DARWIN: On the Path to the Ultimate Liquid-xenon Astroparticle Observatory

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On behalf of DARWIN/XLZD

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Rencontres de Blois

23th of October, 2024

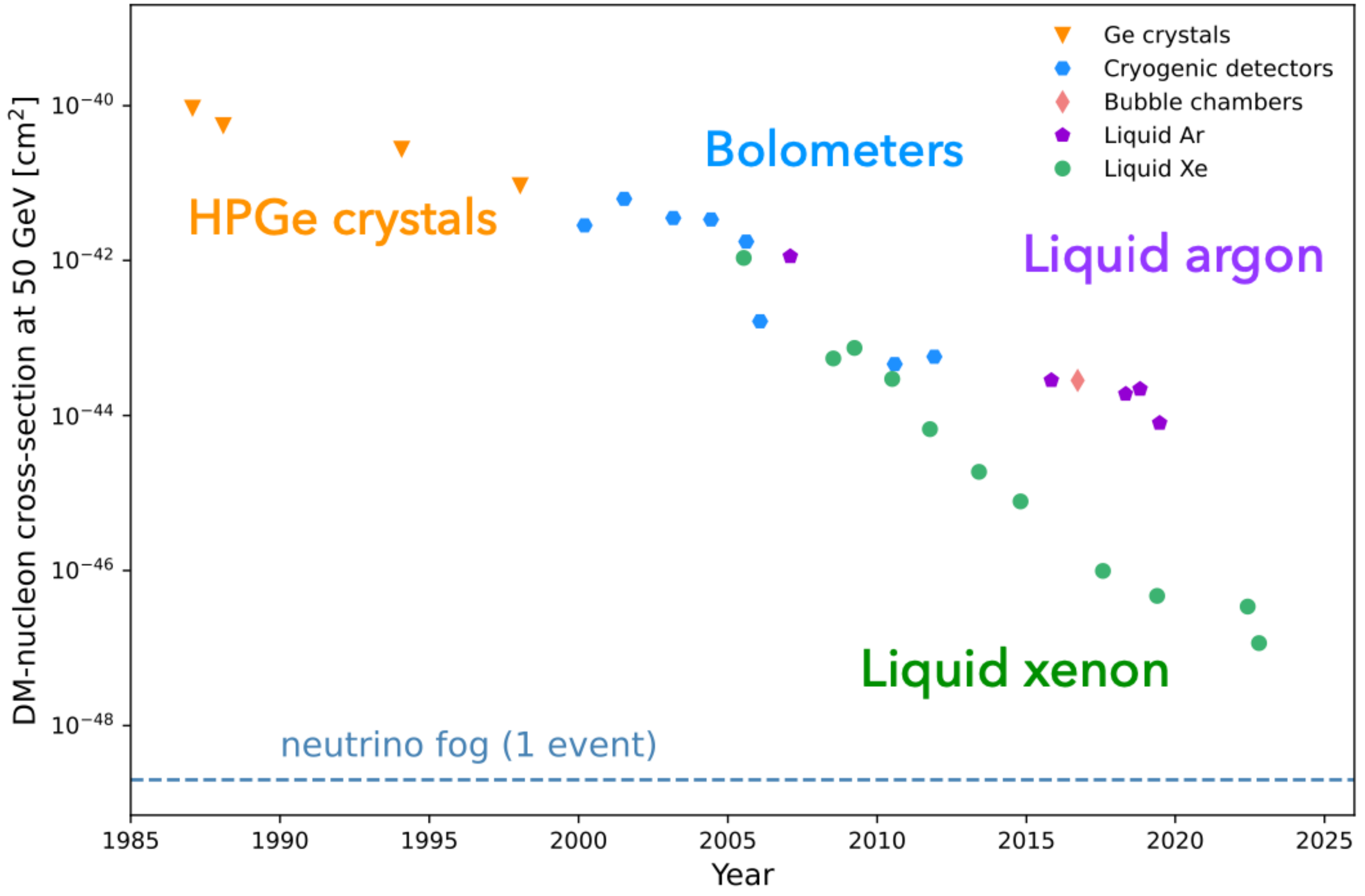
WIMP search with Xenon

Noble gases Time Projection Chamber

- Leading sensitivity @ mass range $\mathcal{O}$(10-1000) GeV

Upper limits for a 50 GeV WIMP

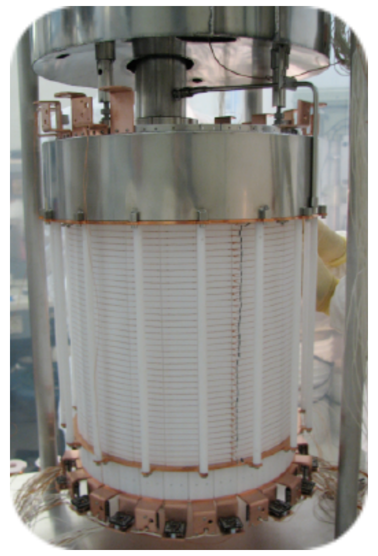
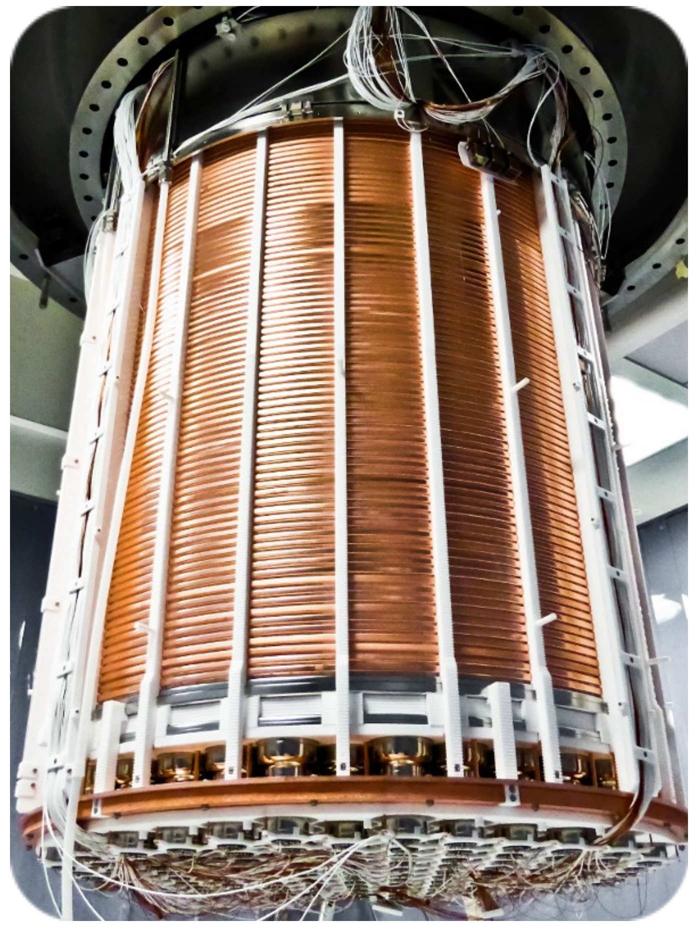
L. Baudis, IDM 2024



WIMP search with Xenon

Noble gases Time Projection Chamber

- Leading sensitivity @ mass range $\mathcal{O}$(10-1000) GeV
- Liquid Xenon (LXe) detectors advantages:
  - ➡ Scalability
  - ➡ Ultra-low backgrounds
