# The DARWIN R&D towards the XLZD detector

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On behalf of DARWIN/XLZD

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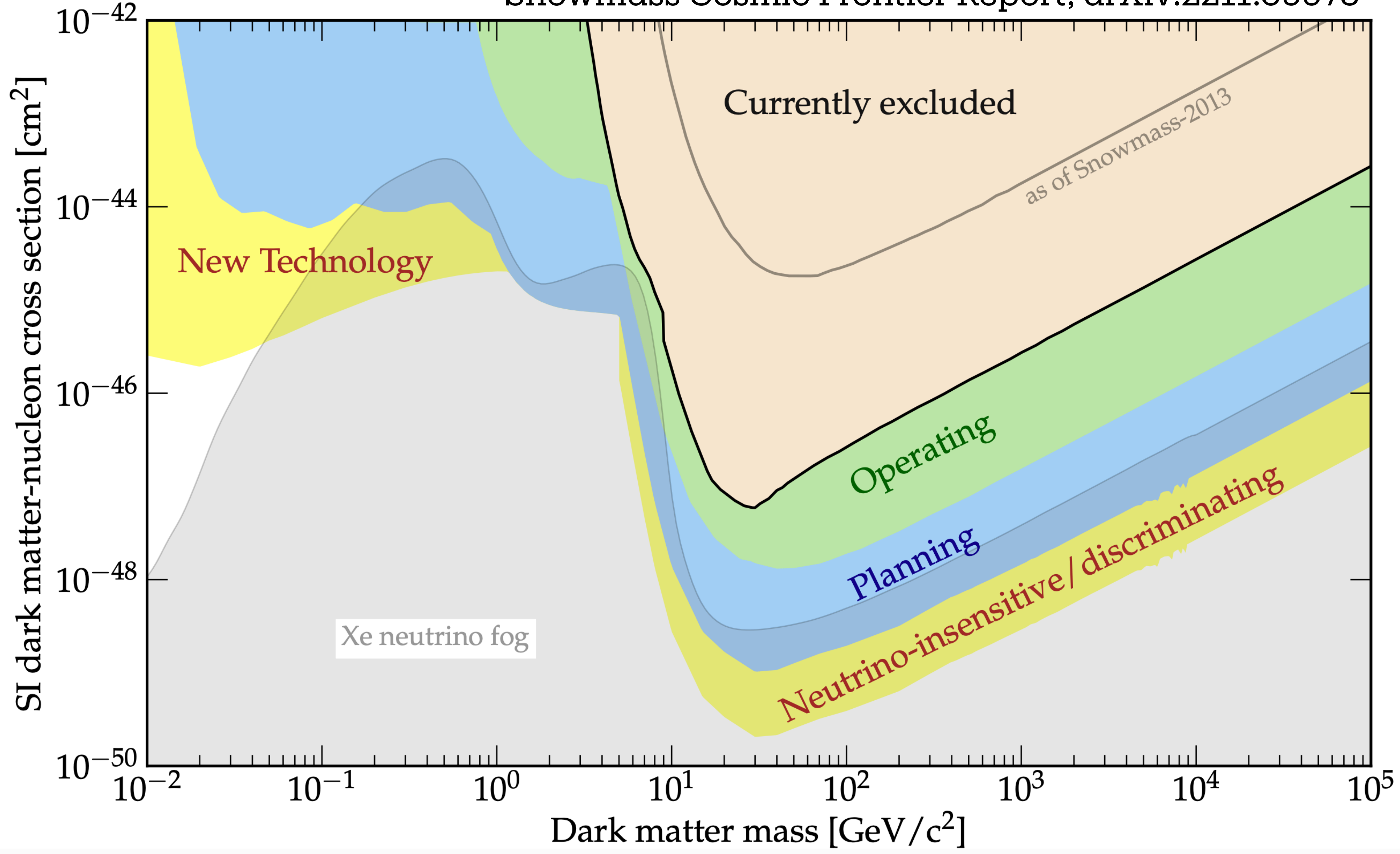
# DARWIN and XLZD

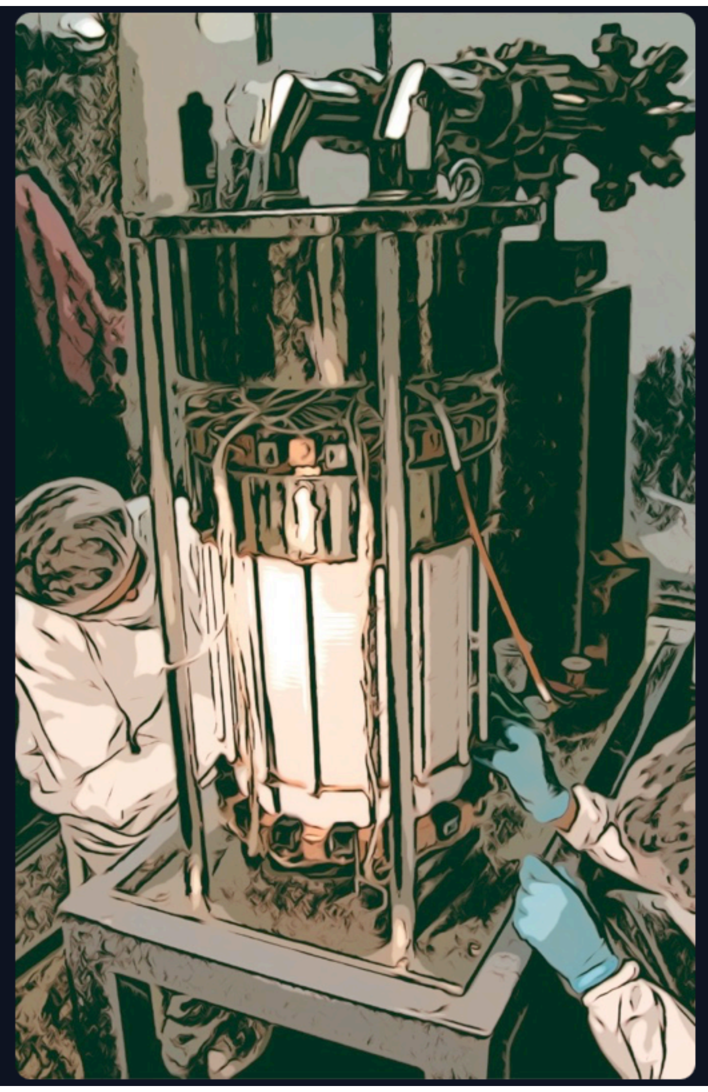
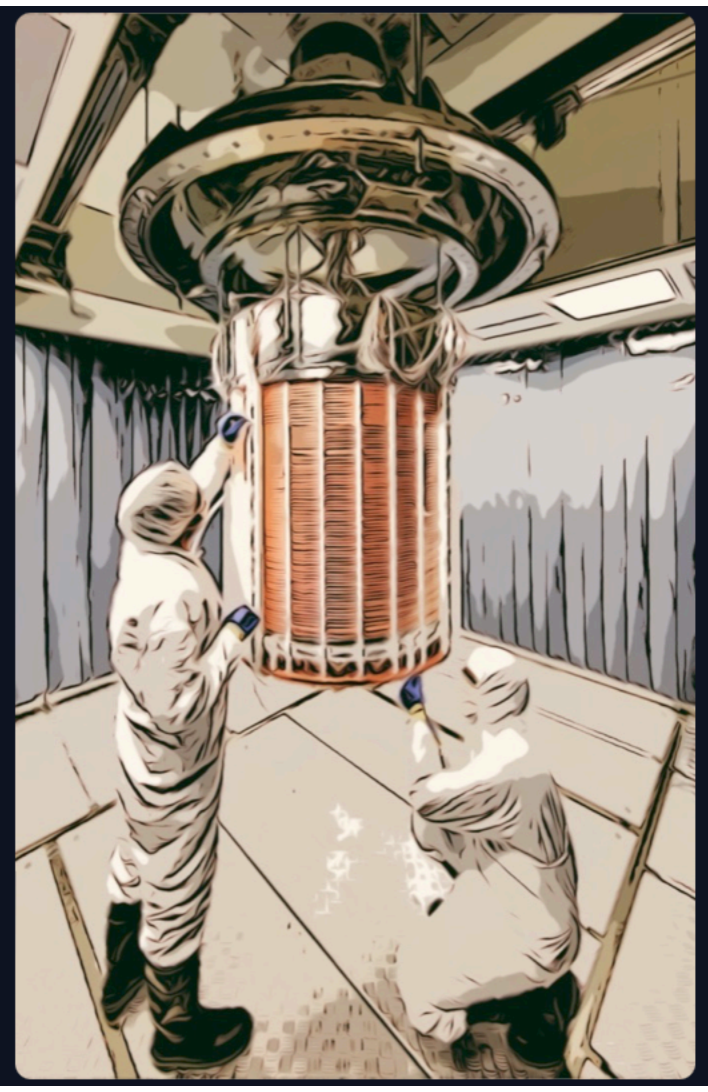
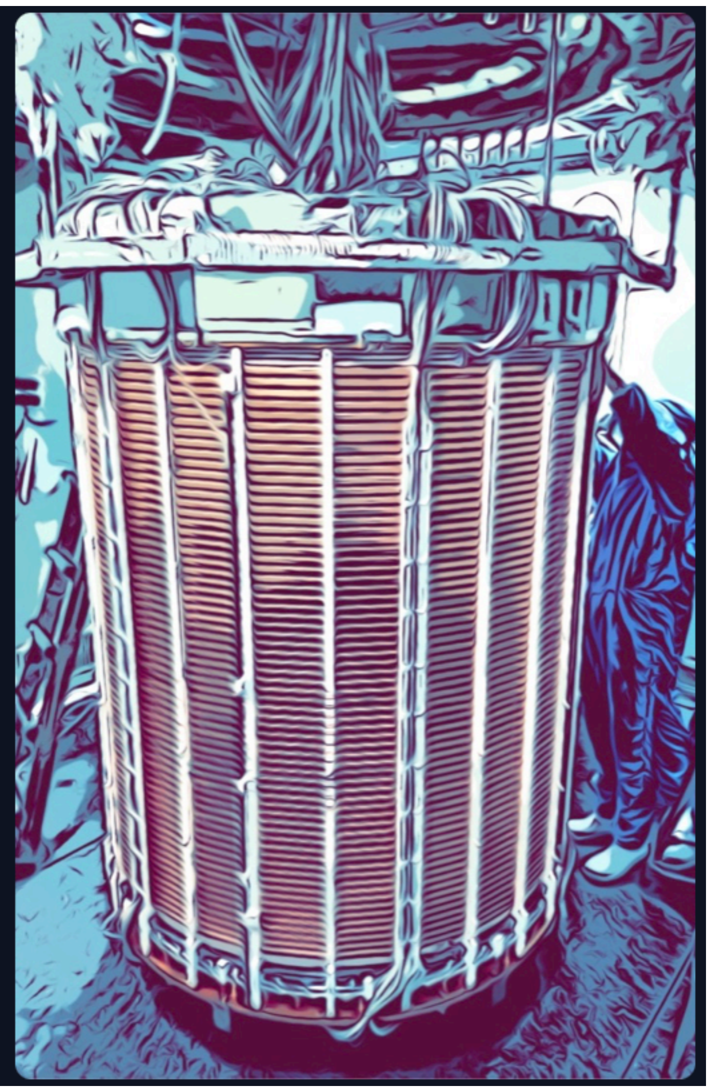
Introduction and science case in previous talk by L. Baudis

- DARWIN collaboration:
  - WIMP search down to the neutrino fog
  - Next generation dual-phase xenon TPC
  - ~200 members from 35 institutions in Europe, USA, Asia, Australia
- XLZD consortium: XENON-LZ-DARWIN
  - Merging the collaborations together to achieve the common goal of reaching the neutrino fog → strengthen knowledge and resources
  - MoU signed in 2021


