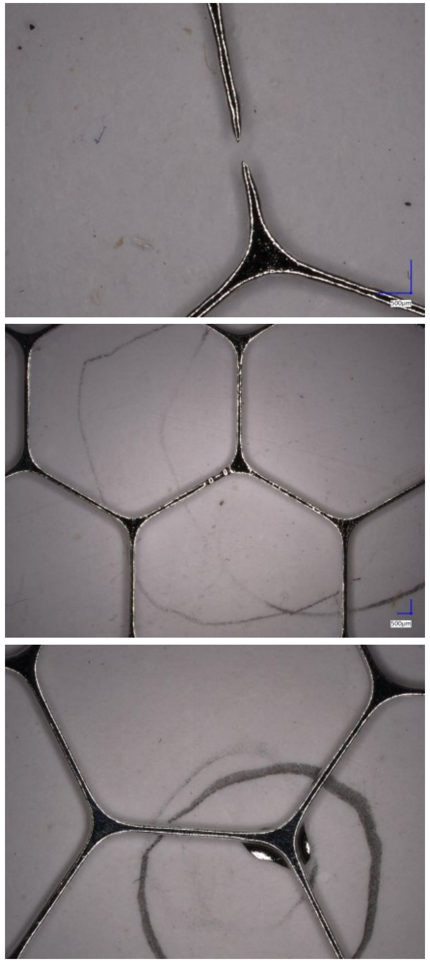
General idea X →  → X'

X | X' | $|X - X'|$

Clean image — Low deviation

Defect image — High deviation





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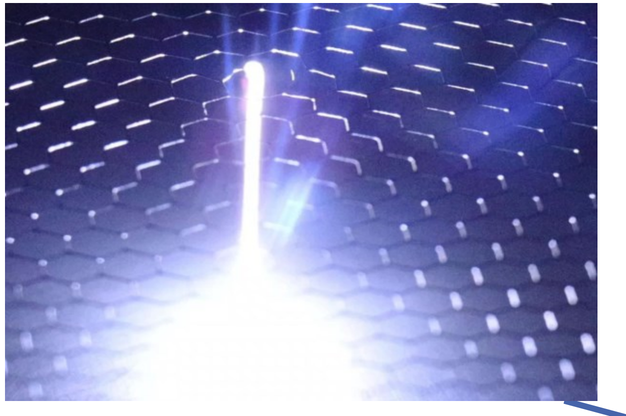
Electrode testing facilities

Testing of electrodes

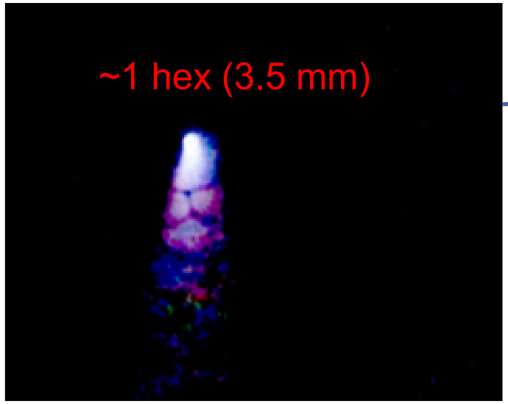
Video:

Zoom-in on known defect

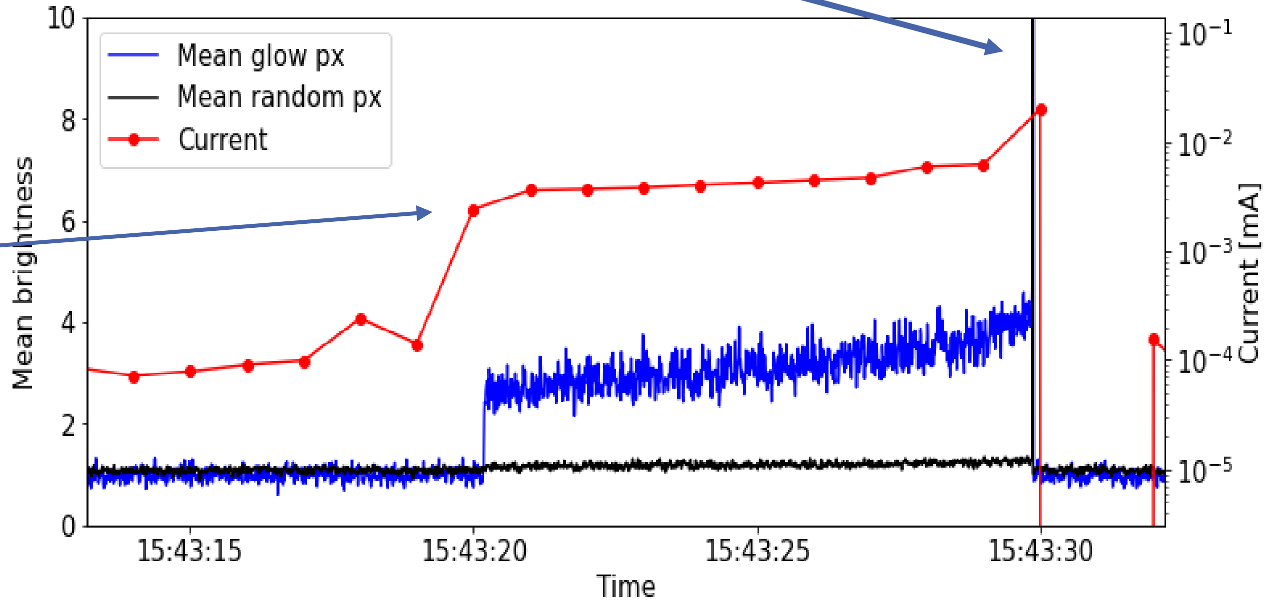
- Glow-up visible:
  - Current increases ~10 seconds before breakdown
  - Brightness of pxs in the defect area increases at same time