    - ❖ Radiopurity, Purification, Self-shielding,…
  - ➡ SI and SD (^{129}Xe, ^{131}Xe) interactions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	XENON10	XENON100	XENON1T	XENONnT
Time	2005	2008	2016	2021
Active mass	15 kg	62 kg	2000 kg	5900 kg
Background [t.day.keV]$^{-1}$	~1000	5.3	0.2	0.04

XENON-LUX-ZEPLIN-DARWIN: XLZD

Towards the ultimate LXe detectors

- New collaboration uniting the strengths of major actors (72 institutions and 163 senior scientists)
  - ➡ XENONnT, LZ - demonstrated experience in large-scale LXe TPCs
  - ➡ DARWIN - Large-scale demonstrators, R&D: electrodes, HV, photosensors,…

xlzd.org

XENON-LUX-ZEPLIN-DARWIN: XLZD

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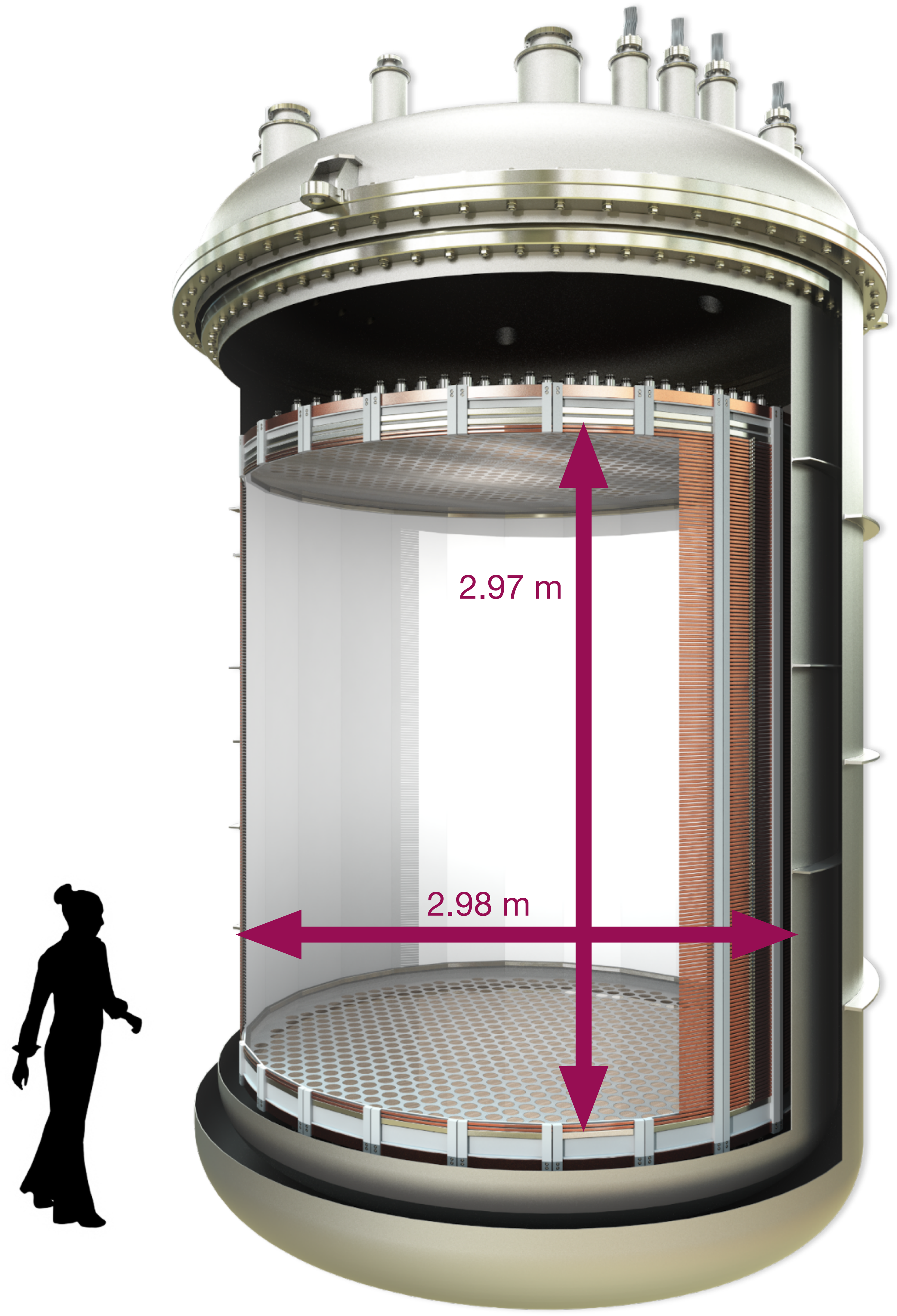
XLZD nominal design