Snowmass Cosmic Frontier Report, arXiv:2211.09978



# The path to multi-ton xenon dual-phase TPCs


XENON10
25 kg LXe
600 [t d keV]$^{-1}$

XENON100
160 kg LXe
5.3 [t d keV]$^{-1}$

XENON1T
3200 kg LXe
0.2 [t d keV]$^{-1}$

XENONnT
8500 kg LXe
0.04 [t d keV]$^{-1}$

XLZD
78 t LXe
Reduce background down to pp level

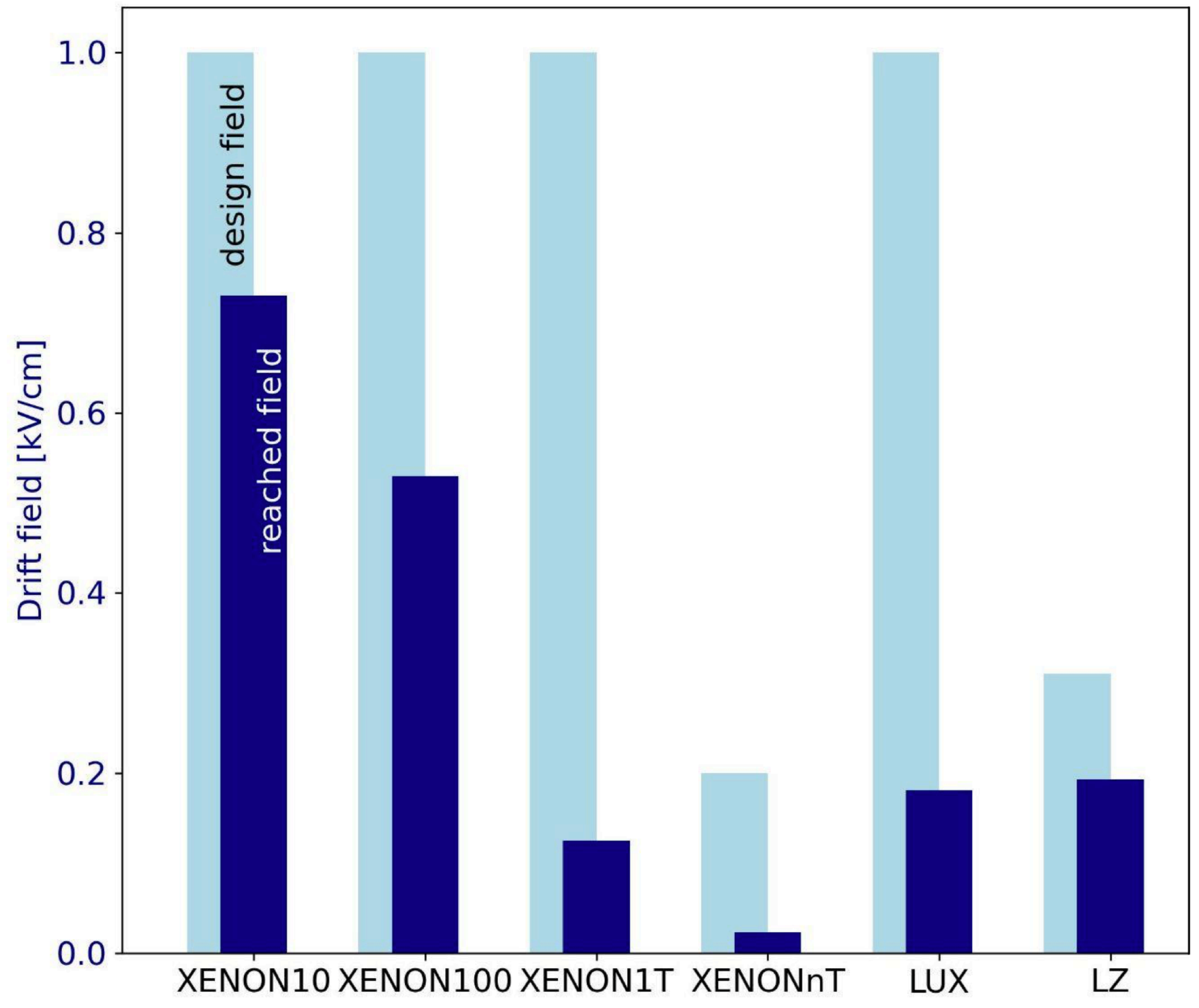
Started in 2006 — 2008 — 2015 — 2020

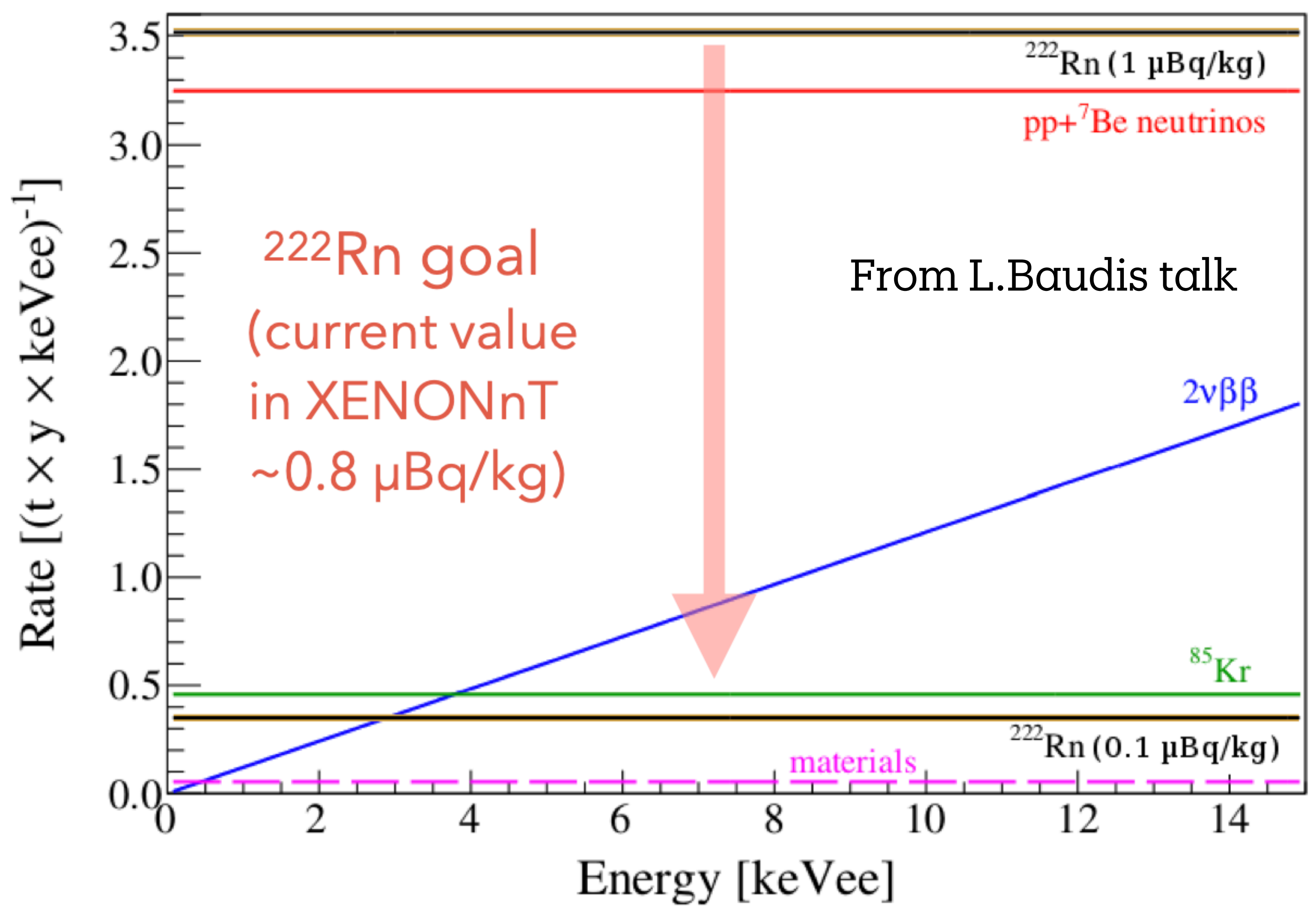
# The XLZD TPC

- ~3 m diameter x ~3 m height
- 78 t/60 t LXe mass/active target ➞ could be increased to 80 t active mass
- Two arrays of photosensors ➞ baseline design with ~2400 3” PMTs
- Double-walled low-background Ti cryostat + LXe “skin” around the TPC
- Drift field of 240-290 V/cm and extraction field of 6-8 kV/cm for optimal discrimination between ER and NR
- Passive and active muon and neutron shielding with gadolinium to enhance neutron capture cross-section
- Possible locations: **LNGS**, **Boulby**, **SURF**, Kamioka, SNOLAB

# Challenges

- High-voltage delivery:
  - Currently drift of ~23 V/cm in XENONnT and ~193 V/cm in LZ
  - Electrodes design and construction
  - Electric field homogeneity
- Liquid xenon purity
- Background mitigation
- Light collection efficiency
- Photosensors performance

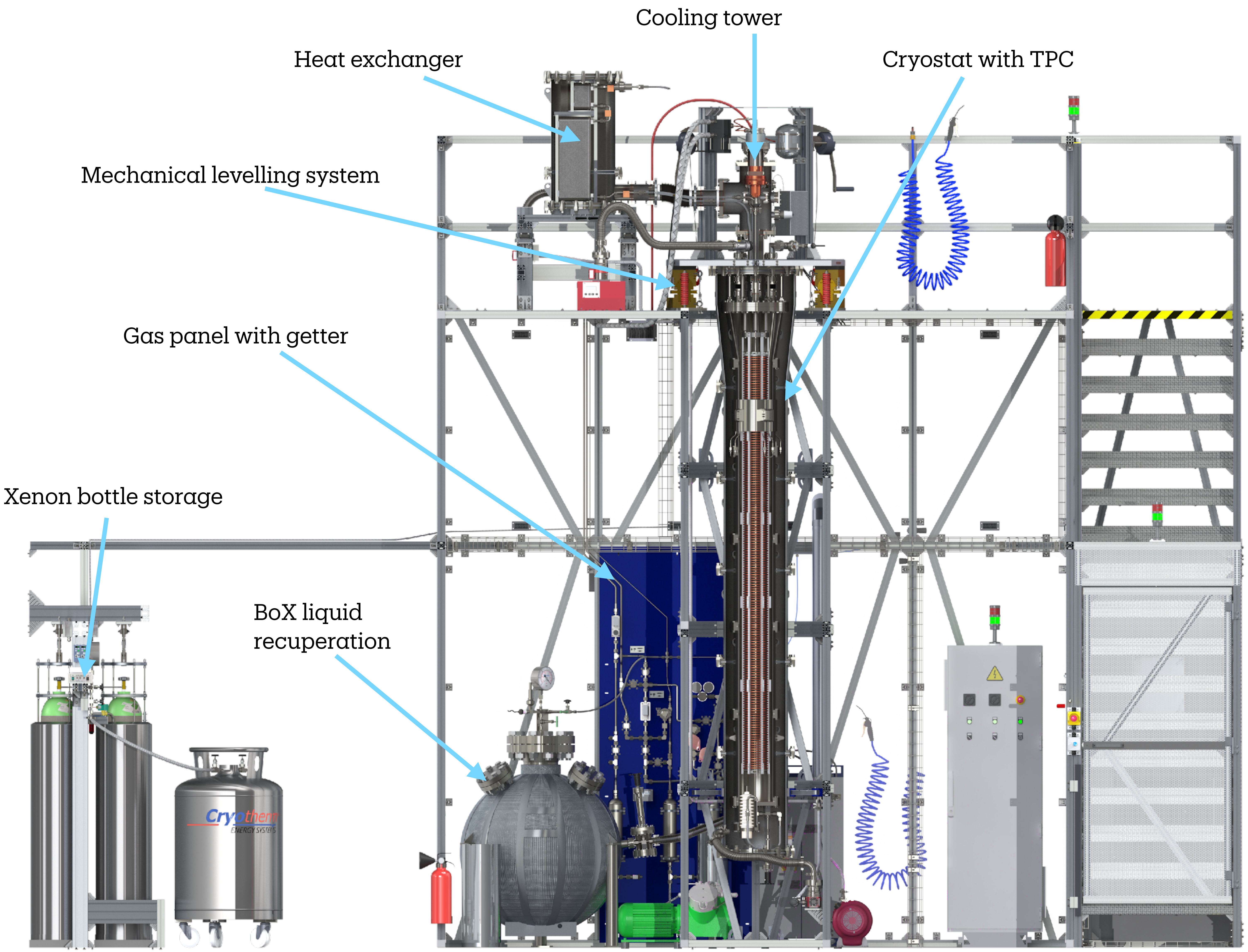


# Xenoscope at UZH

JINST 16, P08052 (2021)
Eur. Phys. J. C 83, 717 (2023)

- Vertical demonstrator with goals:
  - Electron drift over 2.6 m
  - Electron cloud diffusion
  - Custom HV
  - Xenon optical properties
- ~400 kg of xenon mass
- Phase 1: purity monitor → completed
- Phase 2: modular TPC → under commissioning



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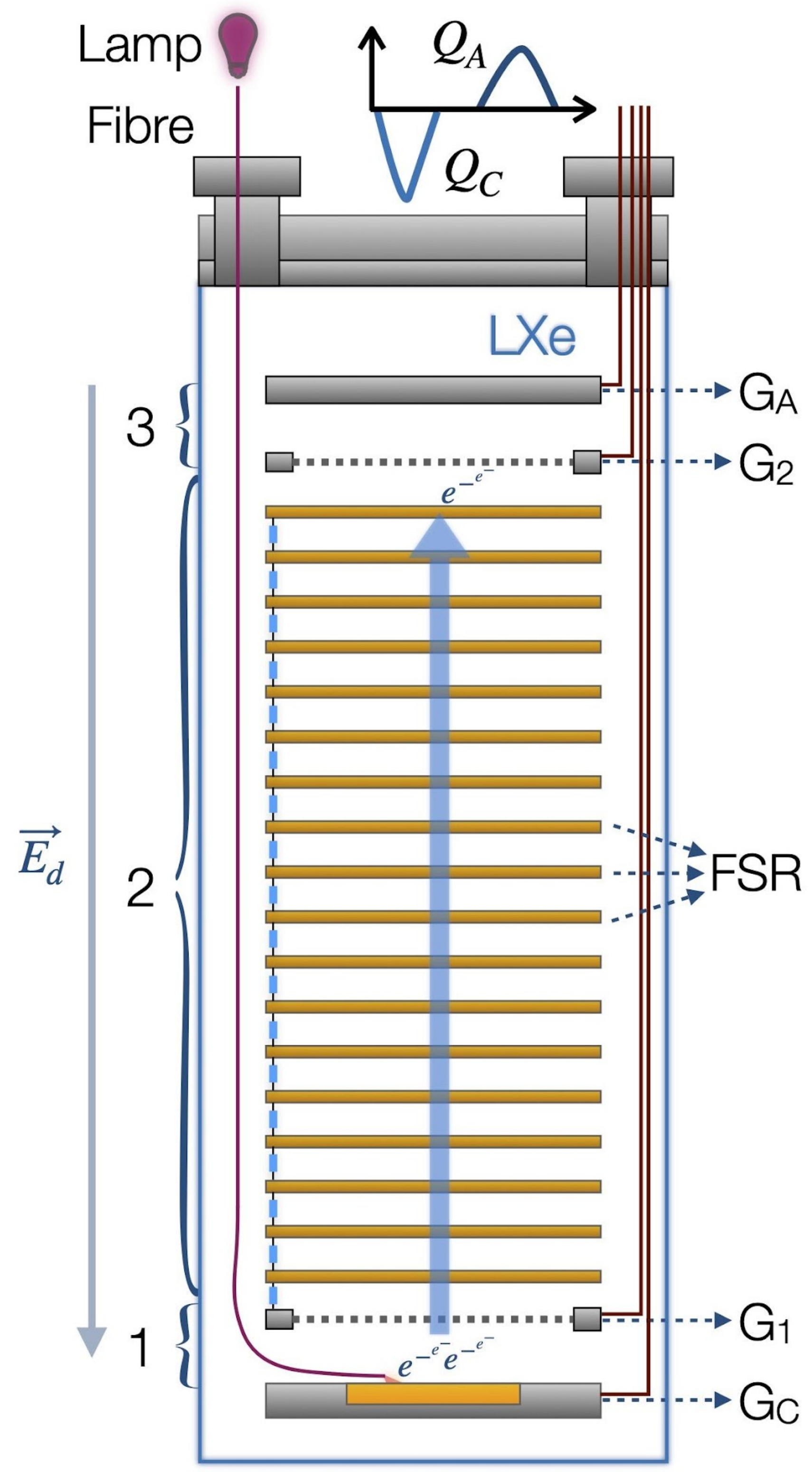
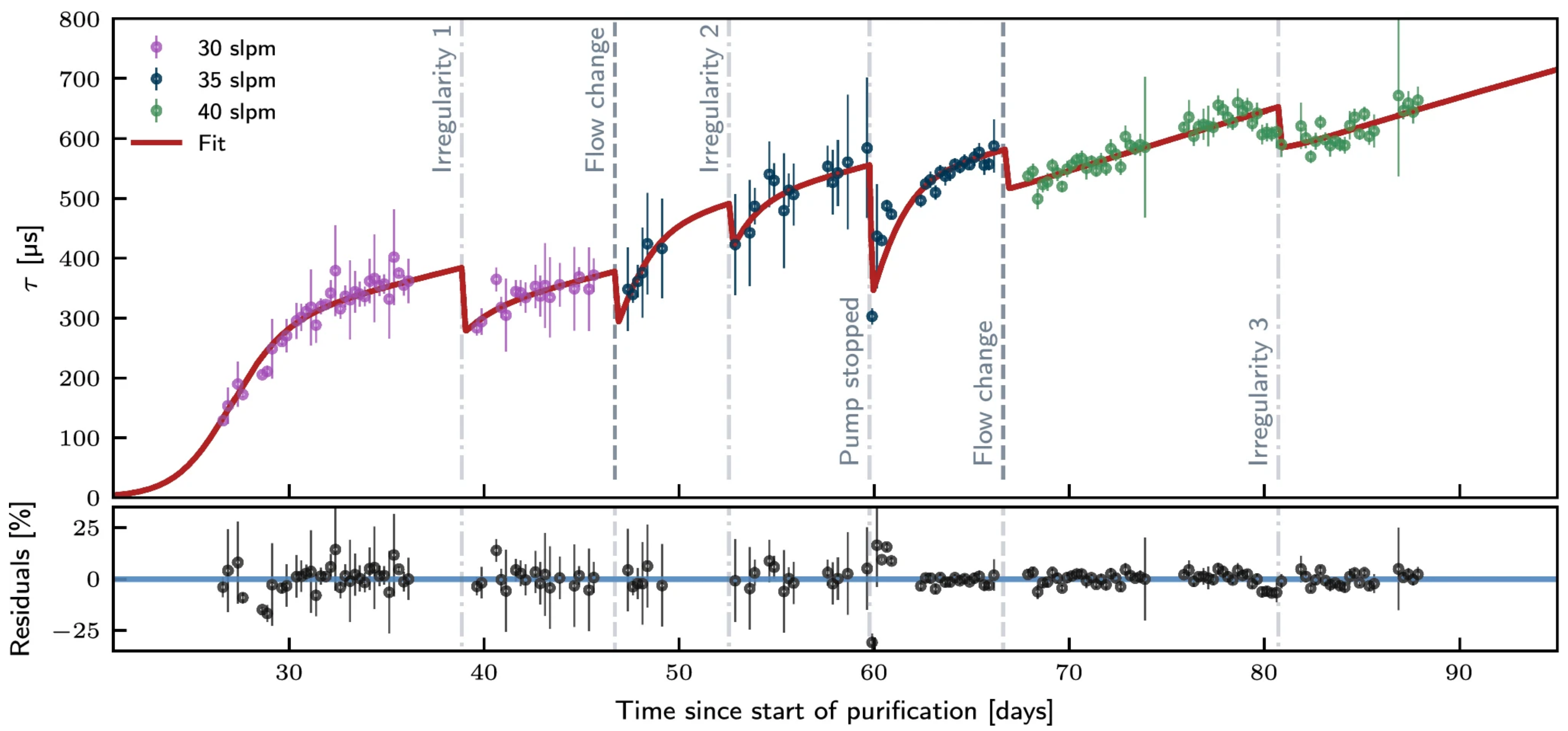
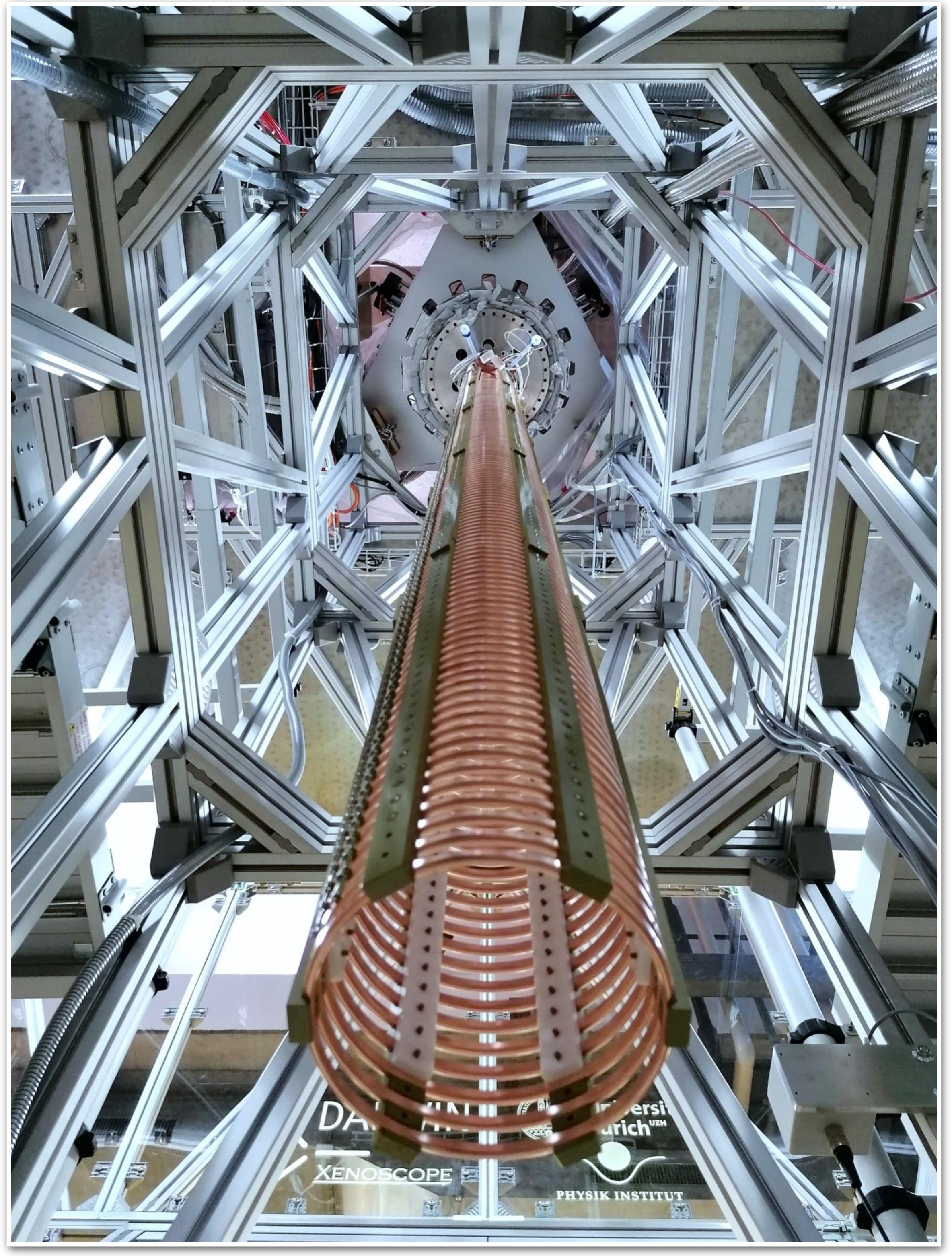