Zoom-in breakdown single frame



Zoom-in a - pre-breakdown



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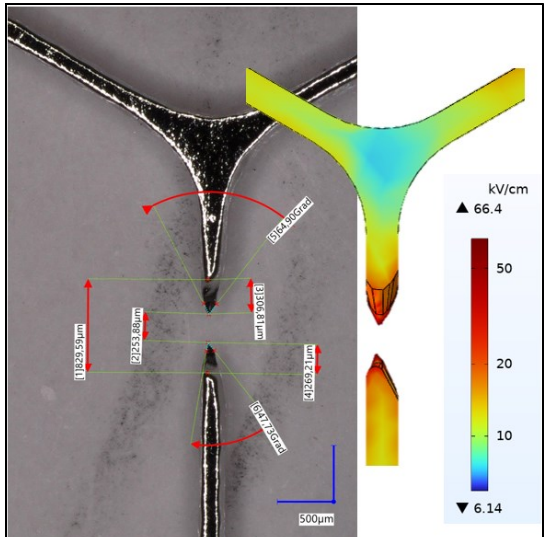
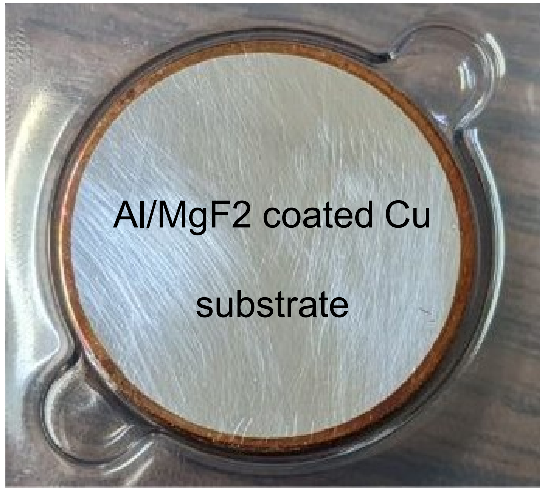
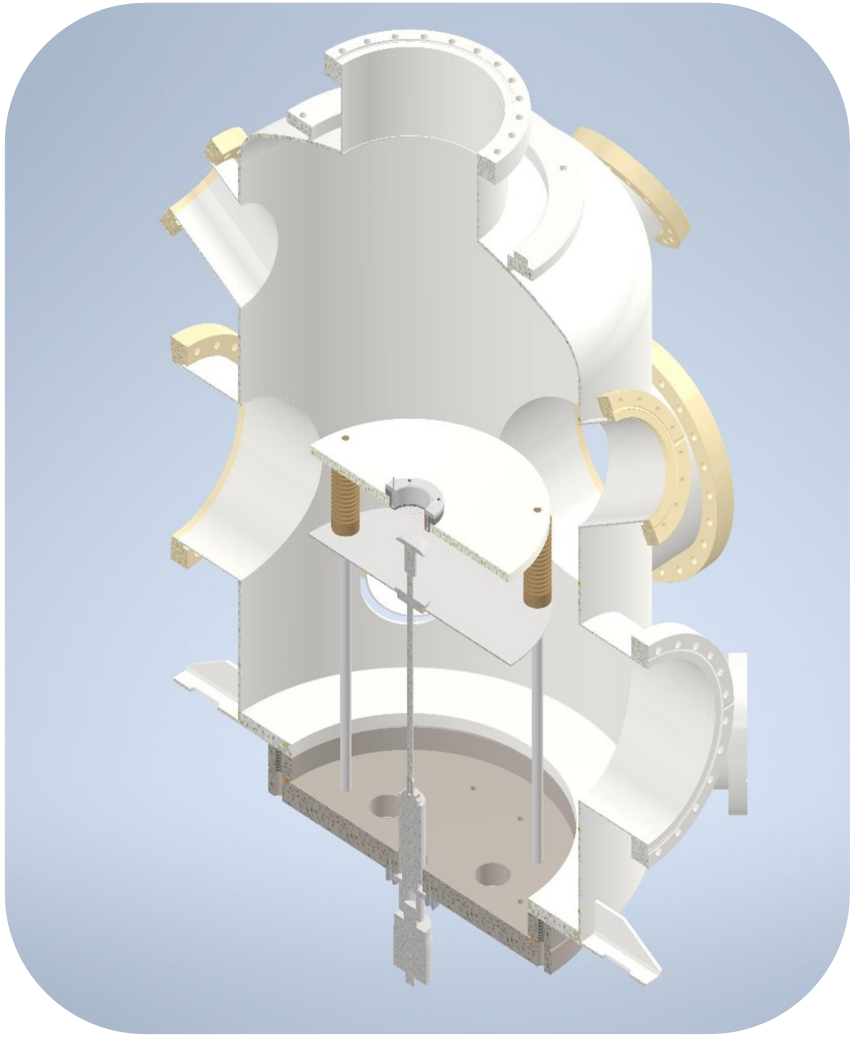
Electrode coating BHiVE