- 60 t LXe TPC (~80 t total), early science with 40 t LXe
- 3” PMTs, 1182/array
- 2.98 m diameter, and 2.97 m electron drift (can vary [40, 80] t)
- Drift field: 240 - 290 V/vm; Extraction field: 6-8 kV/cm
- Double-walled low-background Ti cryostat + LXe “skin” surrounding the TPC

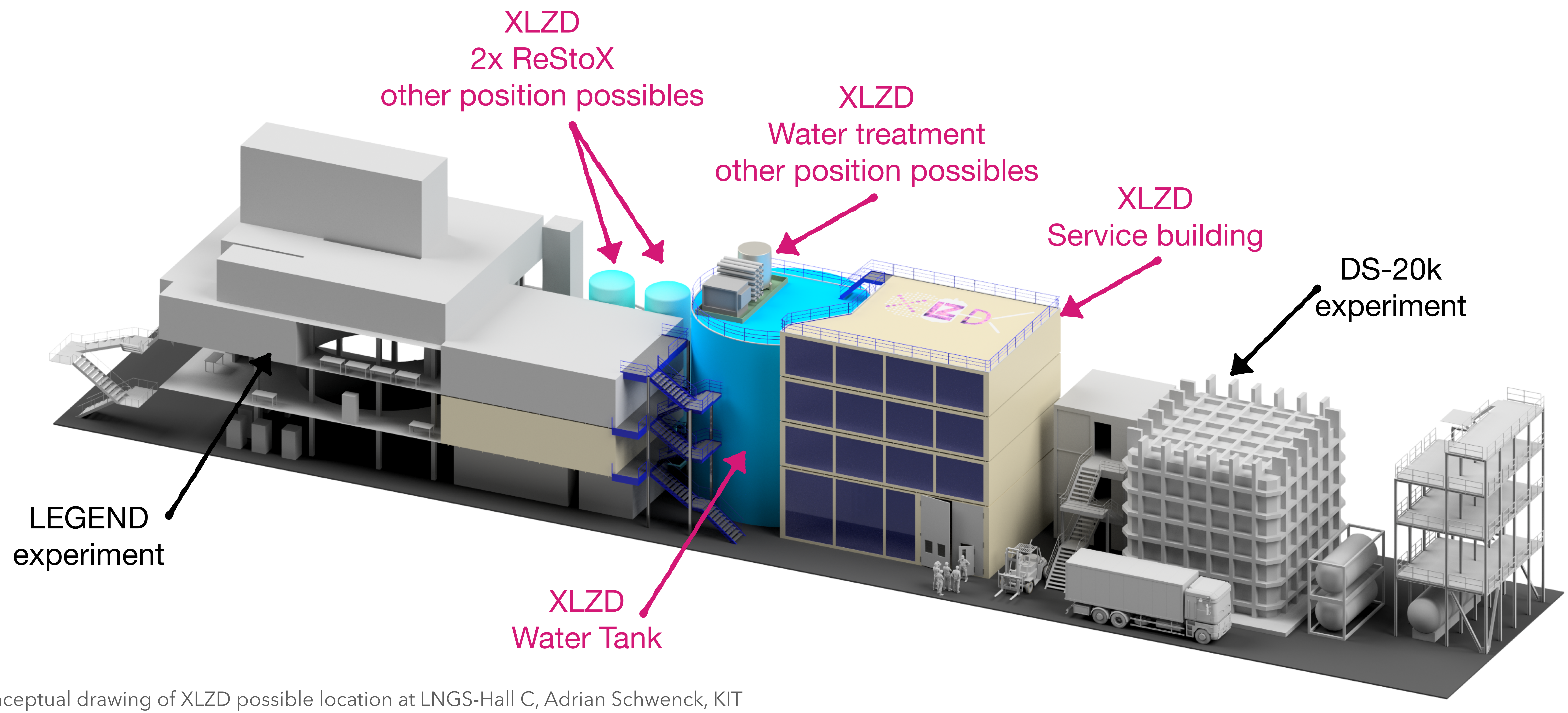


+ Passive and active muon and neutron shielding with gadolinium to enhance capture cross-section (ongoing R&D with current generation of experiment)