- Purity monitor:
  - Drift length: 53.1 cm
  - Light from xenon flash lamp (190 - 200 nm) injected via optical fiber into photocathode
  - Flow limited to 40 slpm → ongoing improvement of the gas system to reach higher circulations
  - Electron lifetime monitor (+ drift velocity and diffusion)




- Dual-phase TPC:
  - 173 shaping rings - 16 cm diameter
  - Top SiPM array
  - HV up to 50 kV
  - Levelling system with levelmeters and weir



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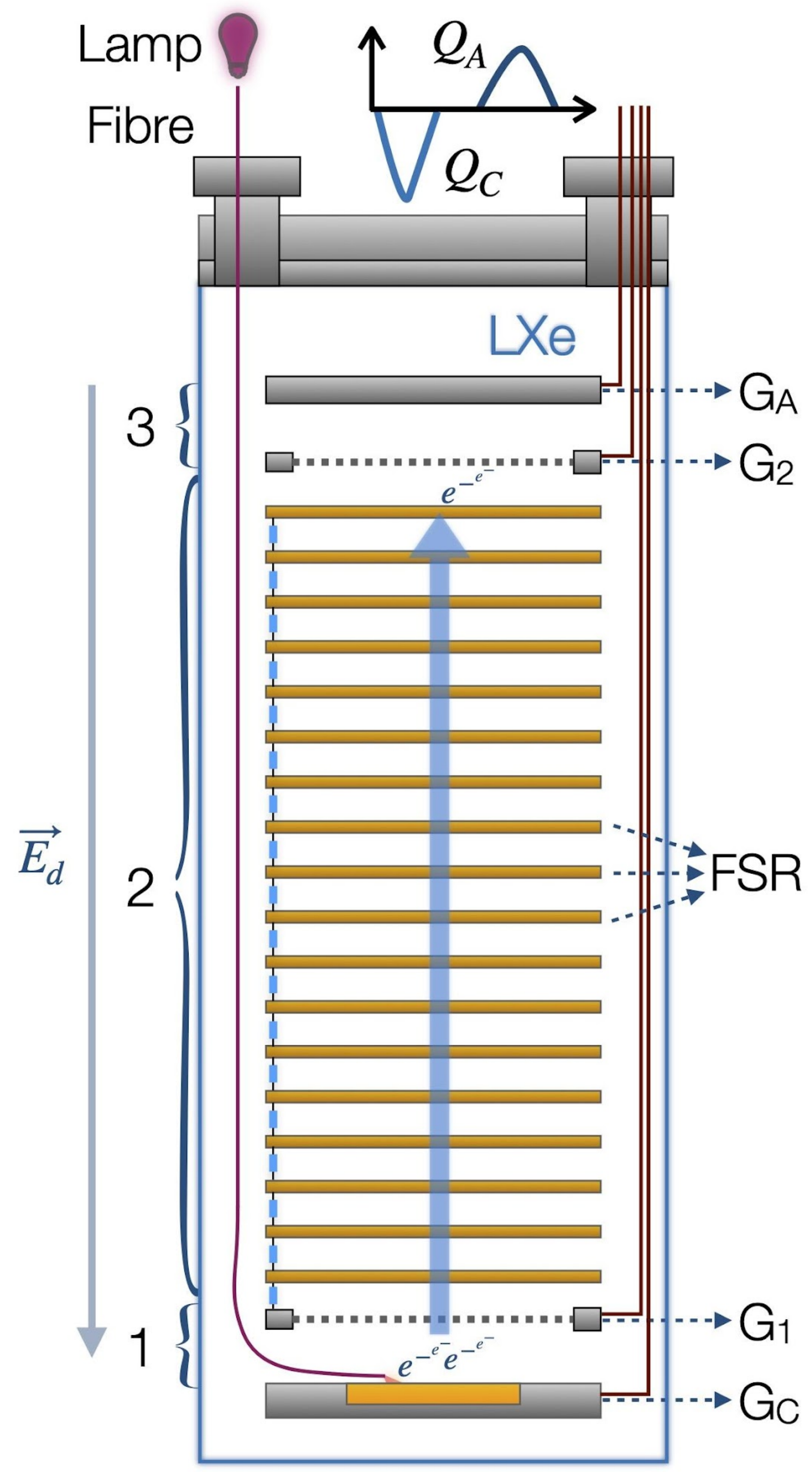


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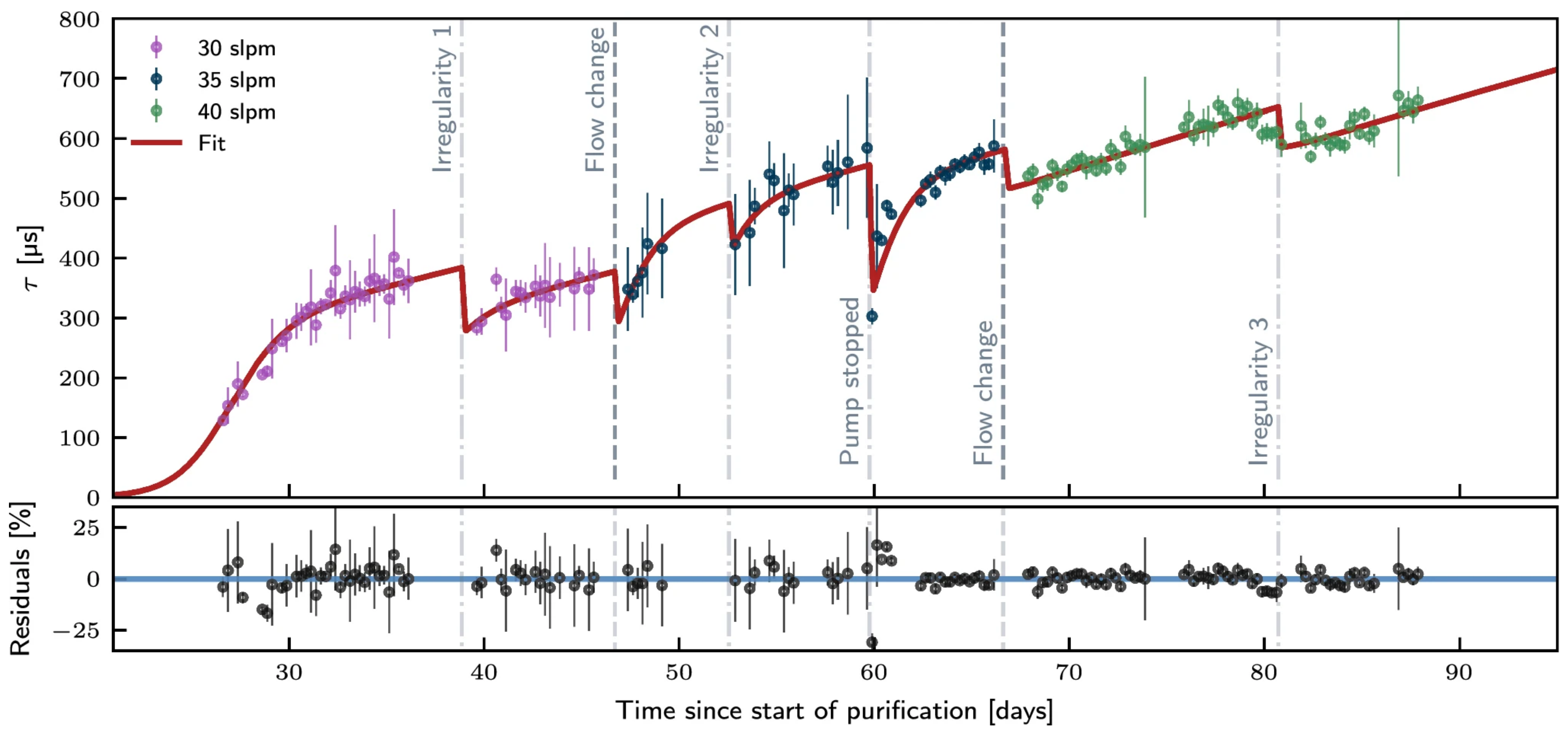
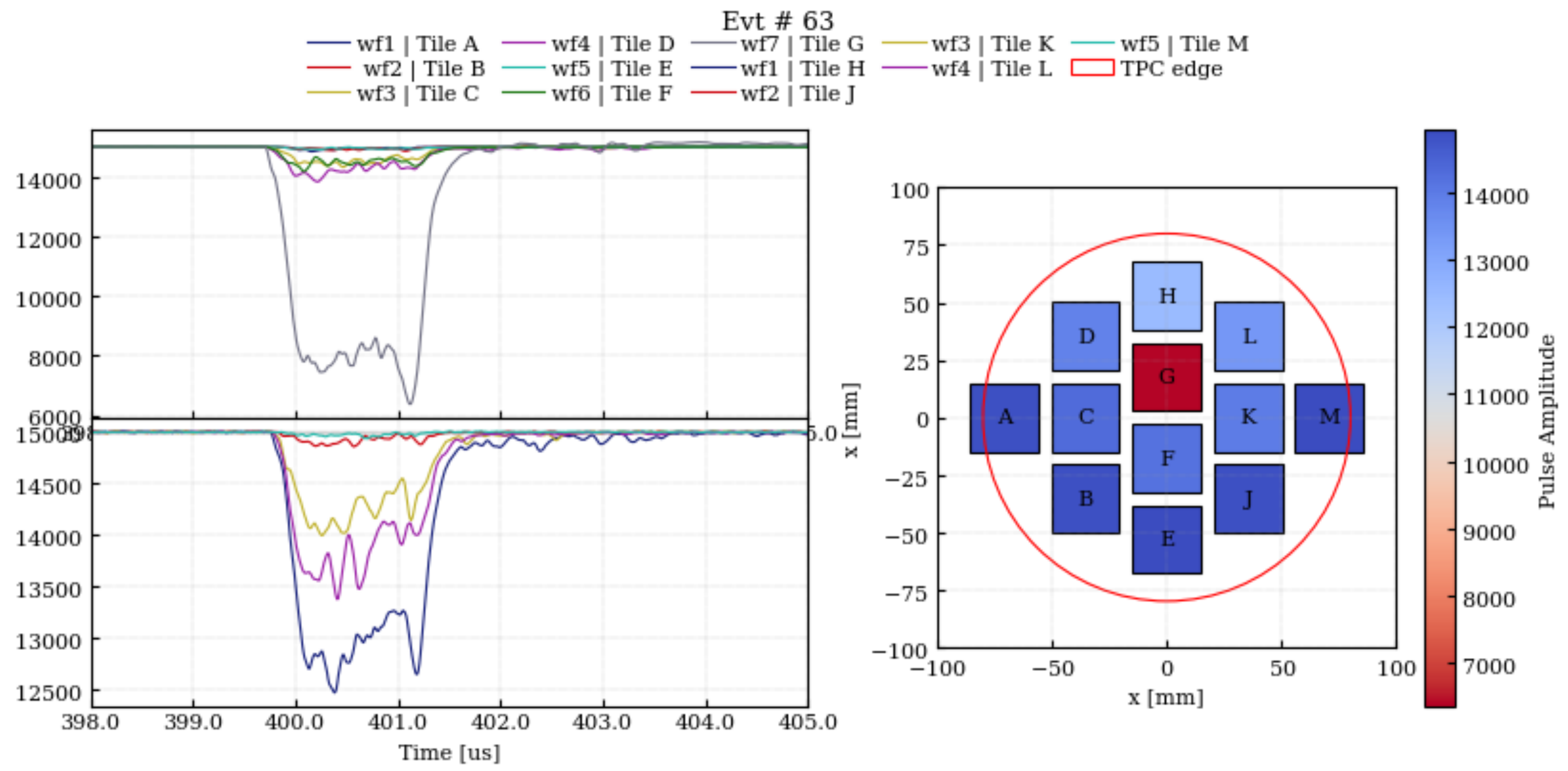



- Dual-phase TPC:
  - 173 shaping rings - 16 cm diameter
  - Top SiPM array
  - HV up to 50 kV
  - Levelling system with levelmeters and weir

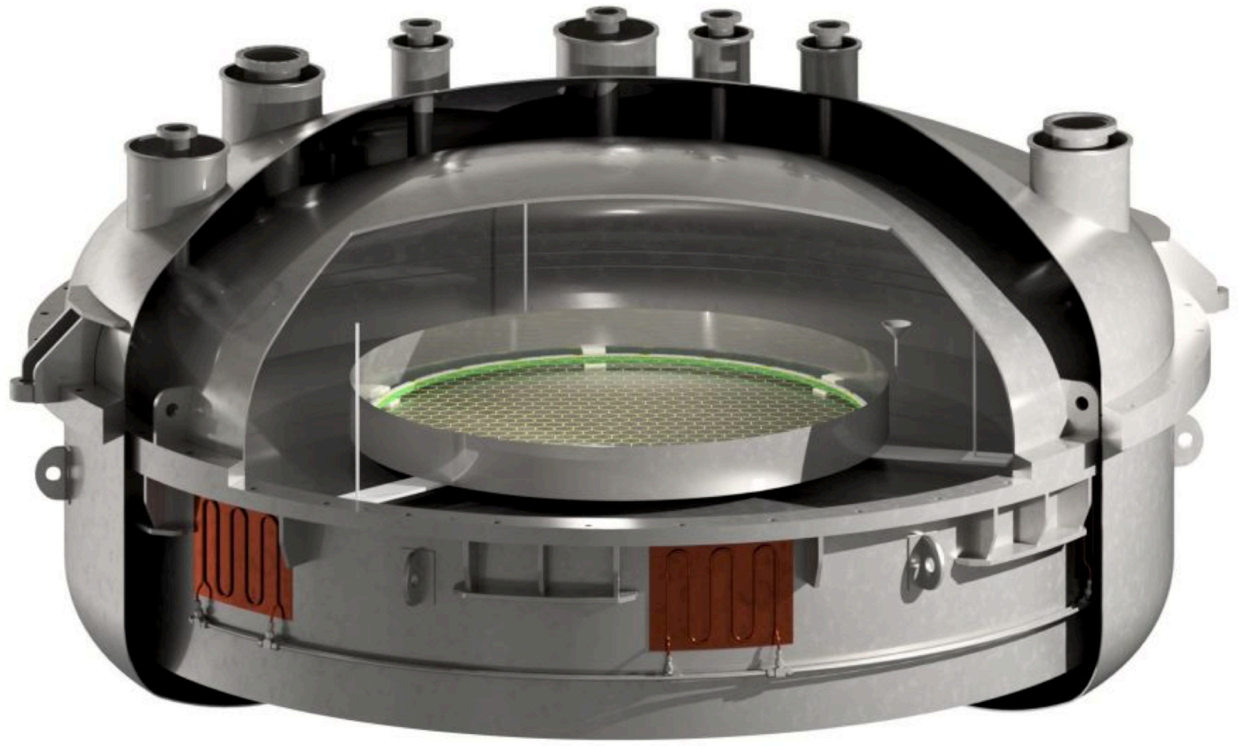
Ongoing commissioning:
Filling, levelling and HV ramp up
First S2 signals in dual-phase TPC mode!