- 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

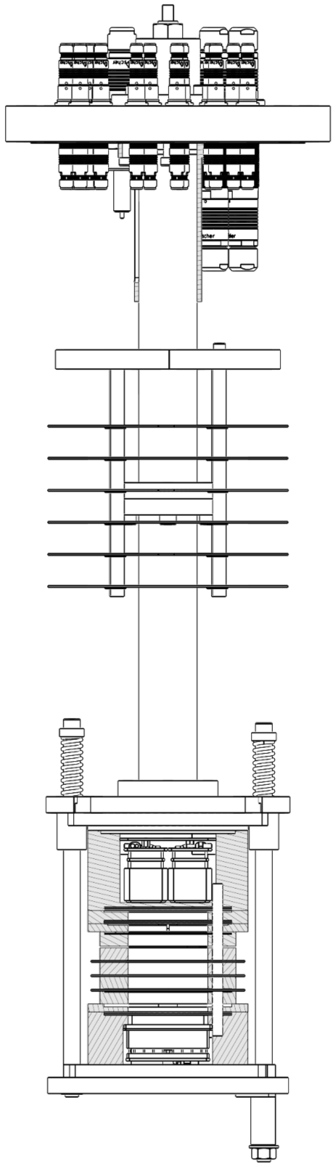


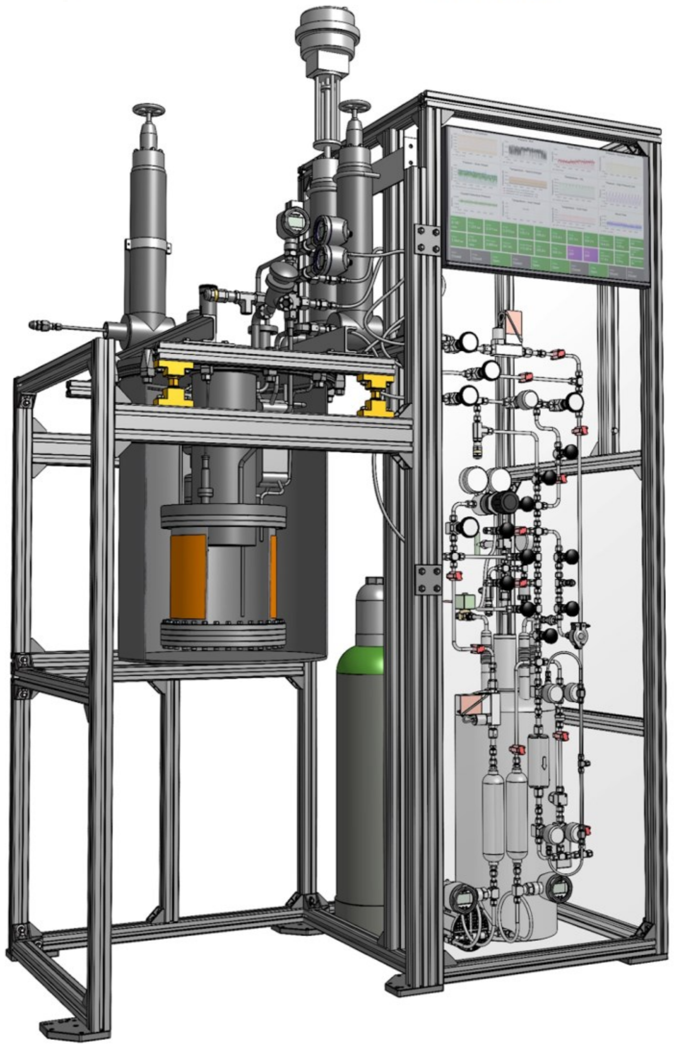




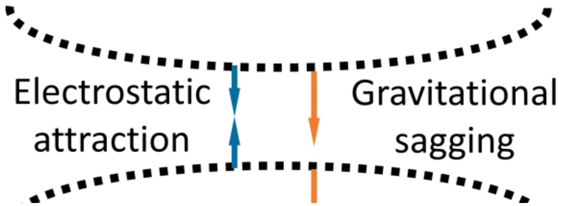
XeLab at LPNHE

- Platform to test new electrode designs for DARWIN
- Potential for photodetector testing
- First xenon dual-phase TPC in France
- Can be used in the context of X-Art (xenon-doped argon)
- Collaboration between Subatech and LPNHE
- Construction: Q1 2024
- Commissioning: Q2-Q3 2024