XENON-LUX-ZEPLIN-DARWIN: XLZD

XLZD siting not fixed yet

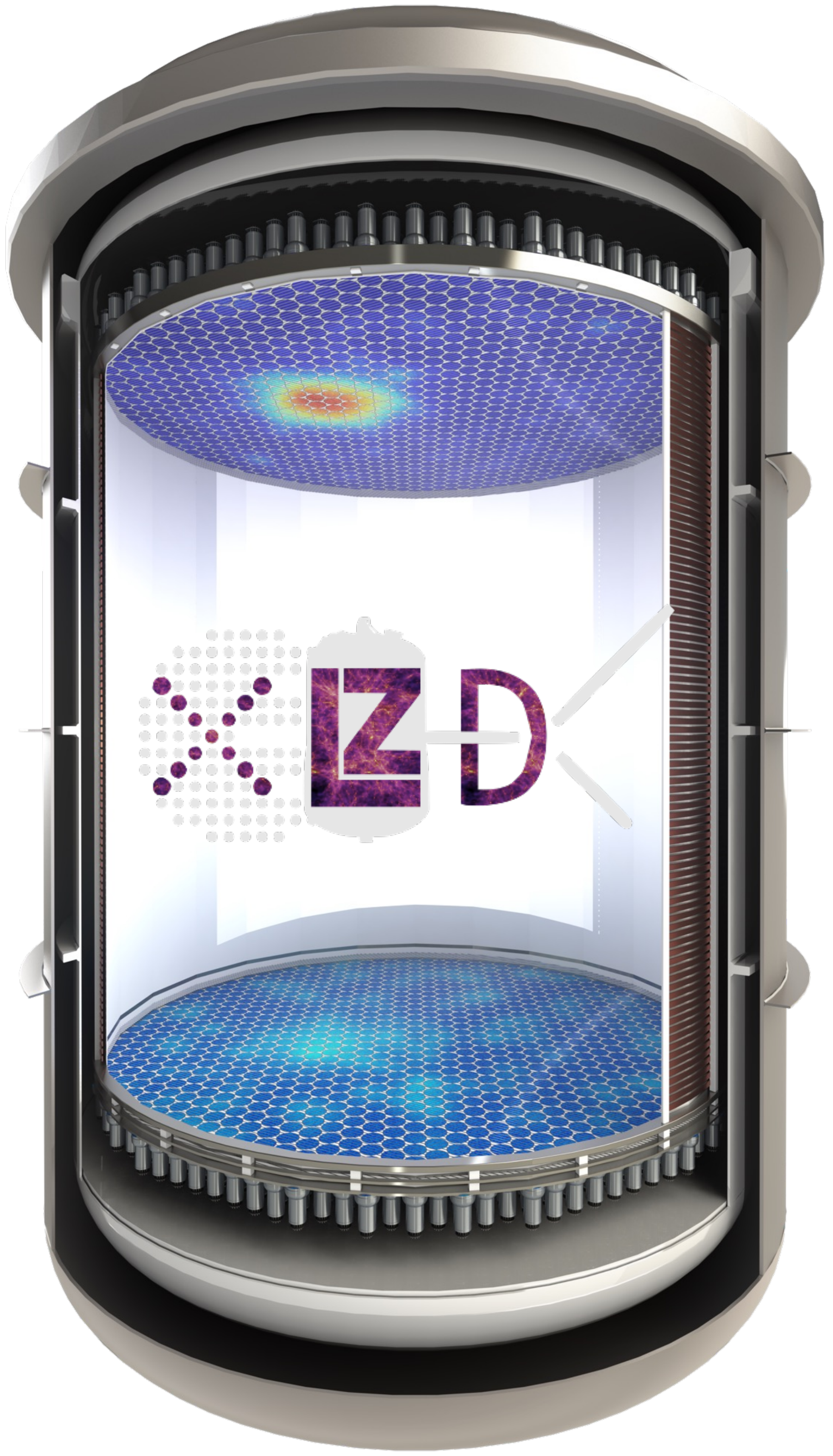
- Laboratori Nazionali del Gran Sasso, Italy
- Boulby Underground Laboratory, United Kingdom
- Sanford Underground Research Facility, USA



Conceptual drawing of XLZD possible location at LNGS-Hall C, Adrian Schwenck, KIT

Science Goals

Dark Matter
WIMPs
Sub-GeV
Inelastic
Axion-like particles
Planck mass
Dark photons



Neutrino nature
Neutrinoless double beta decay
Neutrino magnetic moment
Double electron capture