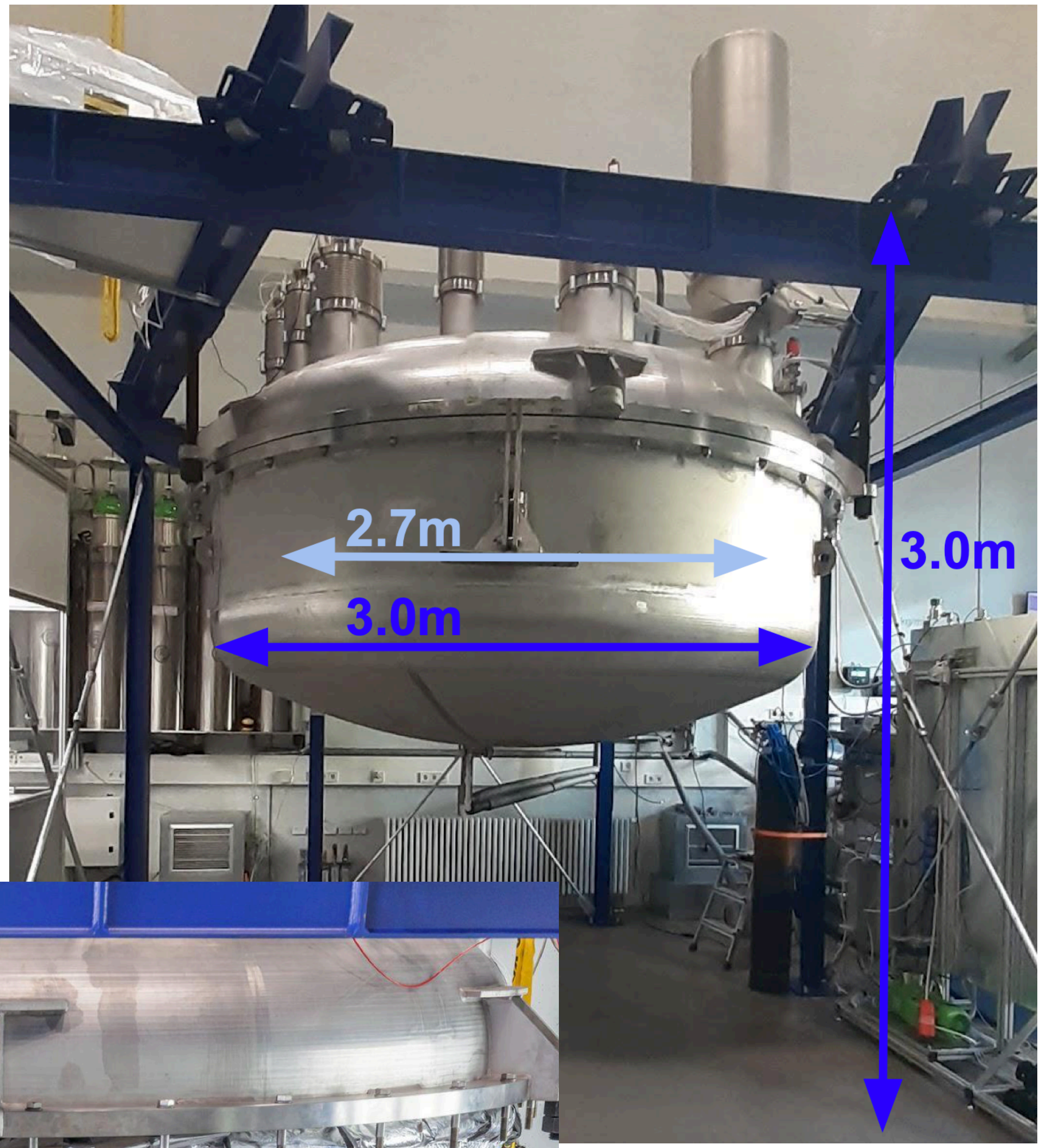


# Pancake at Uni Freiburg

JINST 19 (2024) P05018

- Testing of grids:
  - Wire sagging
  - Hotspots / electron emission
  - Large scale cooling
- 5t stainless steel cryostat with 380 kg of xenon
- Flat floor design and possibility of using open top vessel
- Successful 3 months commissioning
- Next step: instrumentation with photosensors, test of electrodes and HV



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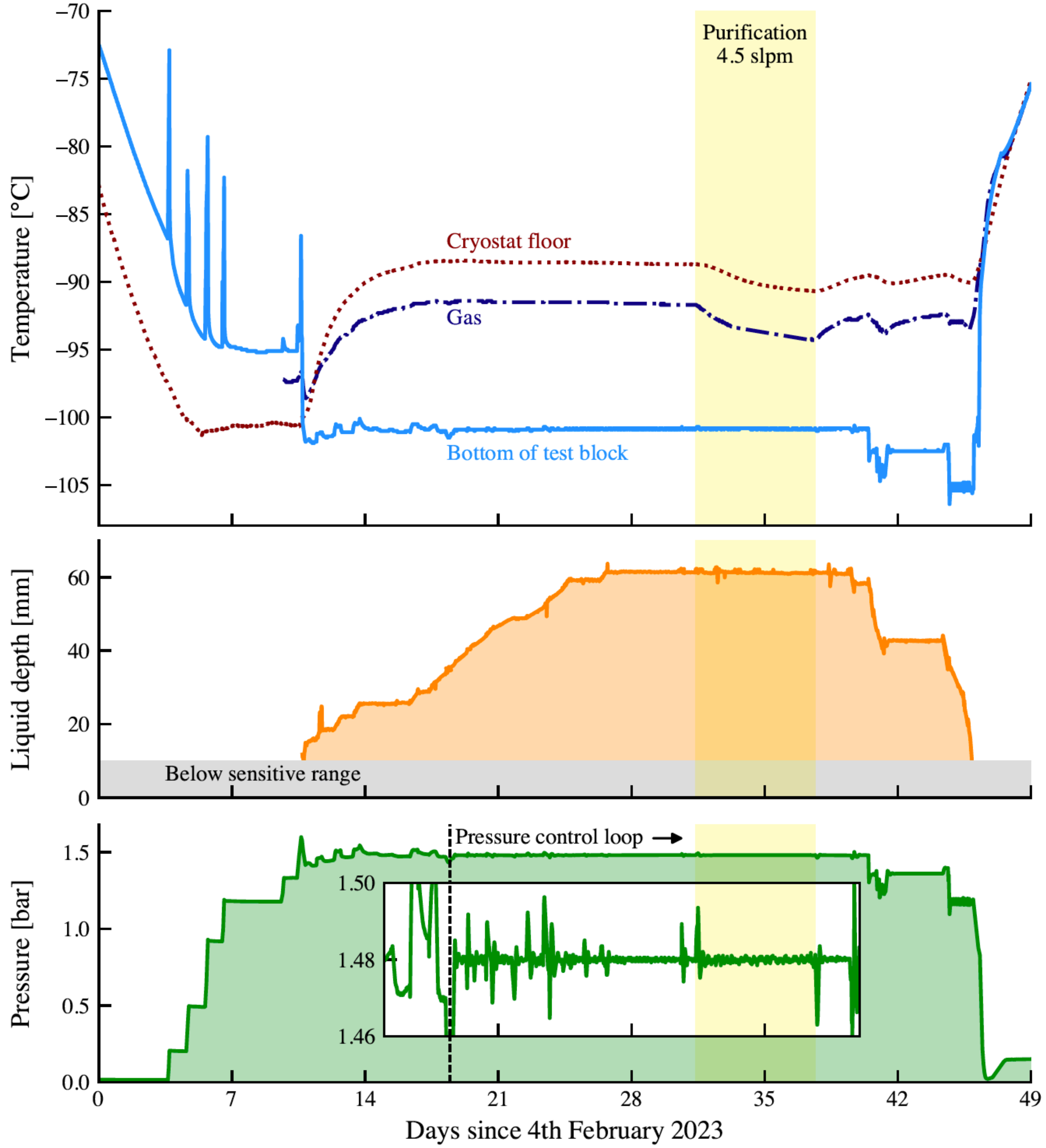
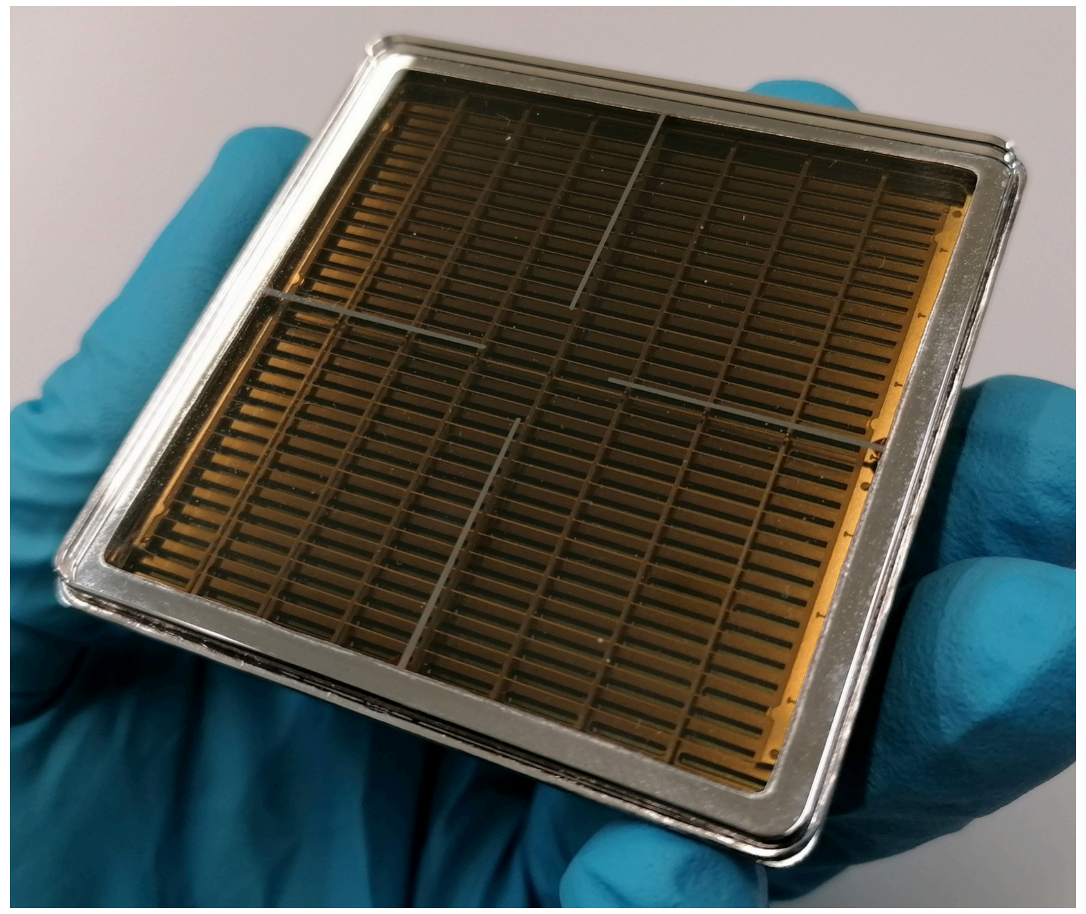
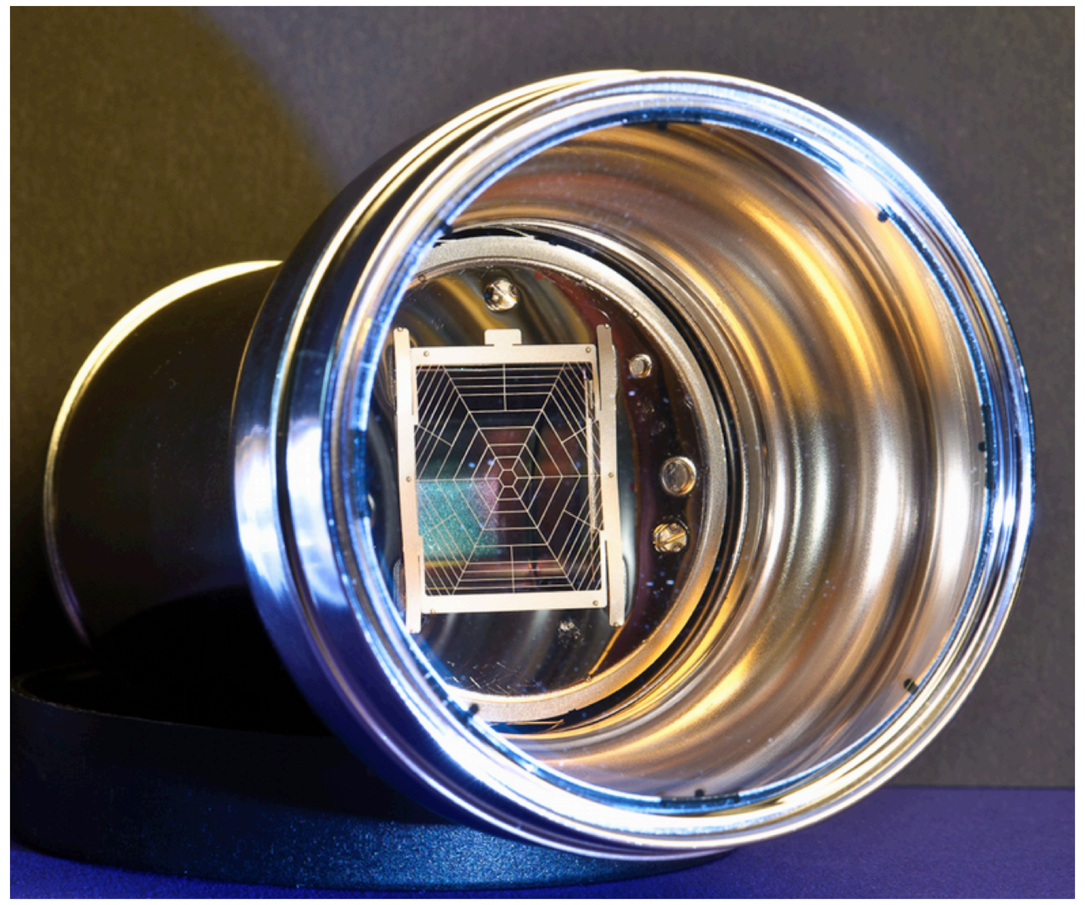


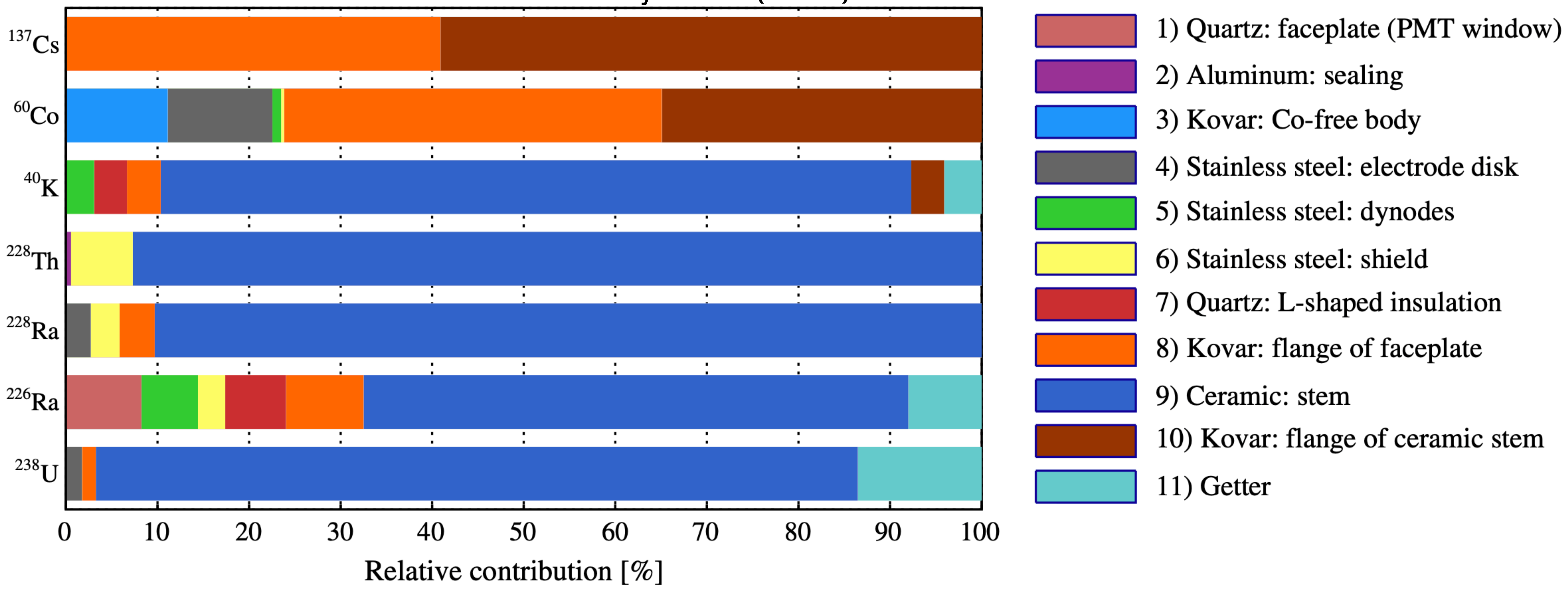
# PMTs

- Baseline photosensors: established technology, low dark count rate (~0.02 Hz/mm$^2$), high quantum efficiency (30-40%)
- PMTs (Hamamatsu R11410-21) material contribute to background in several decay chains
- Radiopurity improvement on 3" PMT (used in XENONnT/LZ)
- Testing of Square 2" PMTs → lower buoyancy and sub-ns rise time
- Characterisation of SPE response, dark counts, light emission, afterpulsing