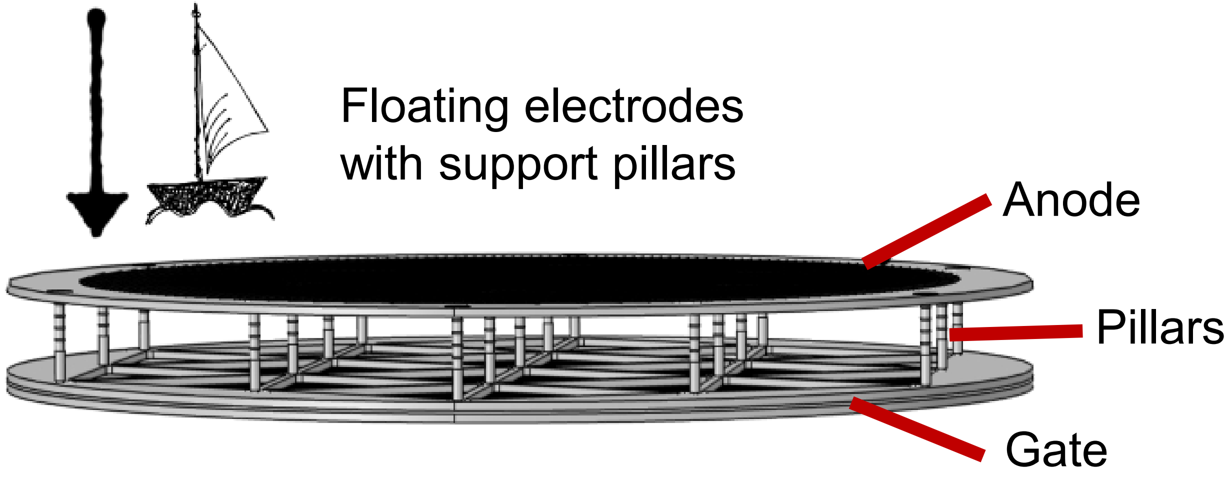


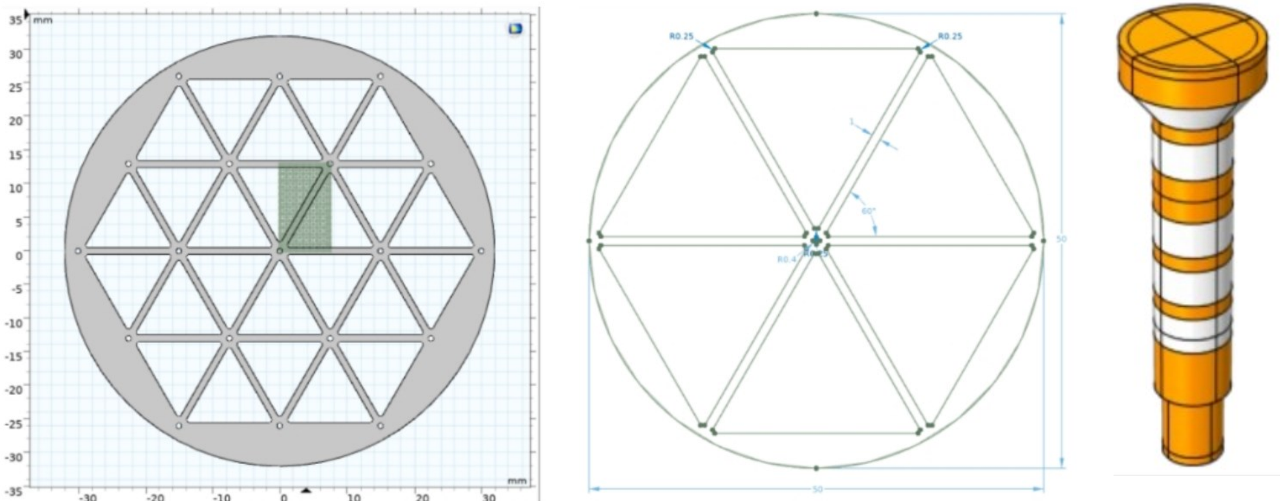


Floating Electrodes



- Concept: use the high density of xenon to float the electrodes
- Rigid support system
  - Even distance between the two electrodes
- Better and even S2 position resolution and amplification
- Challenges:
  - maximize the optical transparency
  - Keep the radioactive background low