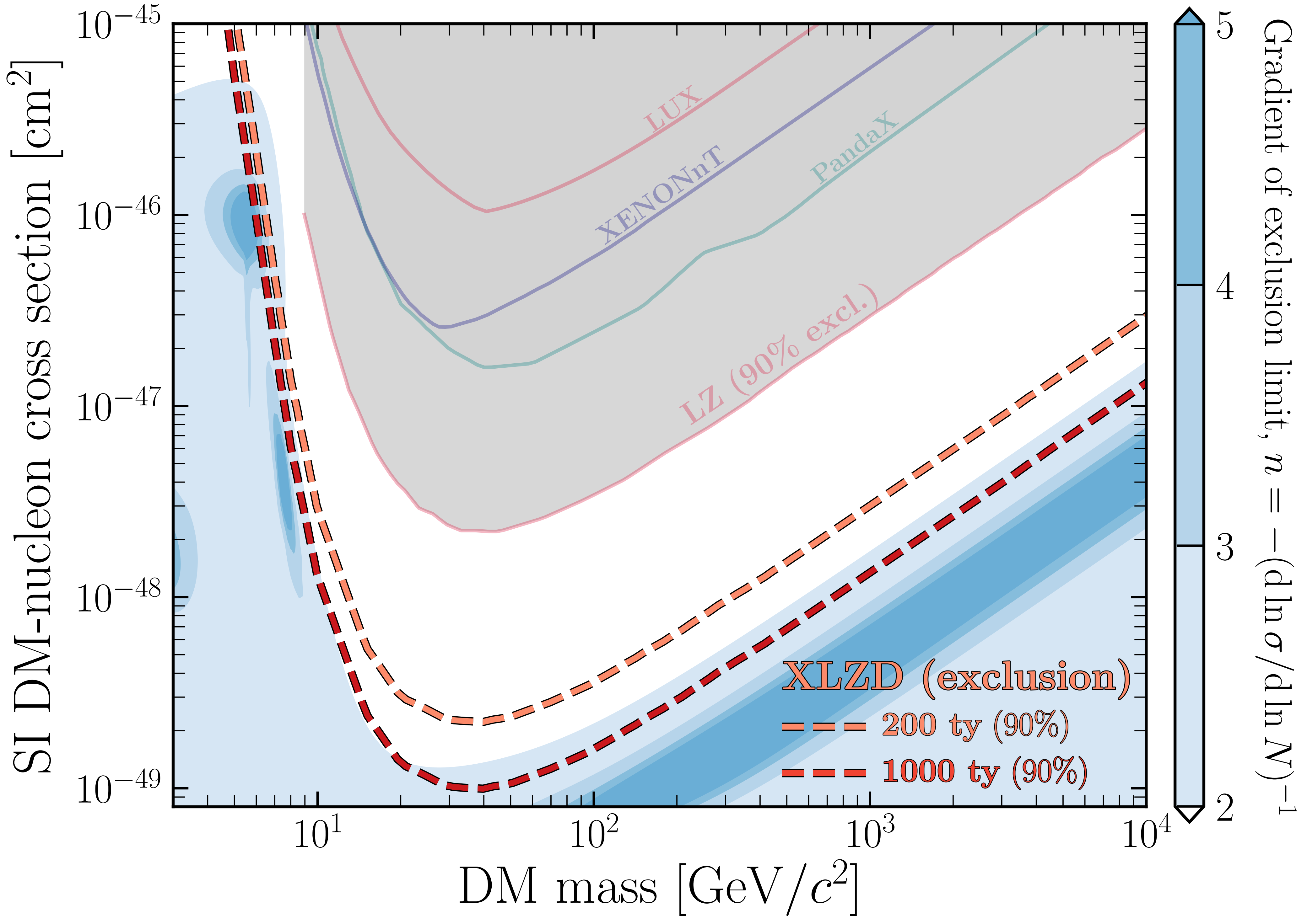
Physics Case
JoPG, 50 013001 (2023)

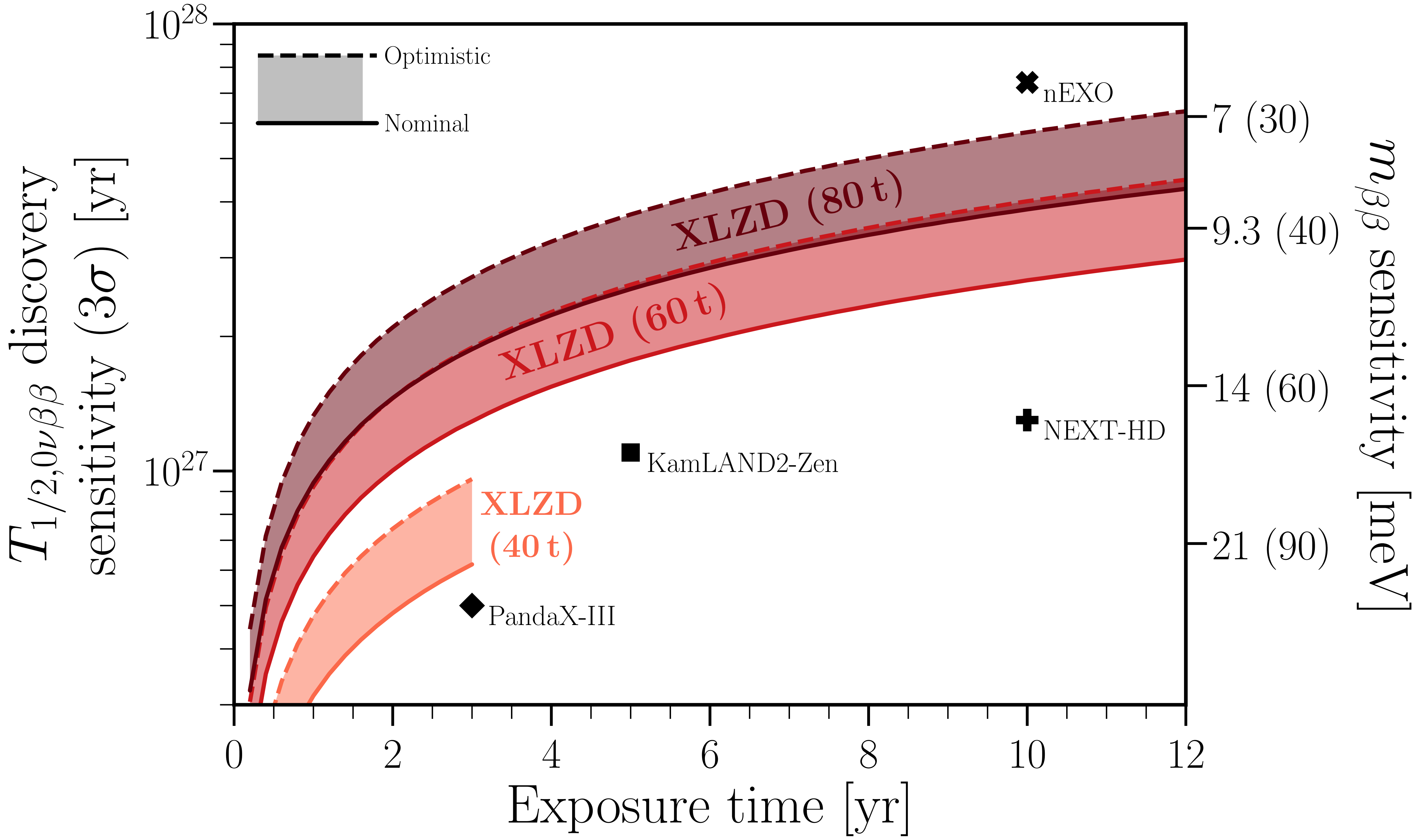
Supernovae
Early alert
Supernova neutrinos
Multi-messenger astrophysics