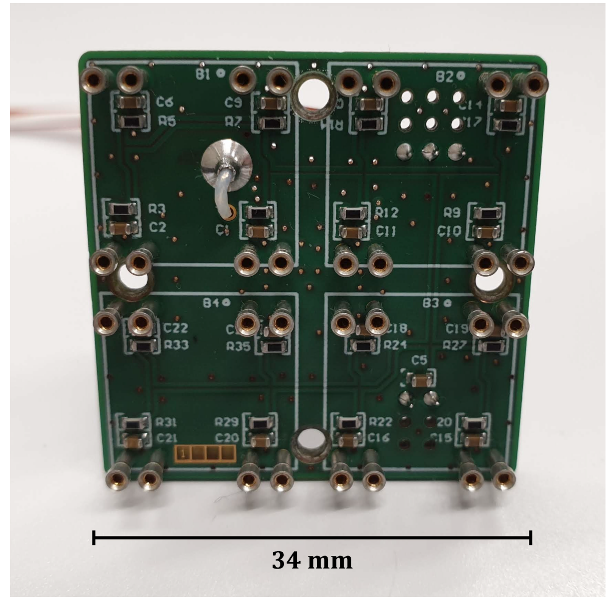


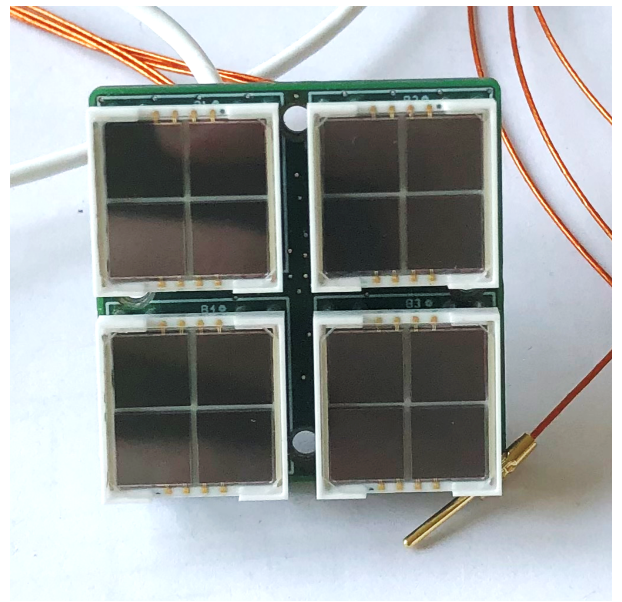
Eur. Phys. J. C (2015) 75: 546

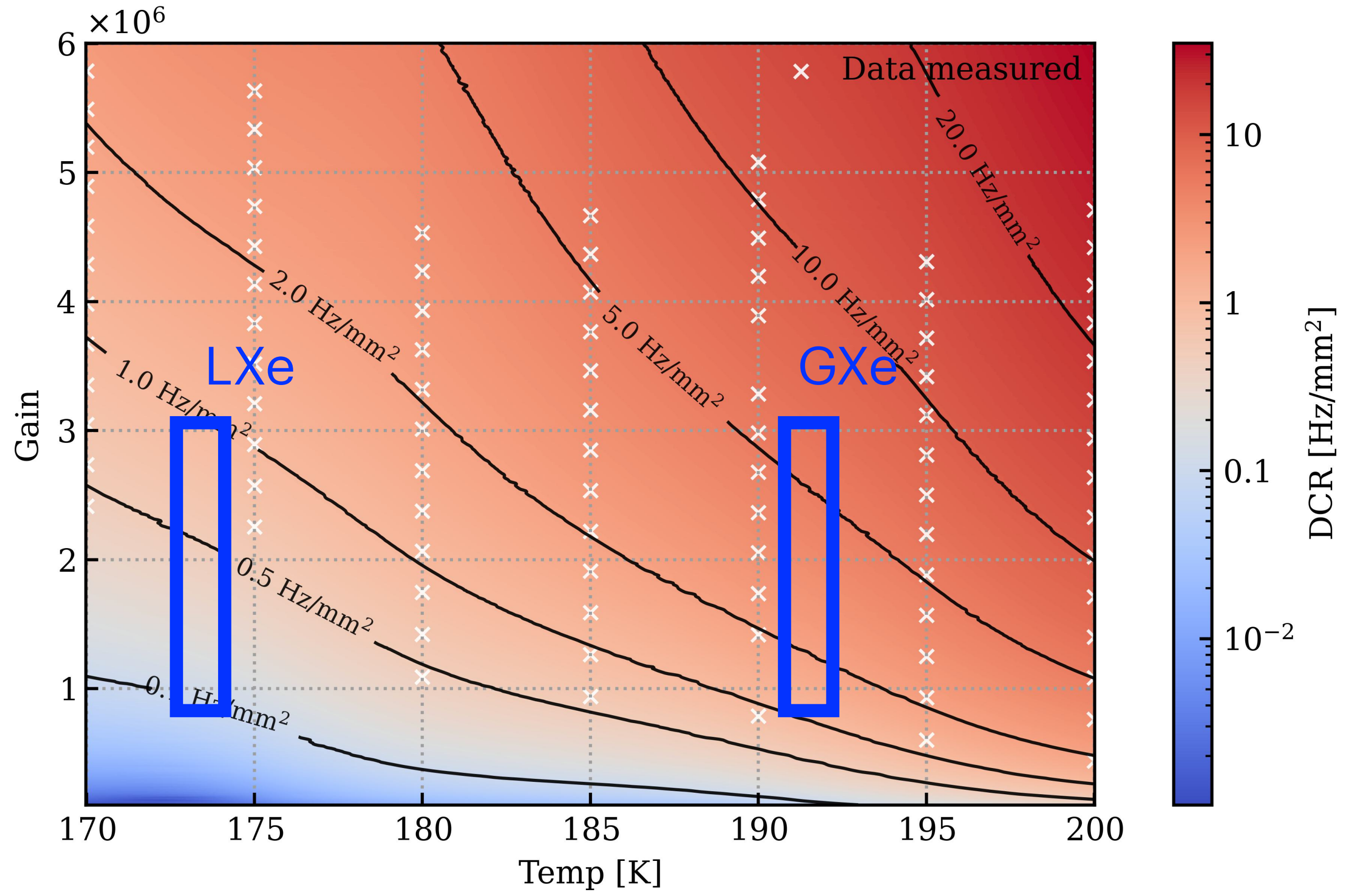


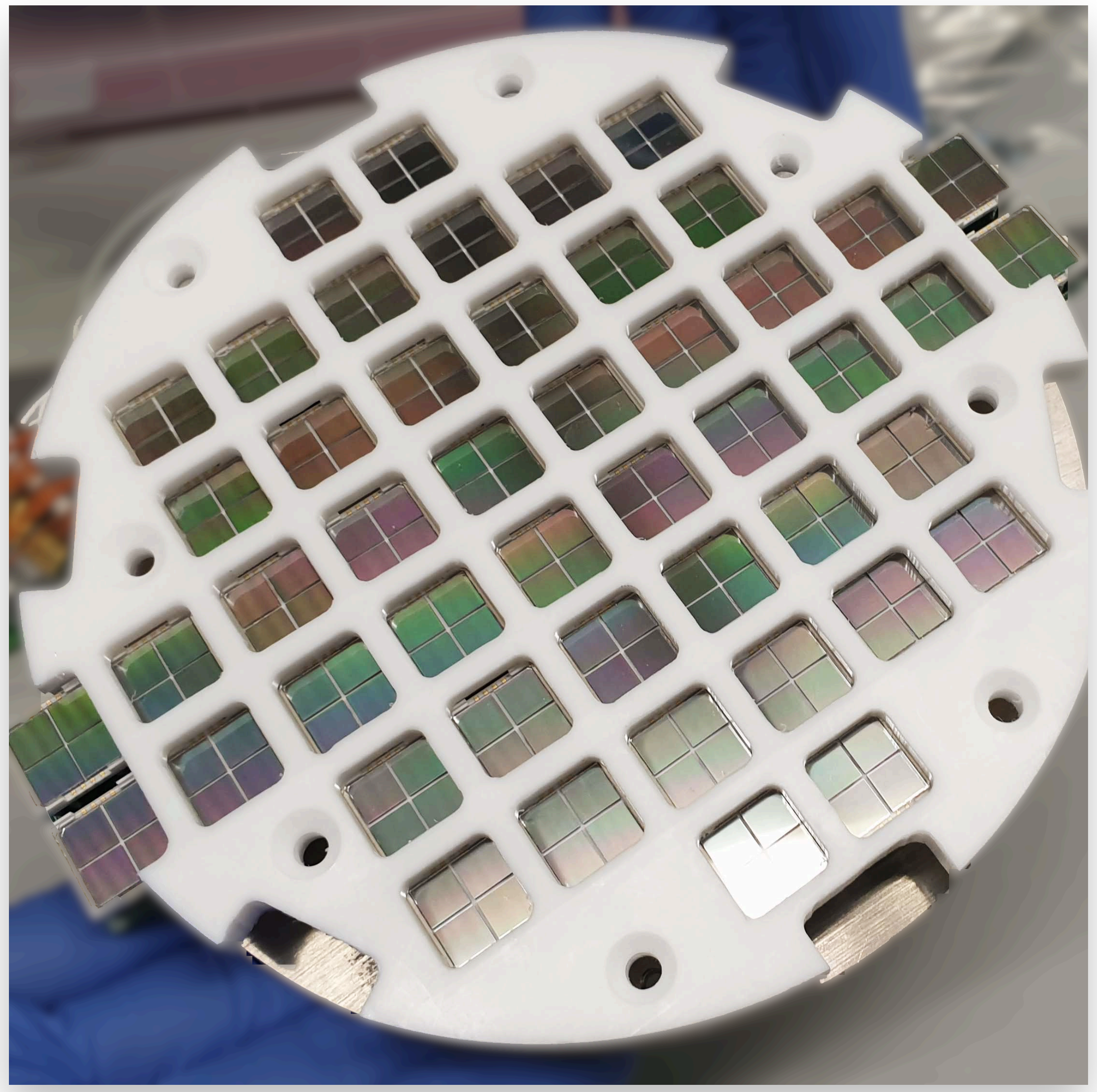
# Other photosensors

- 12x12 mm² MPPC of VUV4 SiPMs (Hamamatsu): JINST 18 C03027 (2023)
  - Low radioactivity
  - Cheaper
  - Higher buoyancy
  - Higher dark count rate
- Digital SiPMs
  - Can turn off single pixels
  - Output already digitised
- LDC VUV SiPMs
- Hybrid sensors (Abalone, ...)
  JINST 17 C01038 (2022)