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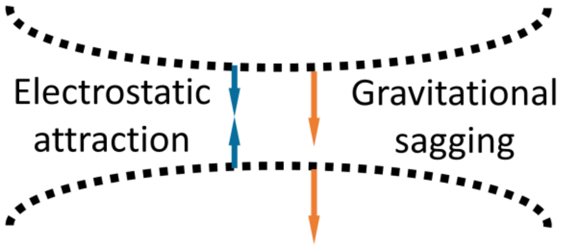
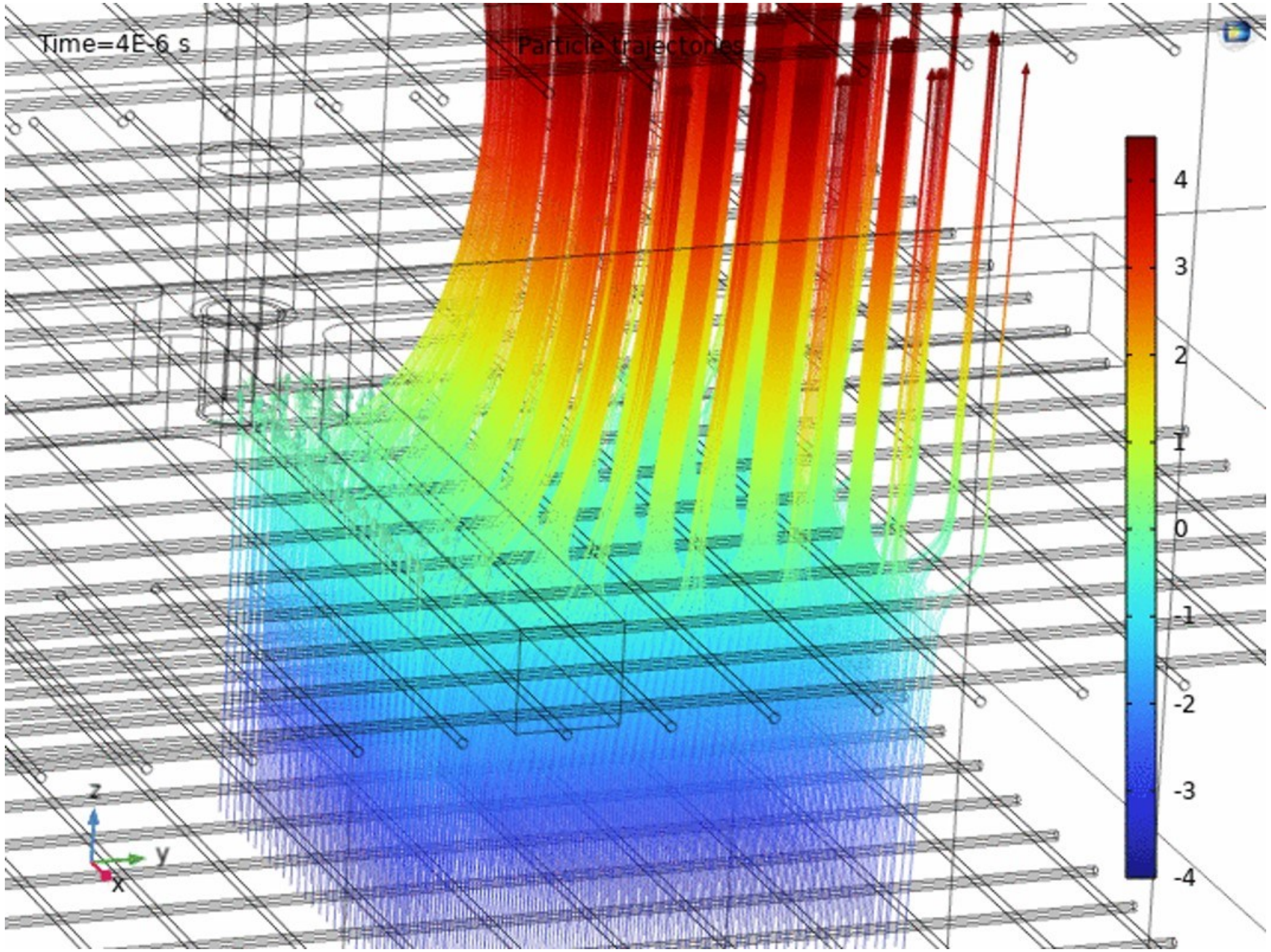
Floating Electrodes Simulations



- COMSOL Multiphysics engine
- Modelling of different electrode designs and electron extraction from the liquid phase to the gas phase
- Design optimization leading to production
- Inform on the path taken by the electrons
  - Can be used for mapping



Pancake @ Uni. Freiburg

- Full DARWIN-scale in diameter test platform
- Capacity: 400 kg LXe
- Test of full-scale electrodes for XENON and DARWIN
  - Electric field homogeneity
  - Electrical discharge
  - Resilience to temperature changes (stretching, fatigue)

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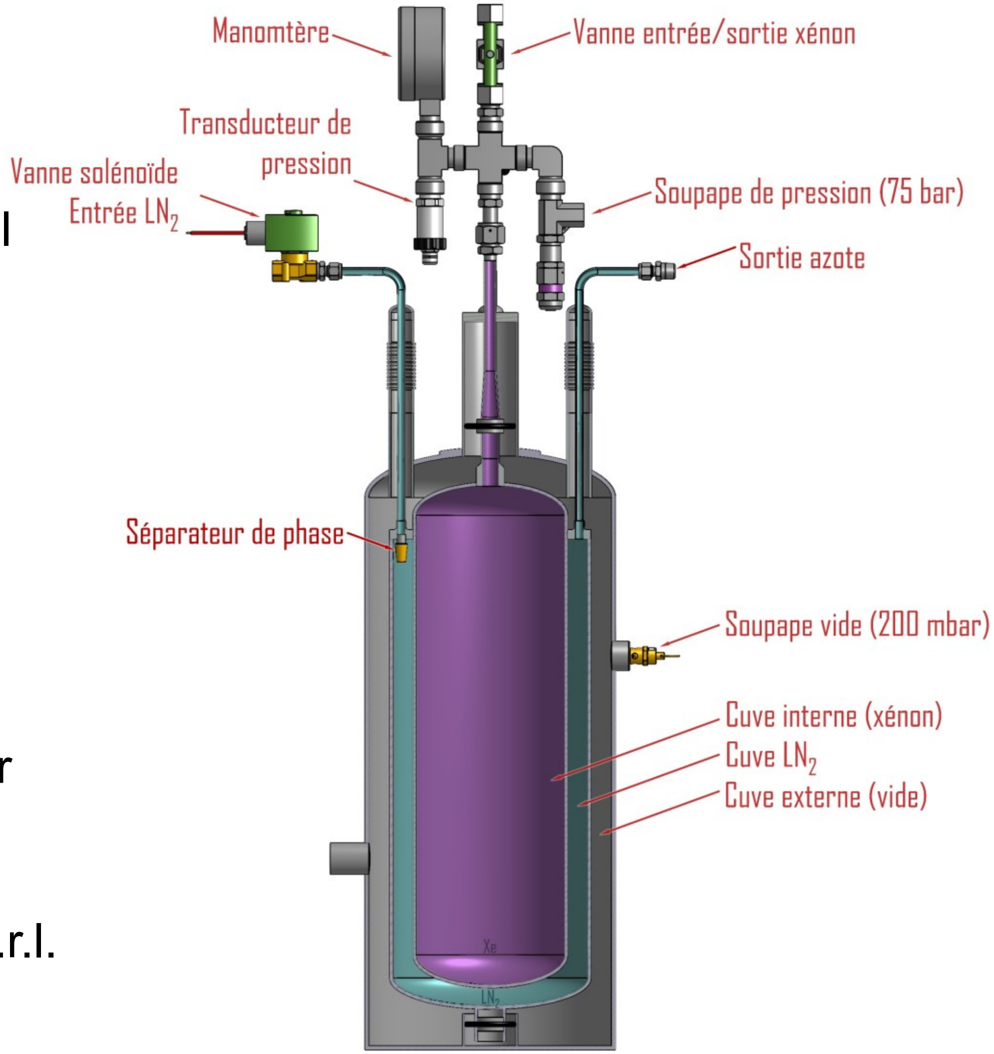
MiniReStoX