Sun
pp neutrinos
Solar metallicity
^{7}Be, ^{8}B, hep

Science Goals

Simultaneously explore WIMP space down to the "neutrino fog" and search for neutrinoless double-β decay of ^{136}Xe



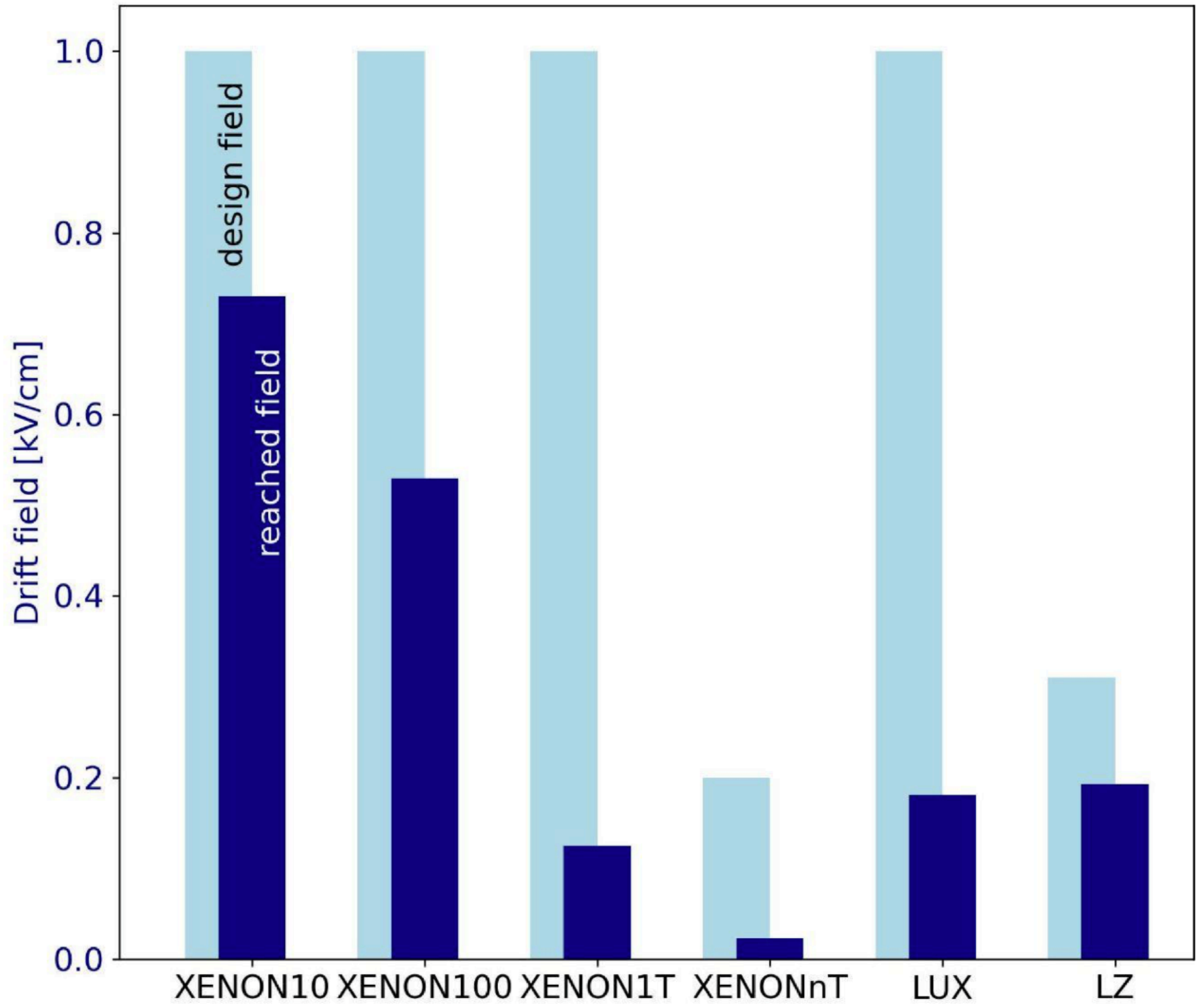


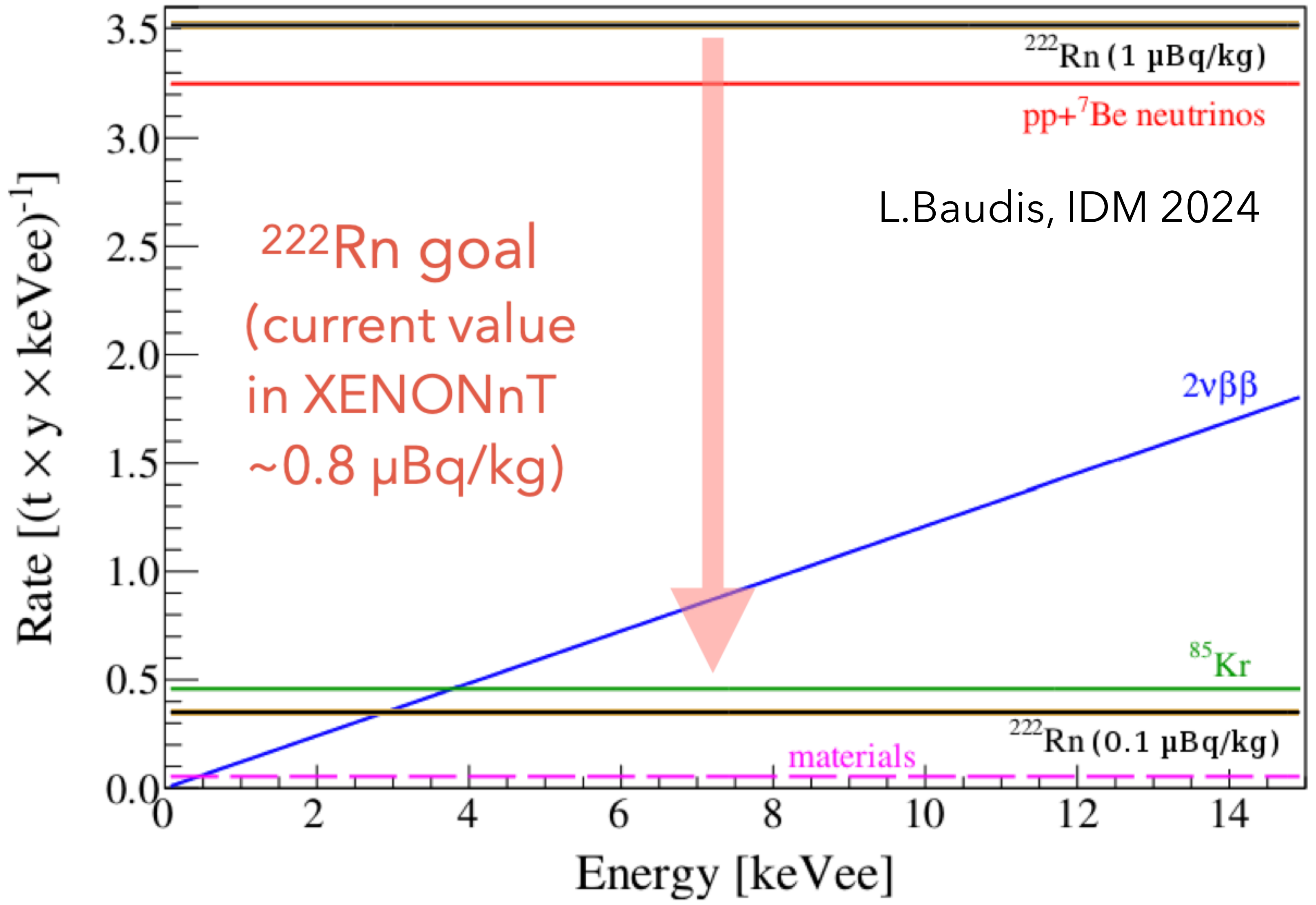
Design Book
arXiv:2410.17137

$0\nu\beta\beta$ projection
On arXiv soon

Challenges

- Drift/Extraction fields in a larger TPC
  - ➡ High-voltage delivery
  - ➡ Electrodes design/construction/test
  - ➡ Electric field homogeneity
- Liquid xenon purity
- Background mitigation (external/intrinsic)
- Light collection efficiency
- Photosensors performance