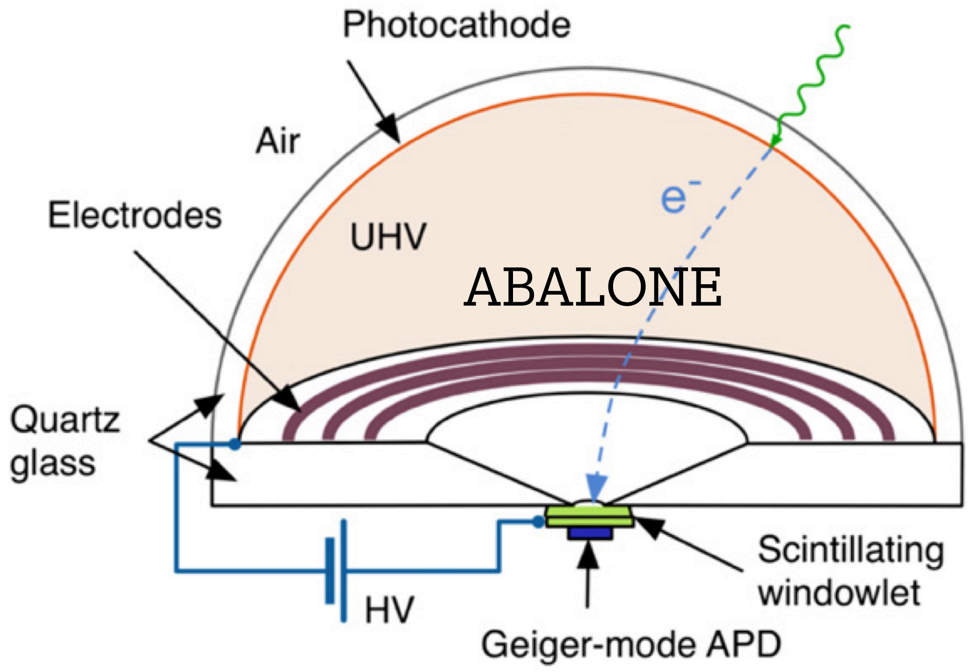


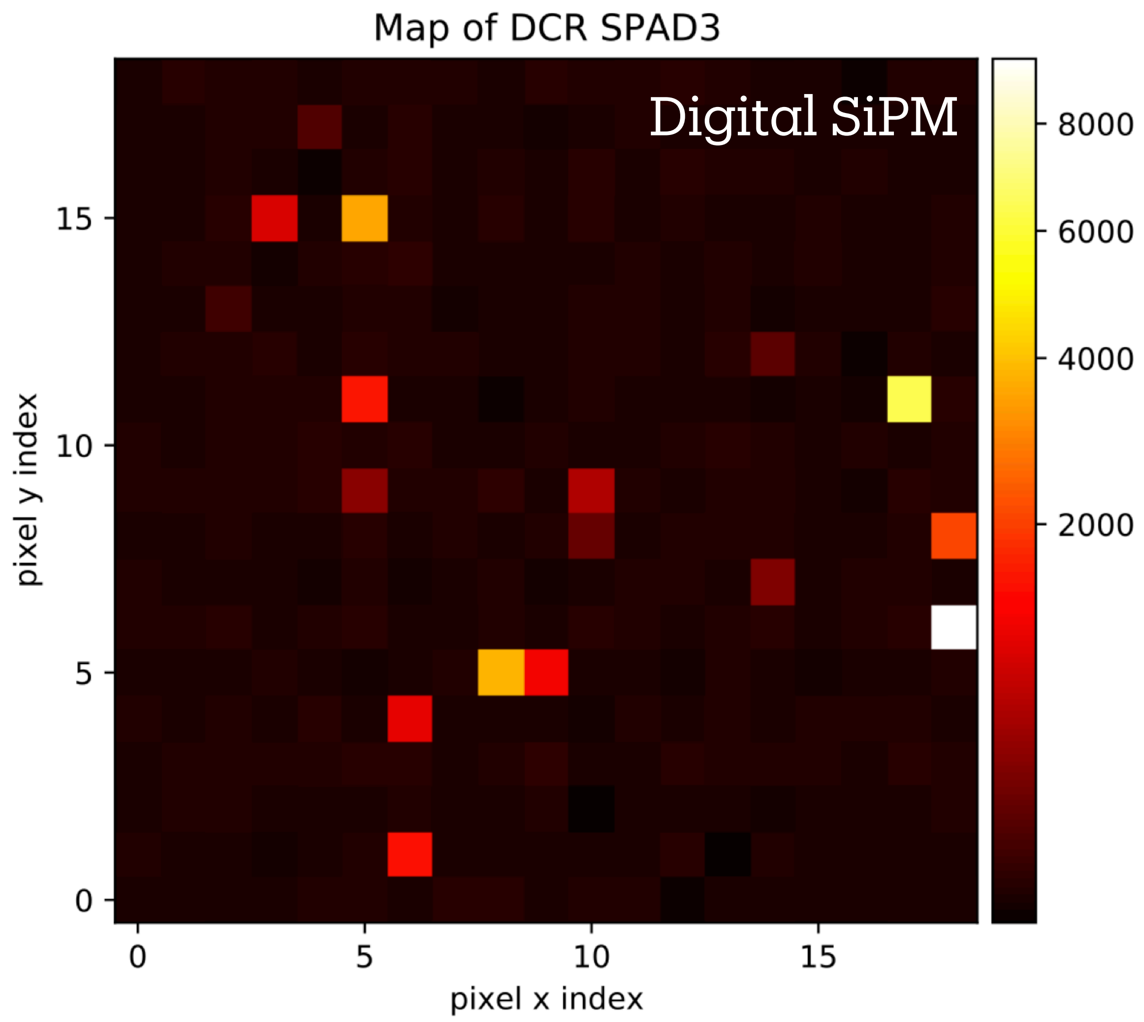





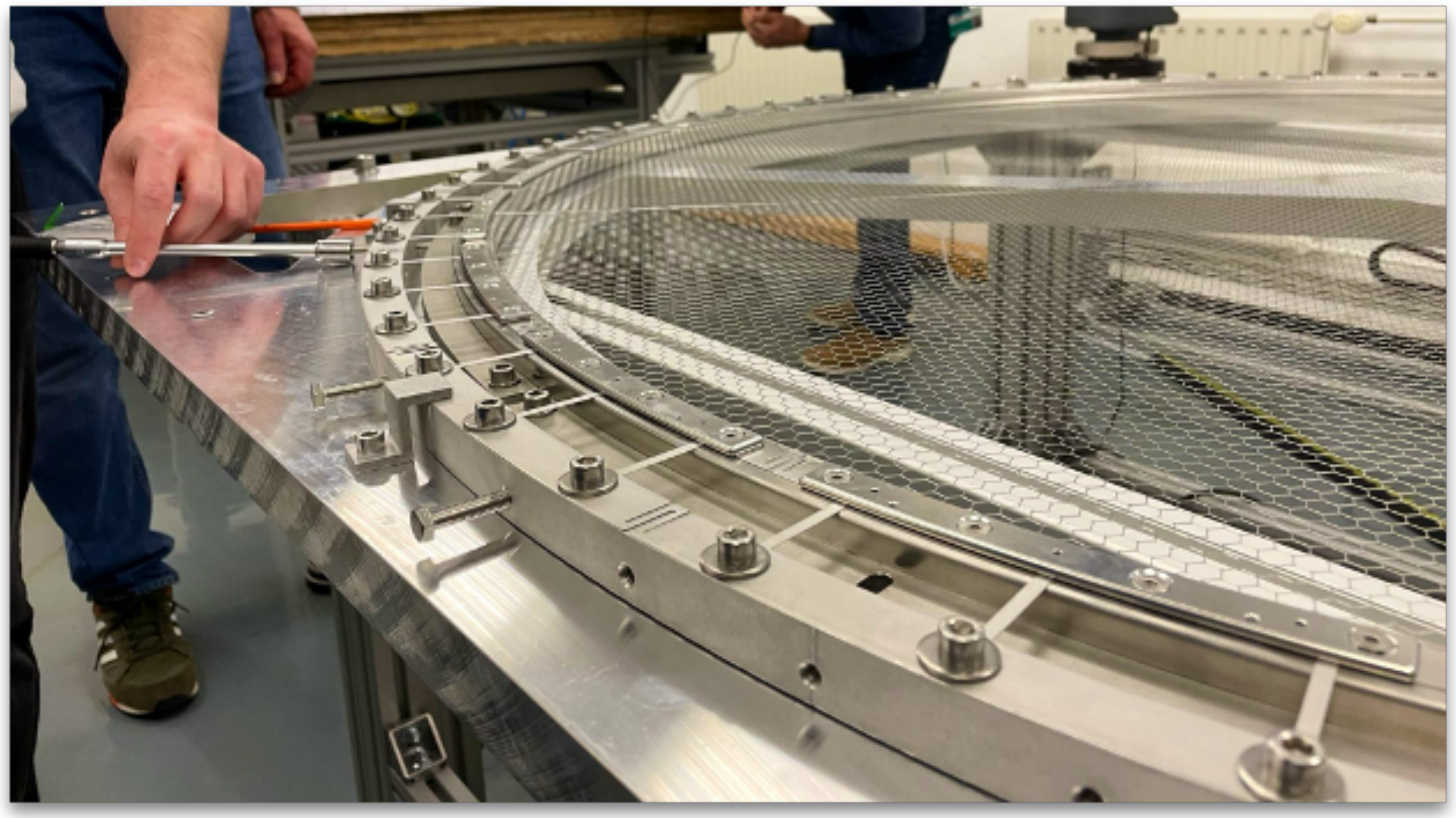



48 12x12 mm² VUV4 MMPCs @ UZH

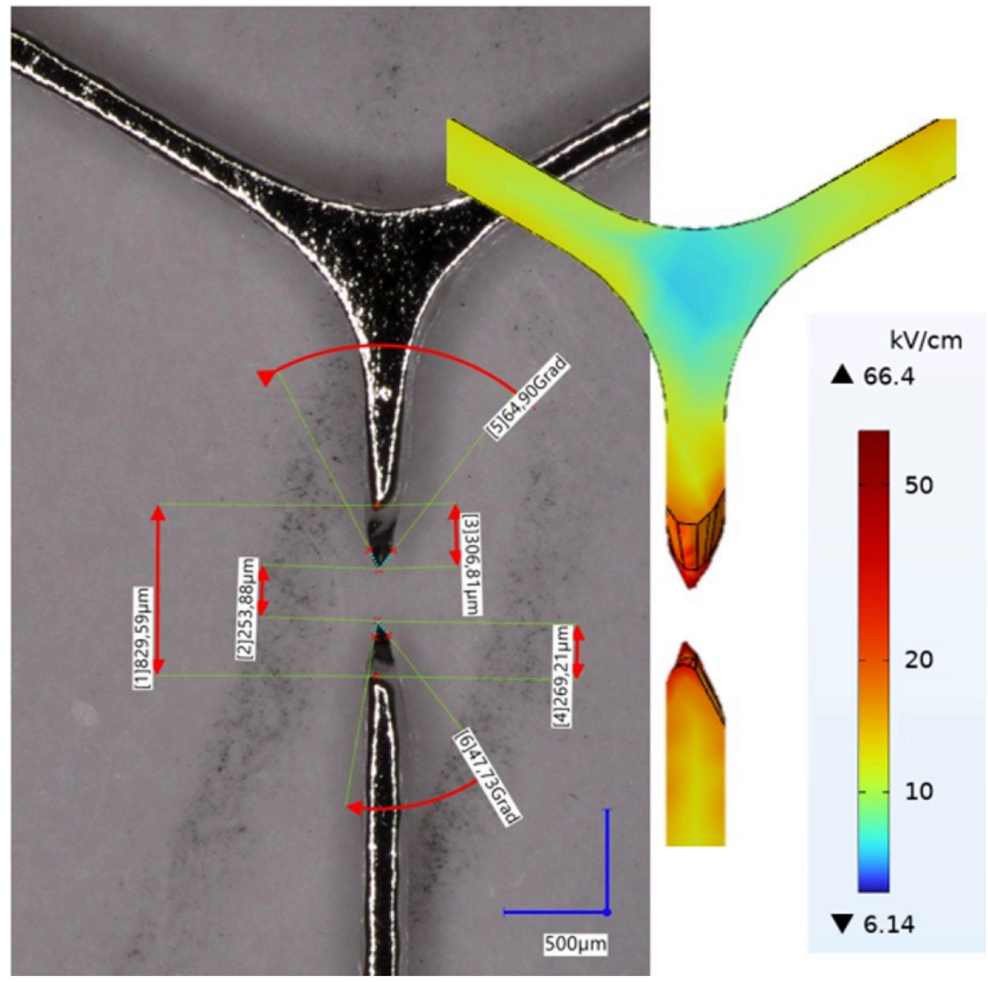


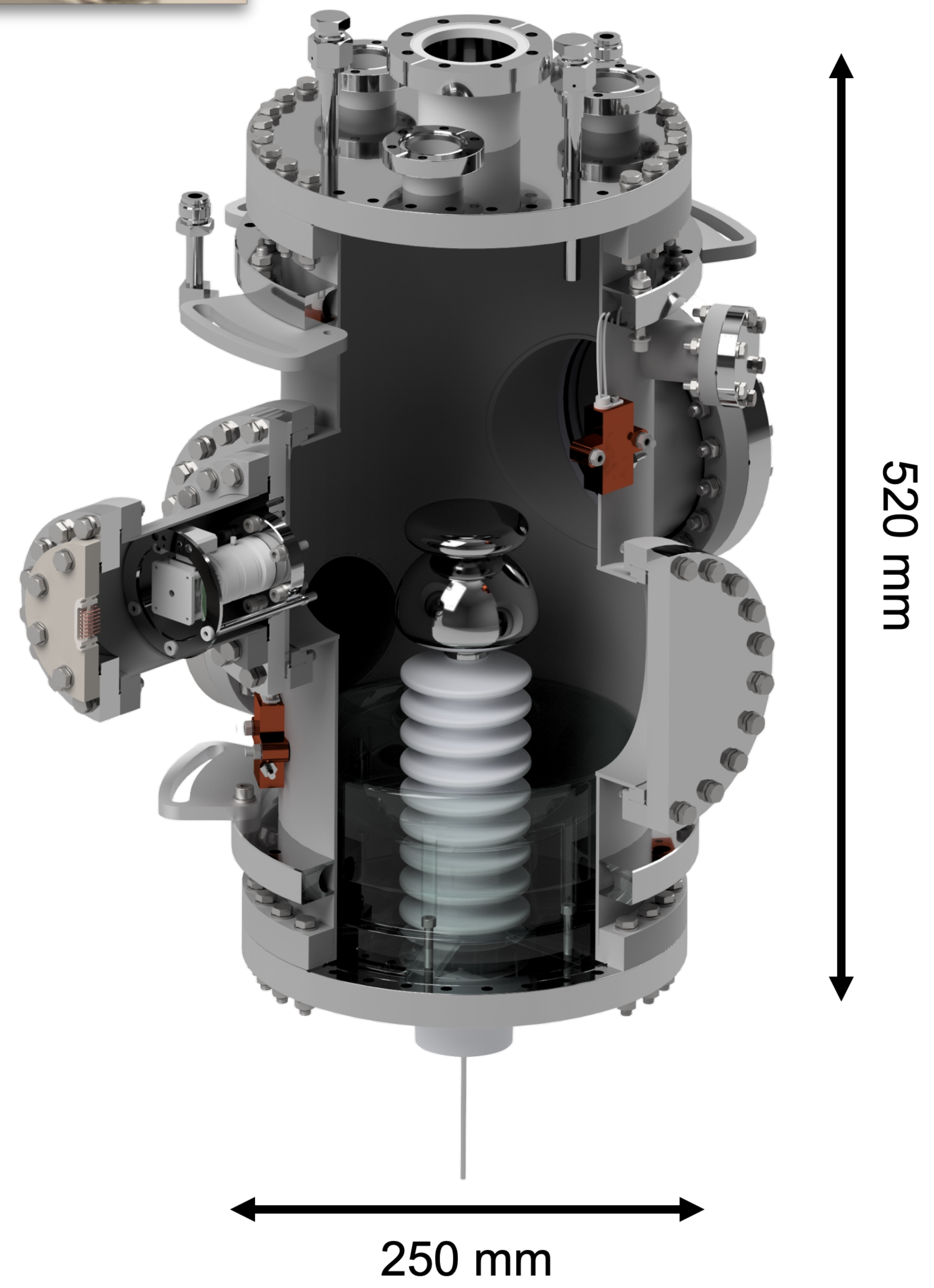



# HV and grids



- Design, production, quality testing and repair of electrodes:
  - Stretching, sagging and flatness of meshes
  - Diagnostic of defects and reparation with laser welding
  - Electrode surface treatment and coating
  - Study electron and photon emission



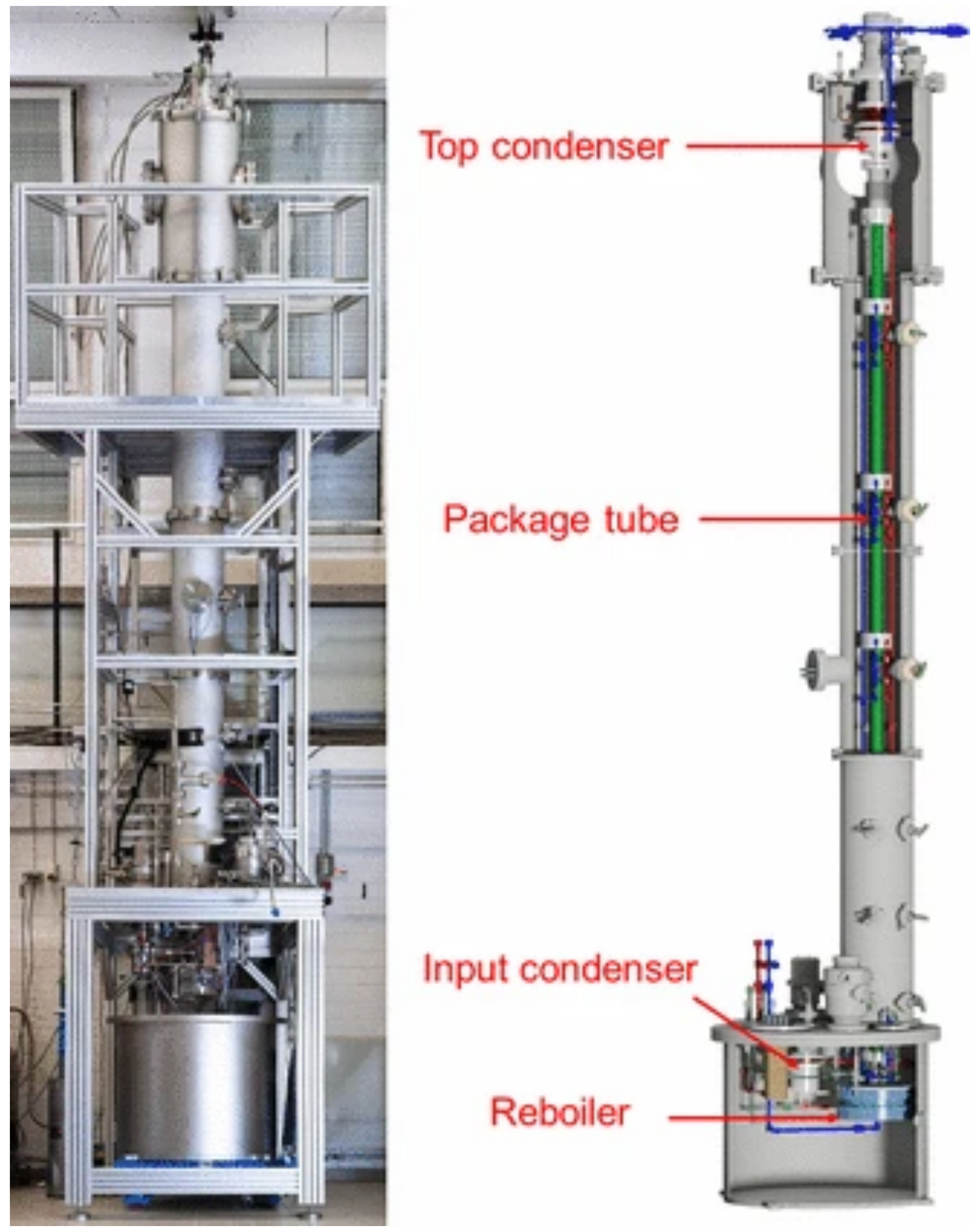

- 80 kg LXe TPC with multiple port access for diagnostic of HV components - up to -200 kV bias

- Additional R&D ongoing within LZ

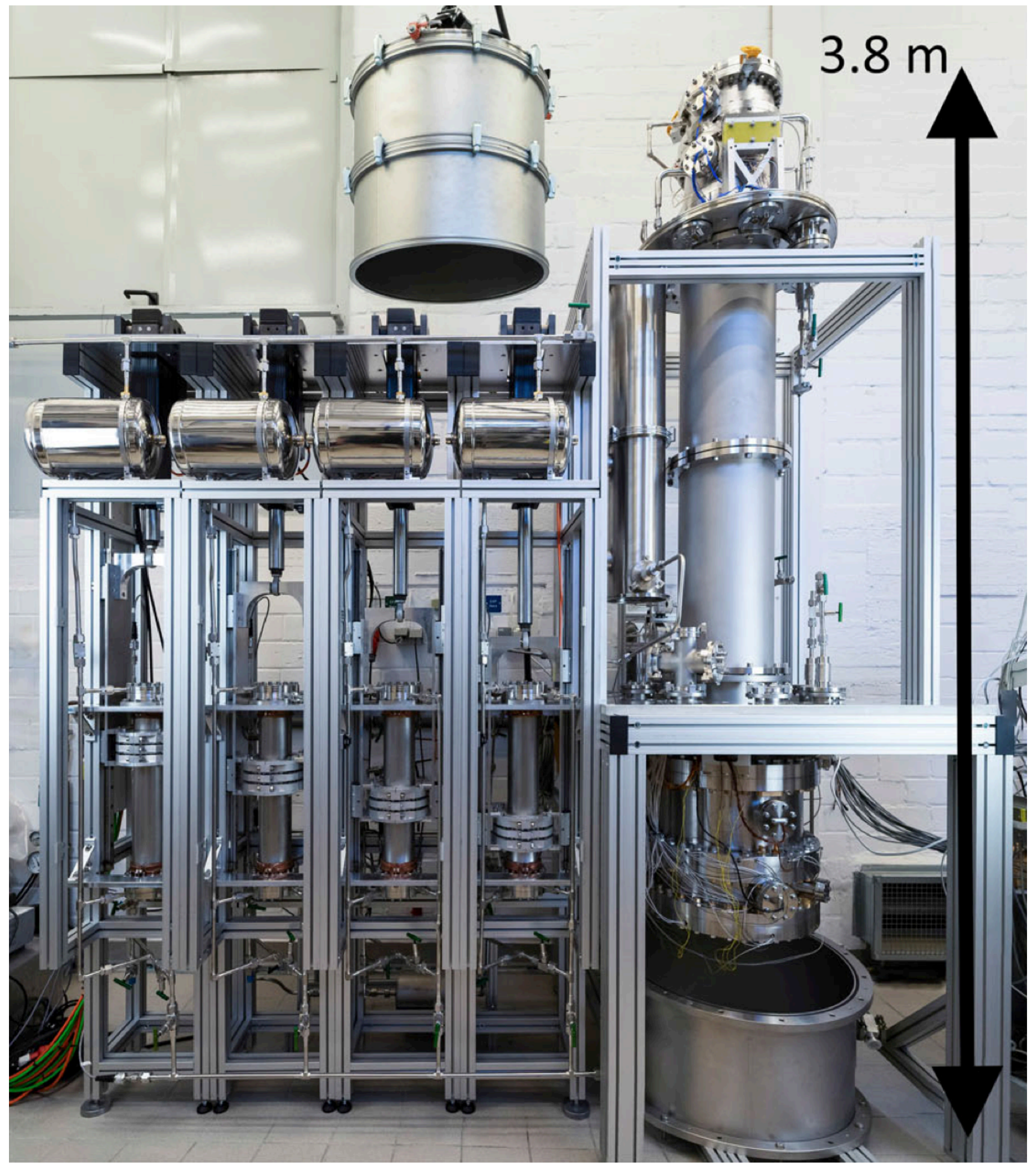
# Background mitigation

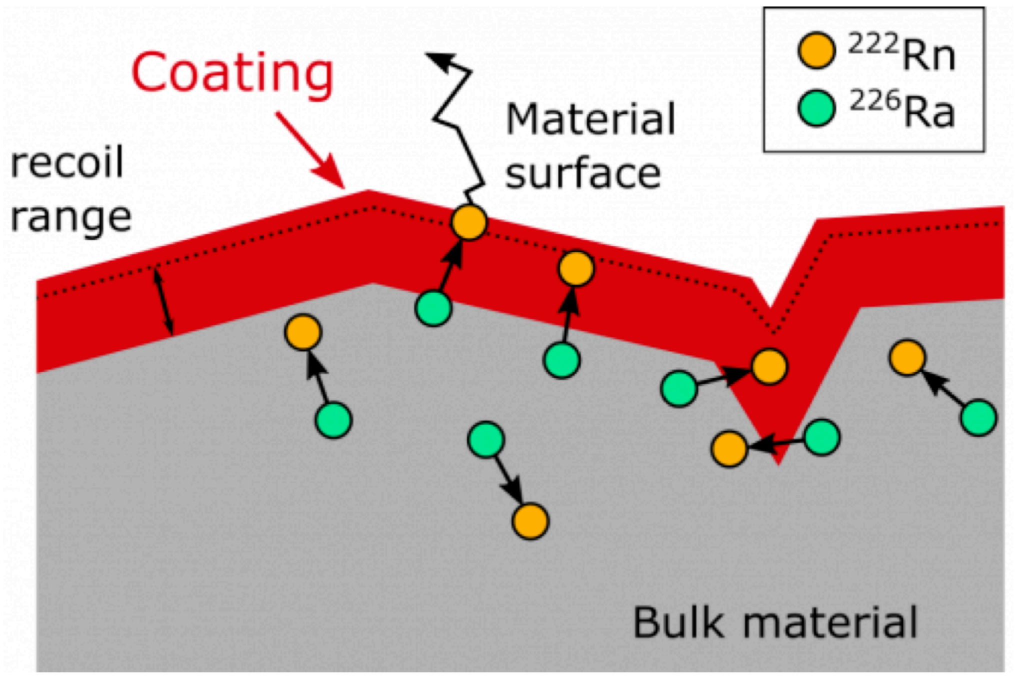
- $^{85}$Kr distillation → goal of 0.1 ppt $^{nat}$Kr already achieved <0.026 ppt
- $^{222}$Rn distillation column → goal of 0.1 µBq/kg (achieved 0.8 µBq/kg) below ER from solar pp neutrinos
- Coating techniques against radon emanation (electrochemical deposition of Cu)
- Fast recirculation in liquid to reduce impurities, with radon-free filters and pumps
- Radio-pure materials with low Rn-emanation
- Software radon-background reduction techniques