- Xenon storage and recuperation vessel
- 3 separate volumes
  - Inner: up to 75 bar Xe
  - Intermediate: LN2 at 77 K
  - Outer: vacuum and superinsulation
- Recuperation: cryopumping
- Kept cold during cryostat operations for emergency recuperation
- Constructed by Costruzioni Generali S.r.l.



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The ReStoX family

XENON

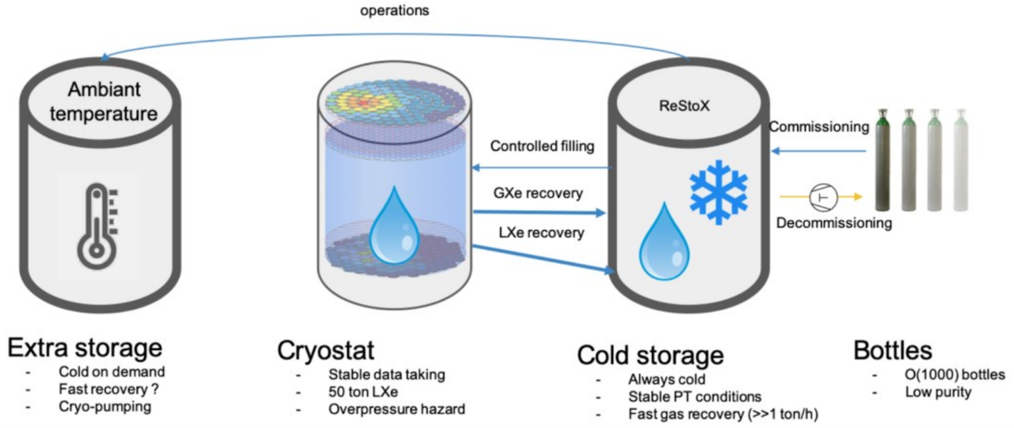
- France was heavily involved in the conception and production of two storage vessels:
- ReStoX1
  - 7 ton Xe (gas, liquid)
- ReStoX2
  - 10 ton Xe (gas, solid)
- ReStoX in XEMIS
- Future: DARWIN & nEXO

Description	ReStoX	ReStoX2
Dimension	2.1 m ⊘ sphere	(1.45 m, 5.5 m) cylinder
Phase	GXe, LXe, SXe	GXe, LXe, SXe
Maximum pressure	73 bar	71.5 bar
Capacity	7.6 t	10 t
Recovery speed	~ 50 kg/h	~ 1000 kg/h
LN_2 consumption in operation	35 kg/d	0 kg/d
LN_2 consumption for recovery	25 kg/h	~ 8000 kg

Subatech

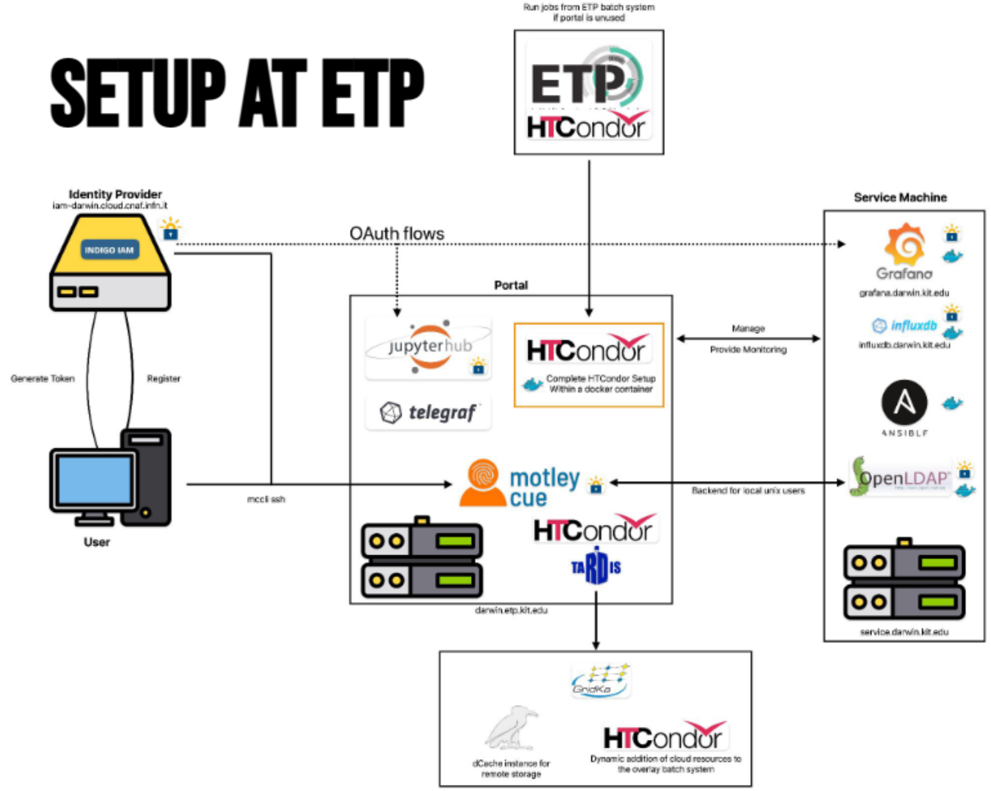
Xenon Storage for DARWIN

- DARWIN will need to store more than 50 ton of xenon
- Design study already performed at Subatech (J. Masbou)
- Horizontal design
- Heater, condenser, crystallizer in the same vessel
- Vacuum insulated
- Cooling power: ~ 1 ton/h of Xe frozen
- Recovery solution for emergencies



Computing

- Mid of 2023: creation of an extra Working Group, WG7 Computing, led by L. Scotto Lavina (LPNHE) and with a strong participation of KIT (other actors are Nikhef and CNAF)
- Setting up an analysis facility at KIT/ETP that will provide several services to all DARWIN members including:
  - Computing resources (local and from GridKa)
  - Remote storage at GridKa
  - all authentication processes will rely entirely on tokens instead of x509
- We have chosen to use INDIGO as Identity and Access Management (IAM) service for DARWIN (deployed and maintained by CNAF)
- The KIT/ETP prototype has grown, and it has been successfully interfaced with IAM
- Next step is to integrate the software environments currently in use in DARWIN (MC simulations, statistical tools, etc…)
- Once consolidated, new EU resources will be added (Nikhef, CC-IN2P3, CNAF)



Sebastian Brommer, Florian von Cube, Manuel Giffels, Robin Hofsäss, Benedikt Maier

Summary

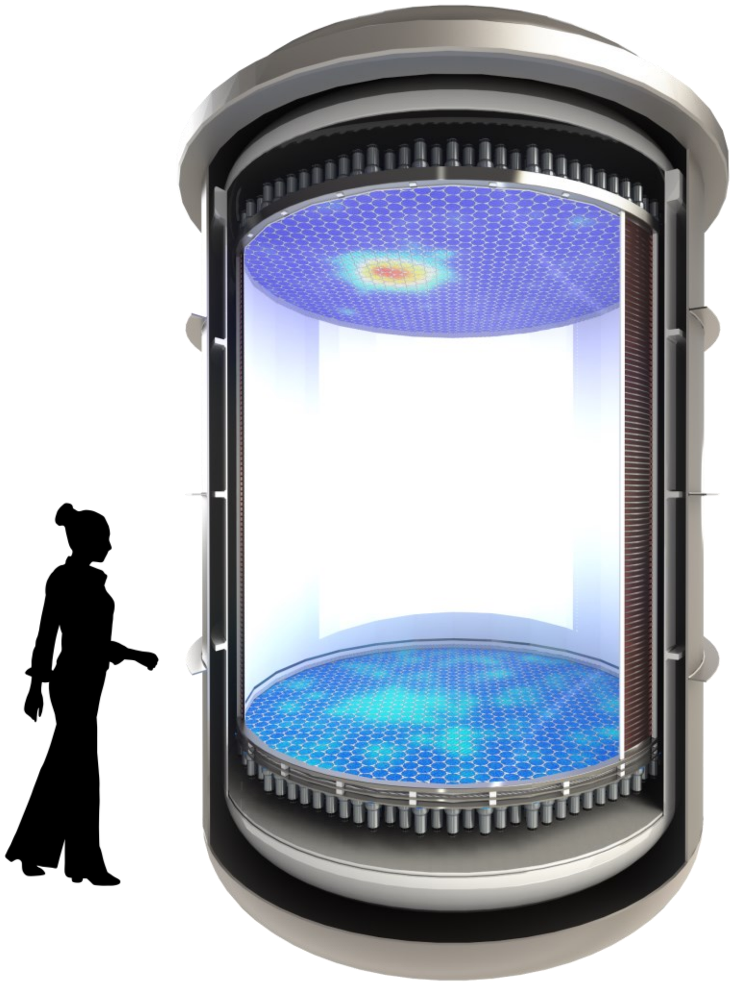
- DARWIN will be the next major dark matter direct detection experiment, and more!
- There is a need to solve technological challenges. German and French groups should provide strong support for the experiment
  - Design and fabrication of new electrodes
  - High voltage distribution
  - Computing
  - Xenon storage and recovery
  - So much more!