Eur. Phys. J. C (2017) 77:275




Eur. Phys. J. C (2022) 82:1104

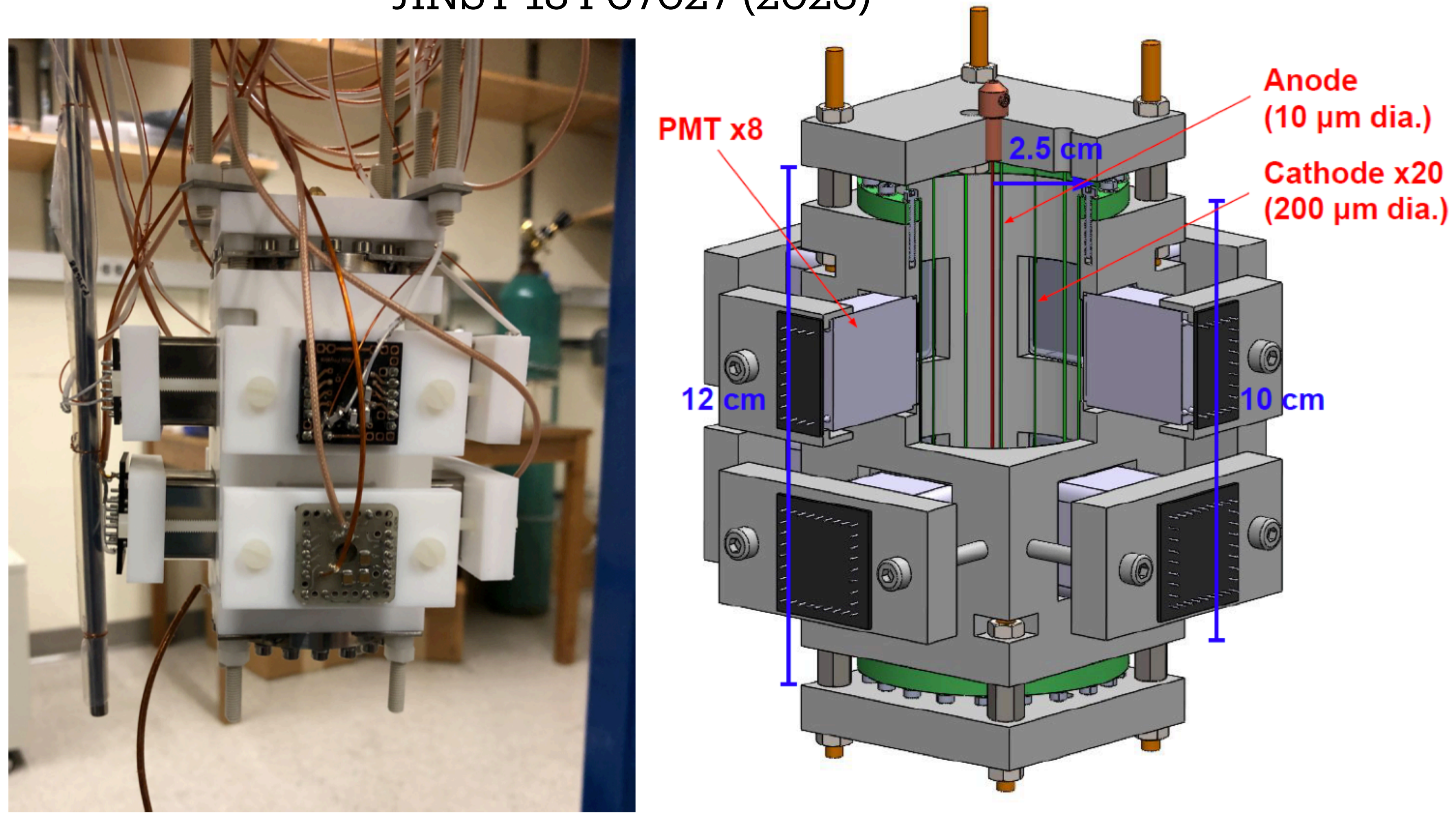


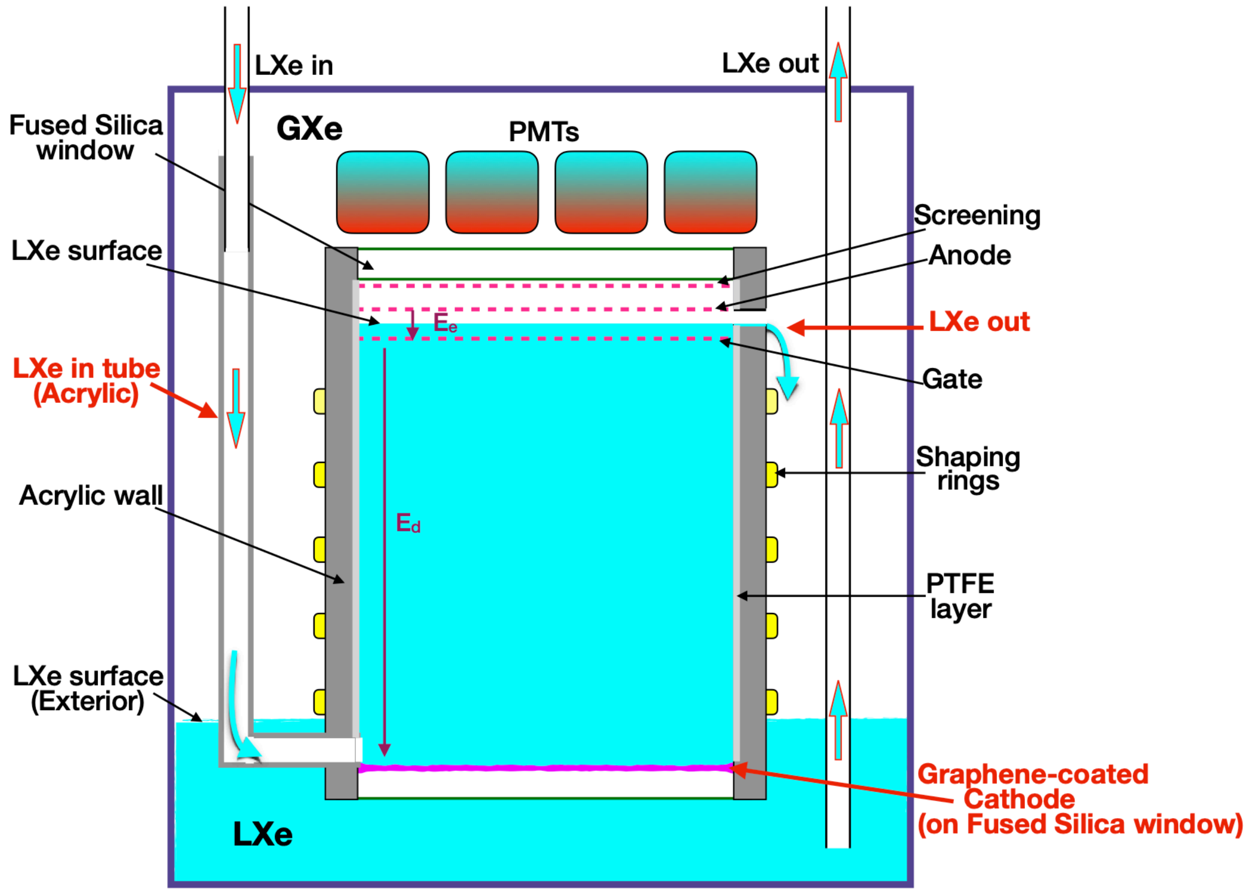



# Alternative designs

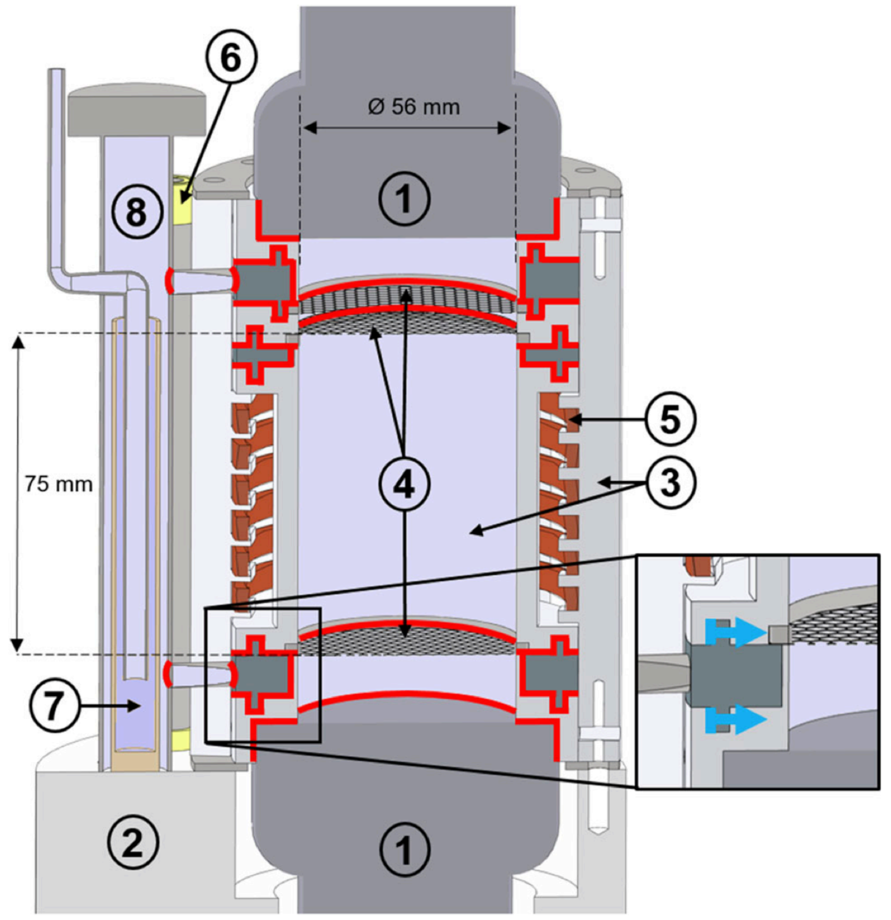
- Single phase TPC
  - Light (S1) and charge (S2) created in liquid phase
  - Simplified TPC design, no liquid level control required
  - Reduce single electron emission
- Hermetic TPC
  - Prevent radon and impurity diffusion into inner volume
- 4π coverage with photosensors

JINST 18 P07027 (2023)




JINST 16 P01018 (2021)

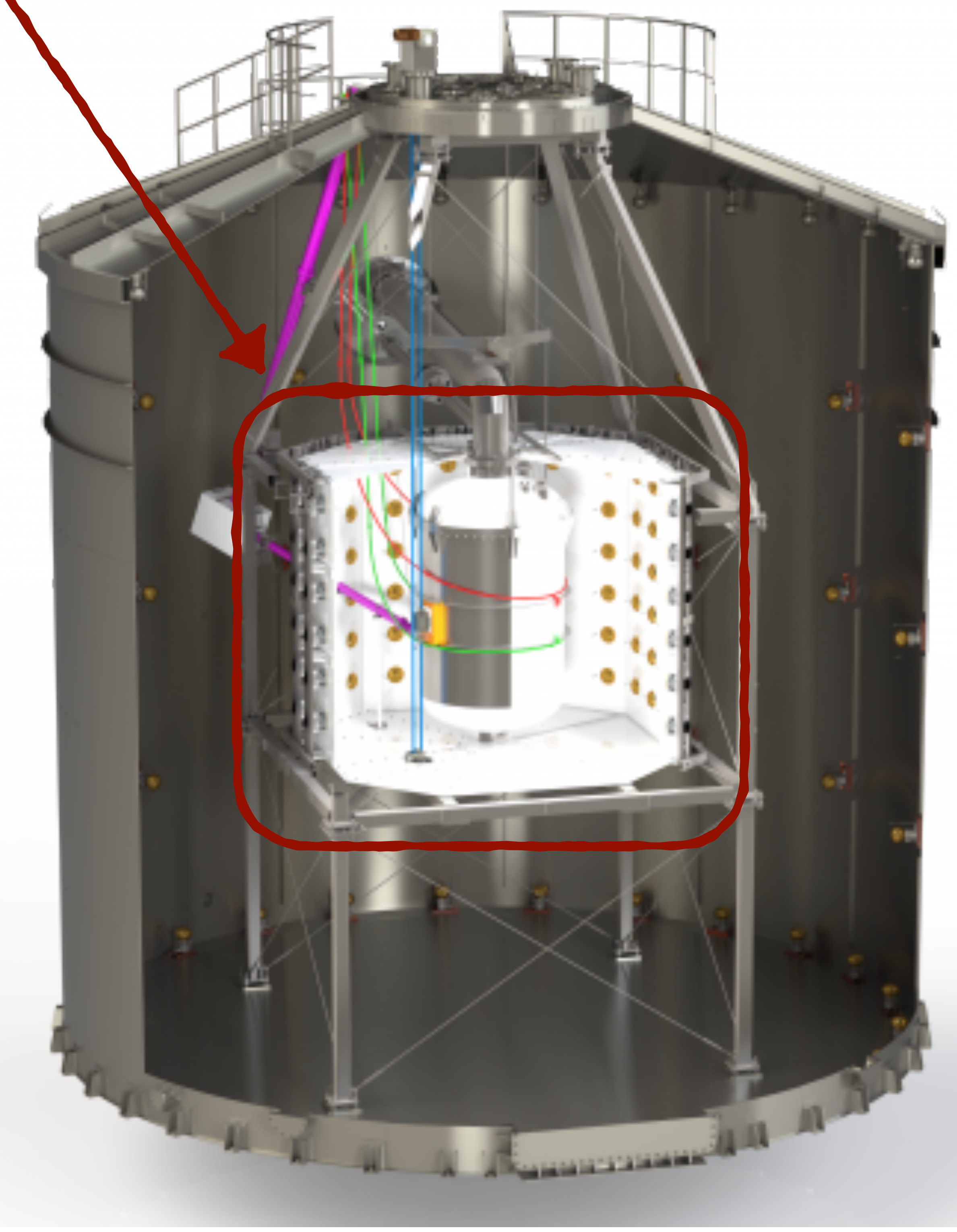



Eur. Phys. J. C (2023) 83:9

# XLZD R&D at LNGS

Preliminary

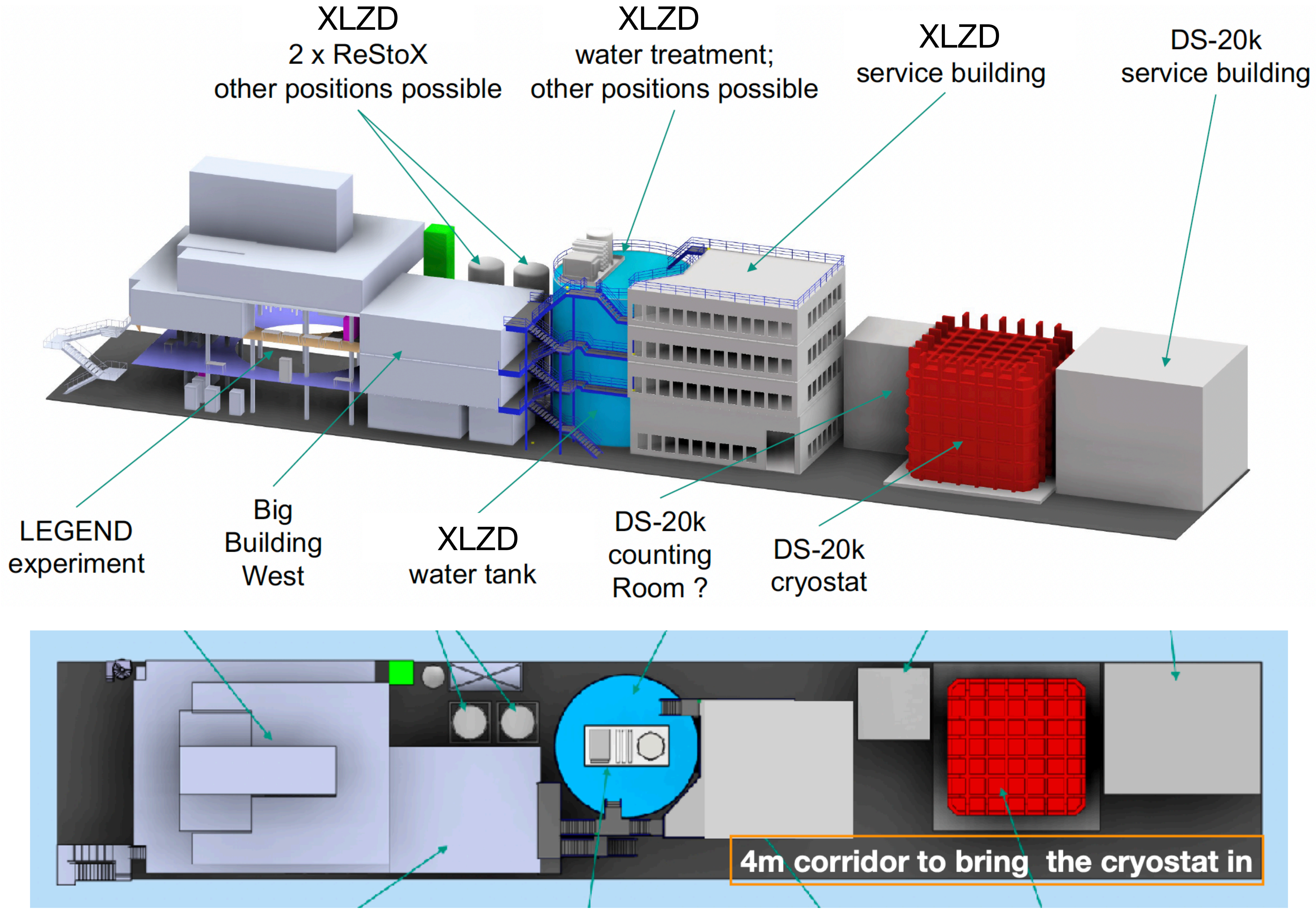
- Proposed DARWIN-10/20 t demonstrator at LNGS-HallB (given funding) after completion of XENONnT
- Test of key components - electrodes and cooling system
- Gd-loading introduced in XENONnT acts also as an ongoing R&D for XLZD