DARWIN

KIT
Karlsruher Institut für Technologie

Subatech

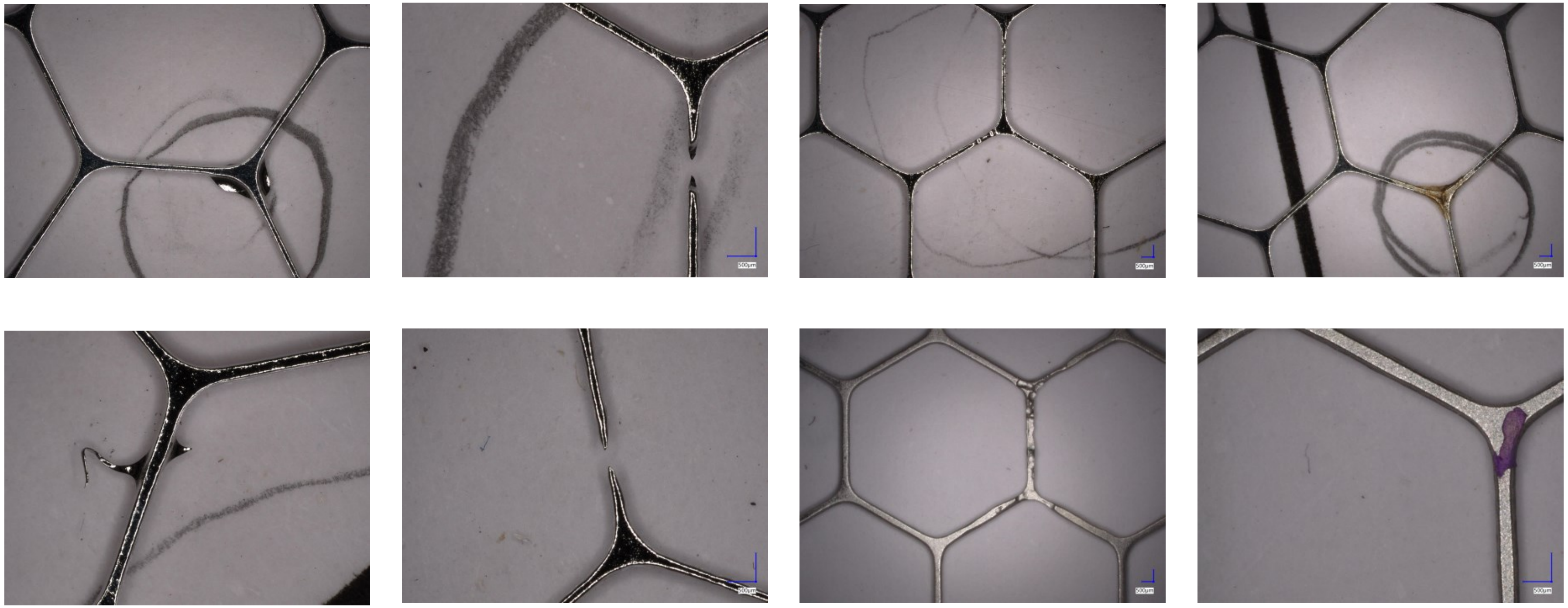
LPNHE
PARIS



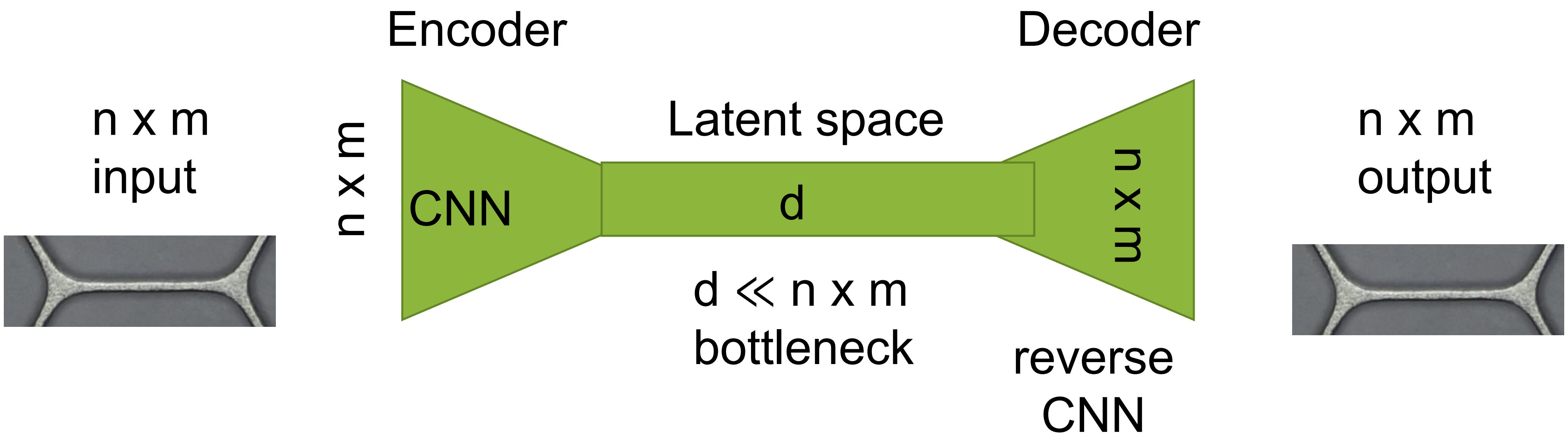
Backups

Electrode quality control: ML

Spikes Breaks Surface damage Dirt



Backup ML



Encoder trained on clean data will reconstruct new clean data, but struggle to reconstruct defects

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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