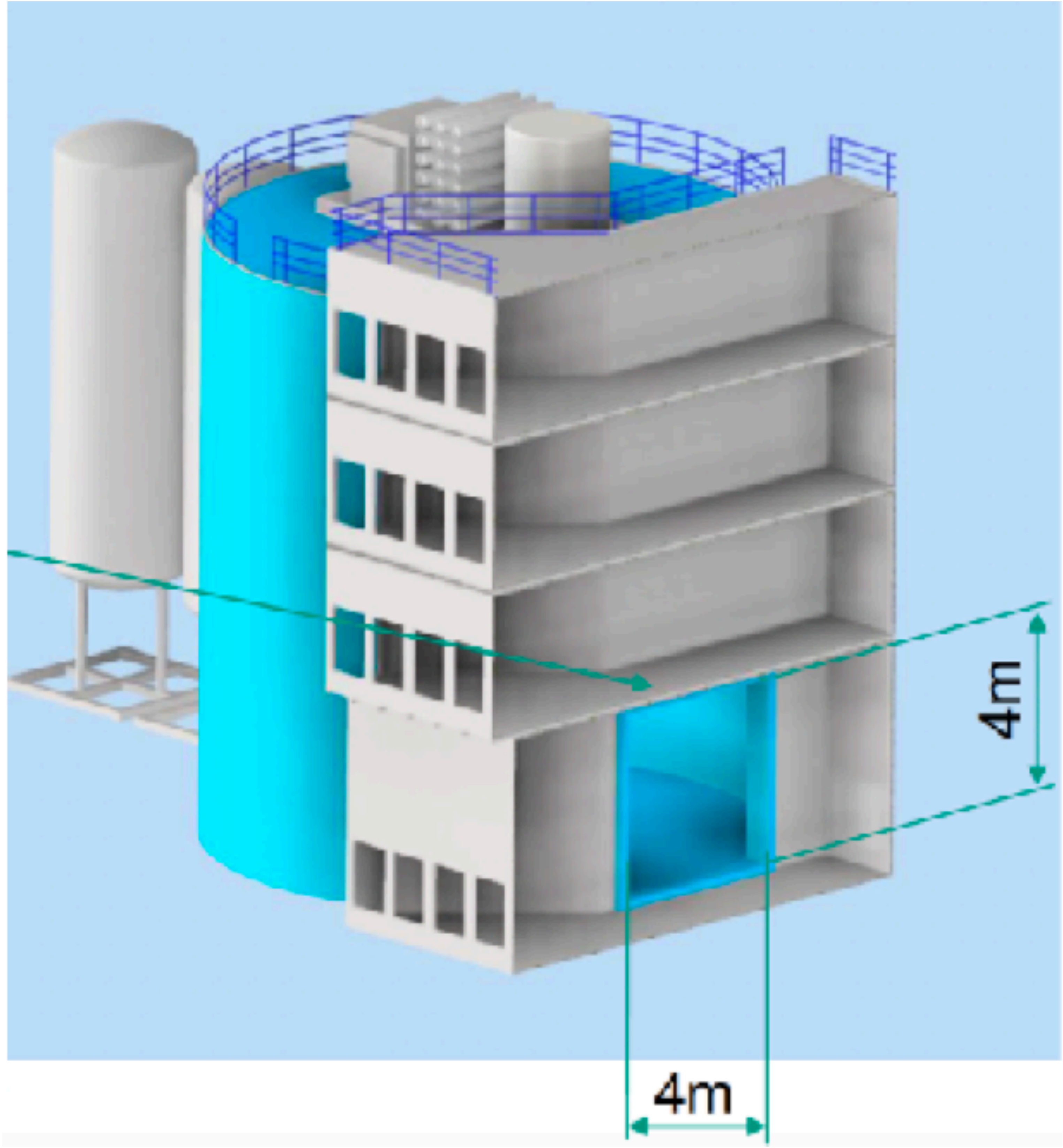


# XLZD at LNGS

Preliminary

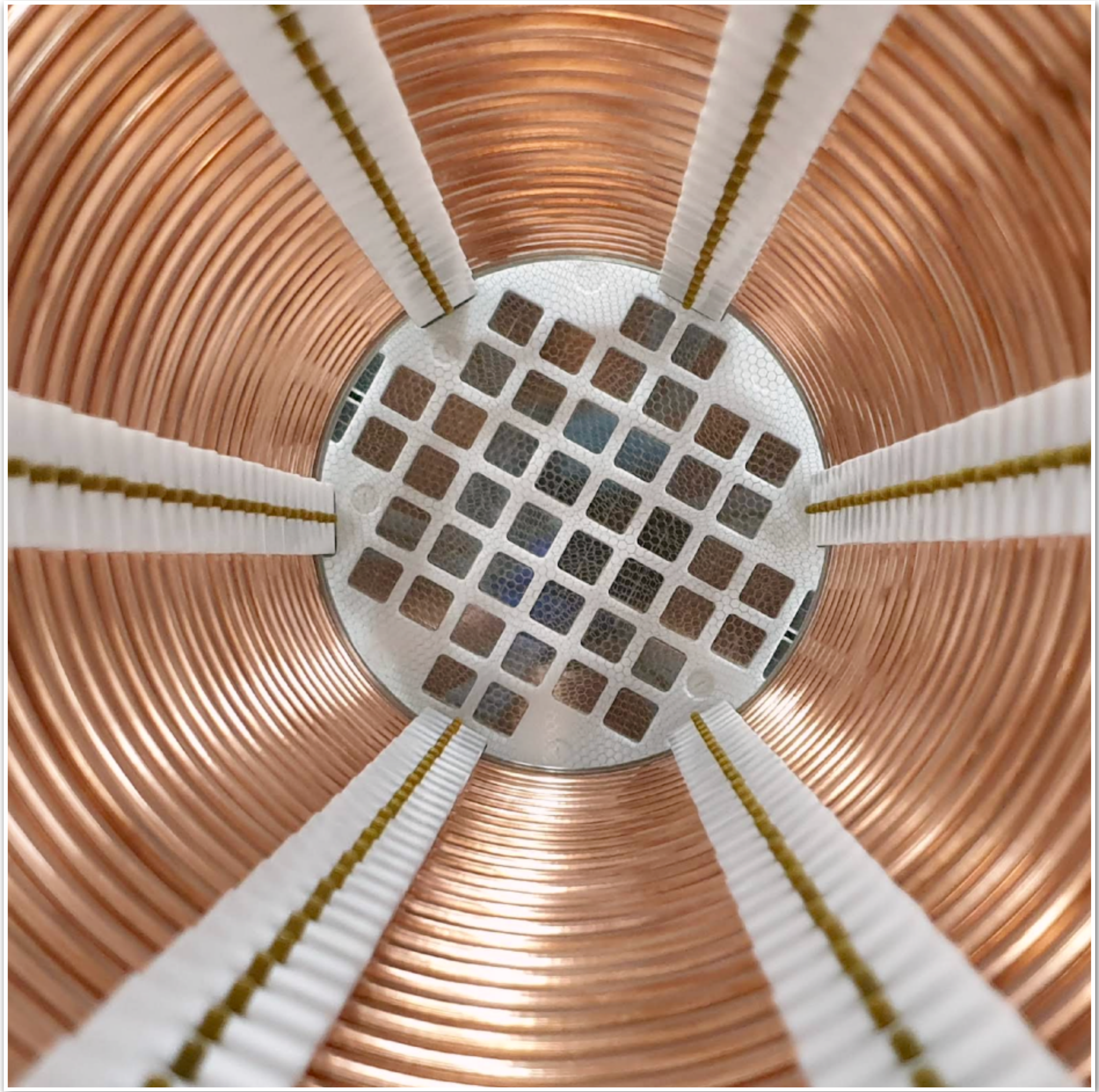
- XLZD siting not fixed yet - LNGS-HallC possible location



# Conclusions

- Active collaboration for next generation LXe TPC for WIMP direct detection down to the neutrino fog
- TPC of ~3 m dimensions and 60 t of active mass
- Rich R&Ds program to tackle the technical challenges:
  - Electric fields
  - Xenon purity
  - Photosensors
  - Background mitigation
- Proposed underground demonstrator at LNGS



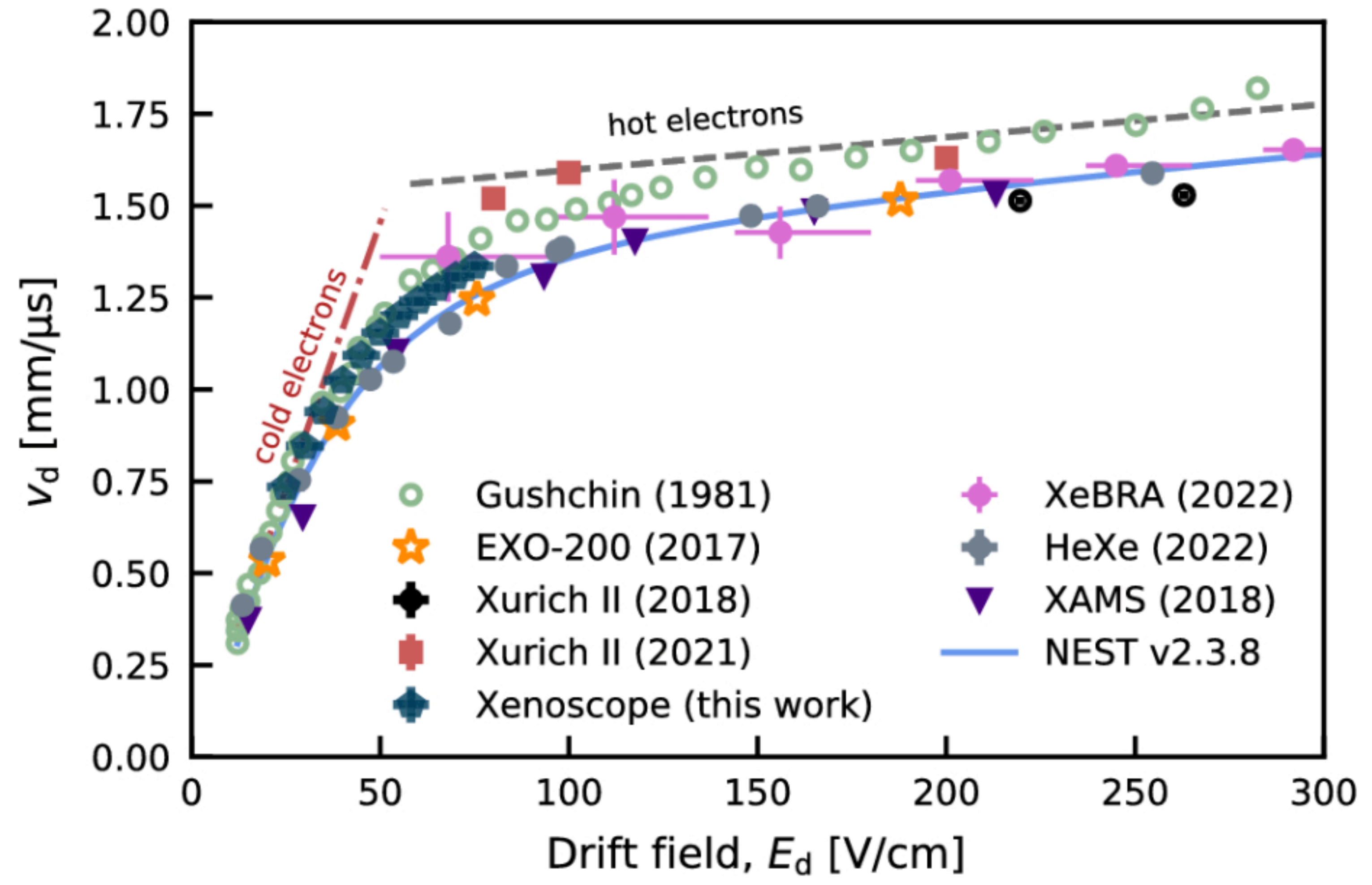
# Backup Slides

# Xenoscope

Eur. Phys. J. C (2023) 83:717

- Electron transport properties with purity monitor - 25 to 75 V/cm

Drift velocity



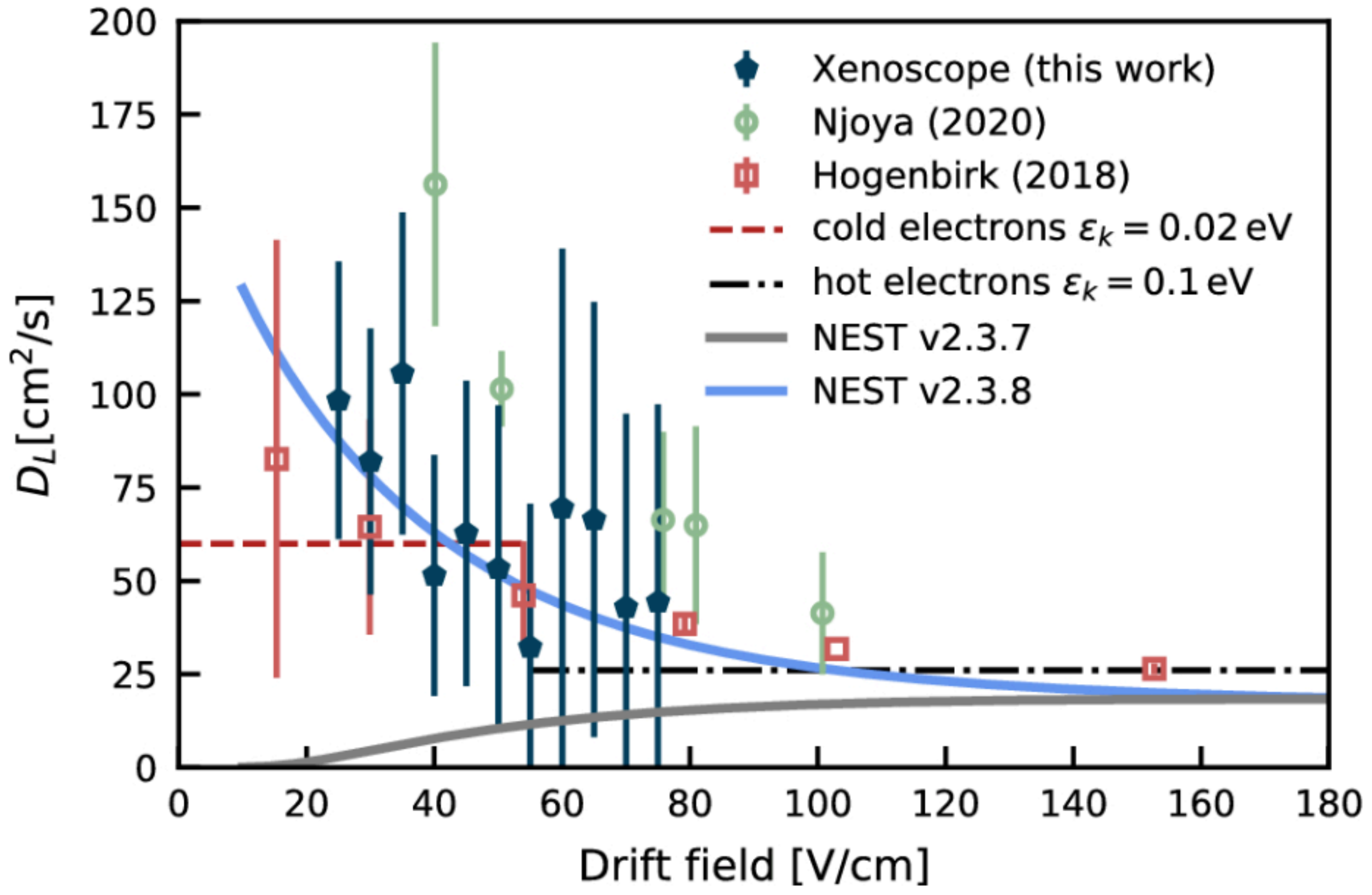

$$v_{\mathrm{d}} = \mu E_{\mathrm{d}} = \frac{d}{t}$$

Drift length

Drift time

Electron mobility gives times between elastic collisions of electrons with xenon (and impurities, also inelastic)

Longitudinal diffusion constant




$$\sigma^2 = \frac{D_L 2 t^3}{d^2} + \sigma_0^2$$

Anode Gaussian peak width

Cathode Gaussian peak width

- Drift velocity from pulse delay from cathode to anode
- Longitudinal diffusion of the electron cloud from pulse width at the anode

# PMT vs SiPM

- Table from EPS-HEP 2023 by R. Peres

| | PMT | SiPM |
|---|---|---|
| Bias voltage | O(1) kV | O(10) V |
| QE @175 nm | ~35 % | ~25 % |
| SPE resolution | 30 % | 4 – 6 % |
| DCR @170-190K | O(0.01) Hz/mm$^2$ | O(0.1 - 1) Hz/mm$^2$ |
| Fill factor | ~ 60 % (XENONnT) | Up to 90% (no packaging) |
| Radioactivity | Large mass/radioactivity per area | Low radioactivity per area |