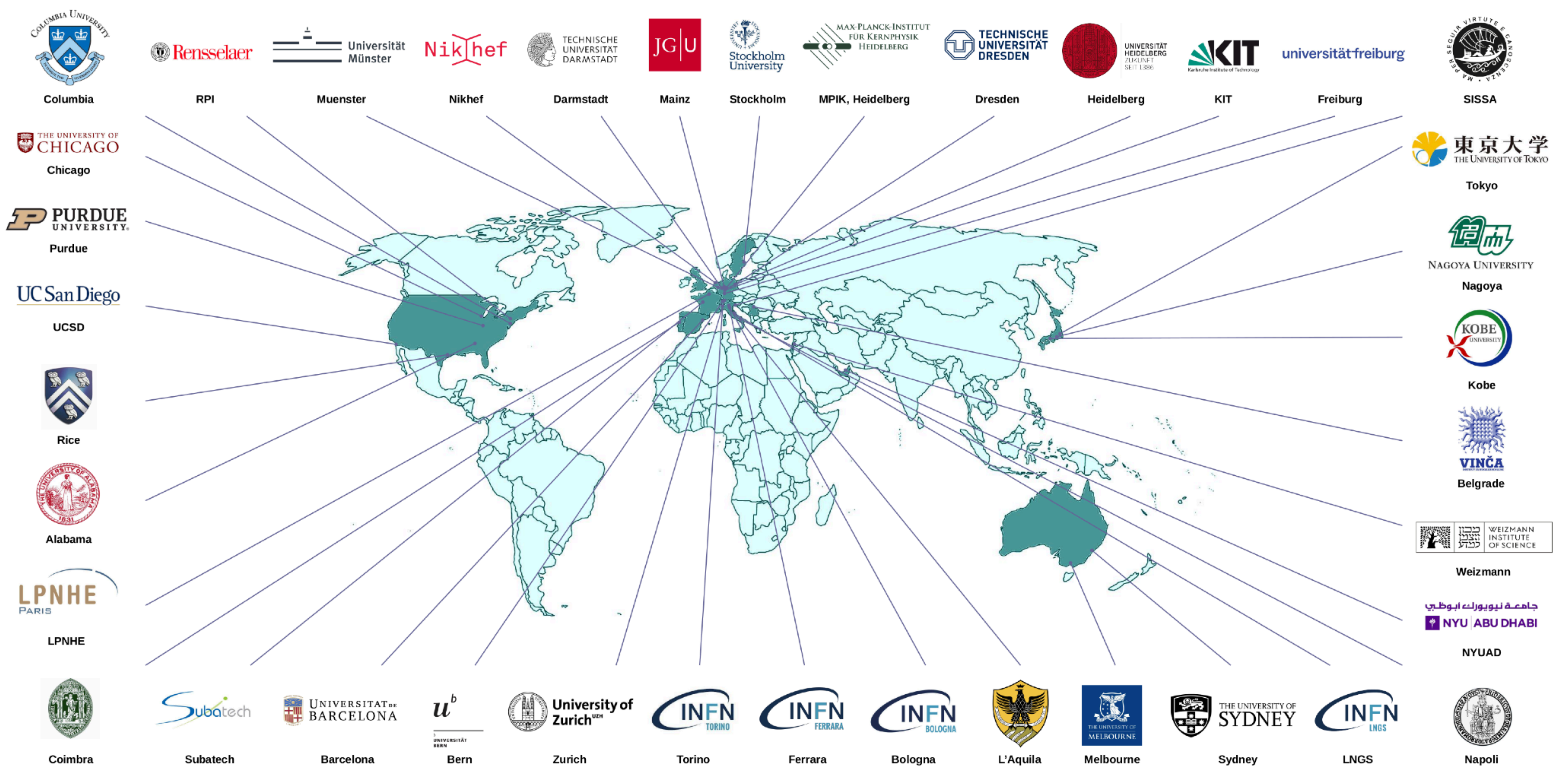




Towards XLZD: DARWIN

The DARWIN Collaboration

- ~200 members from 35 institutions
- Established structure and active working groups
- Several large-scale demonstrators, as well as R&D setups



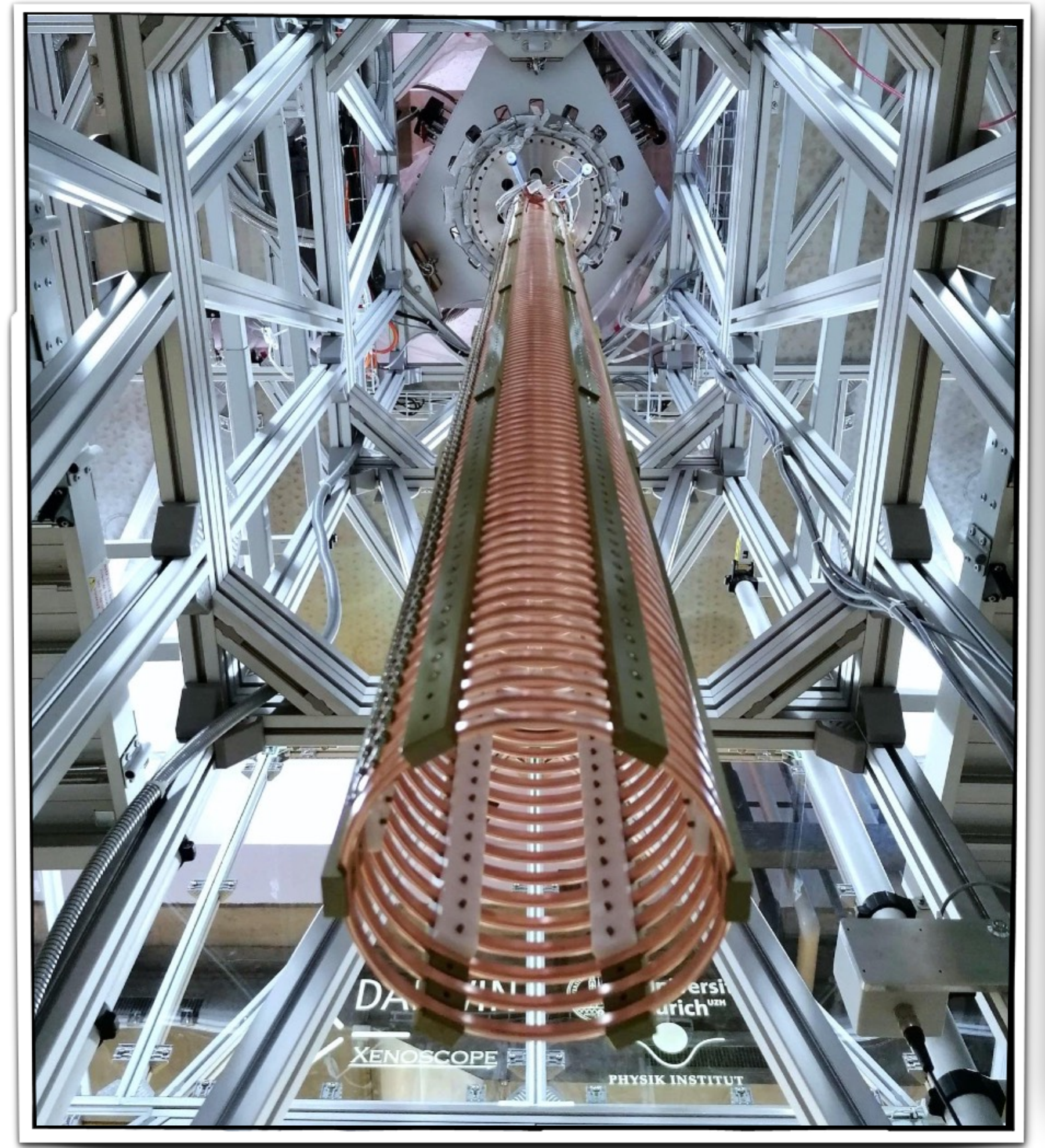
Rich R&D program to tackle these challenges

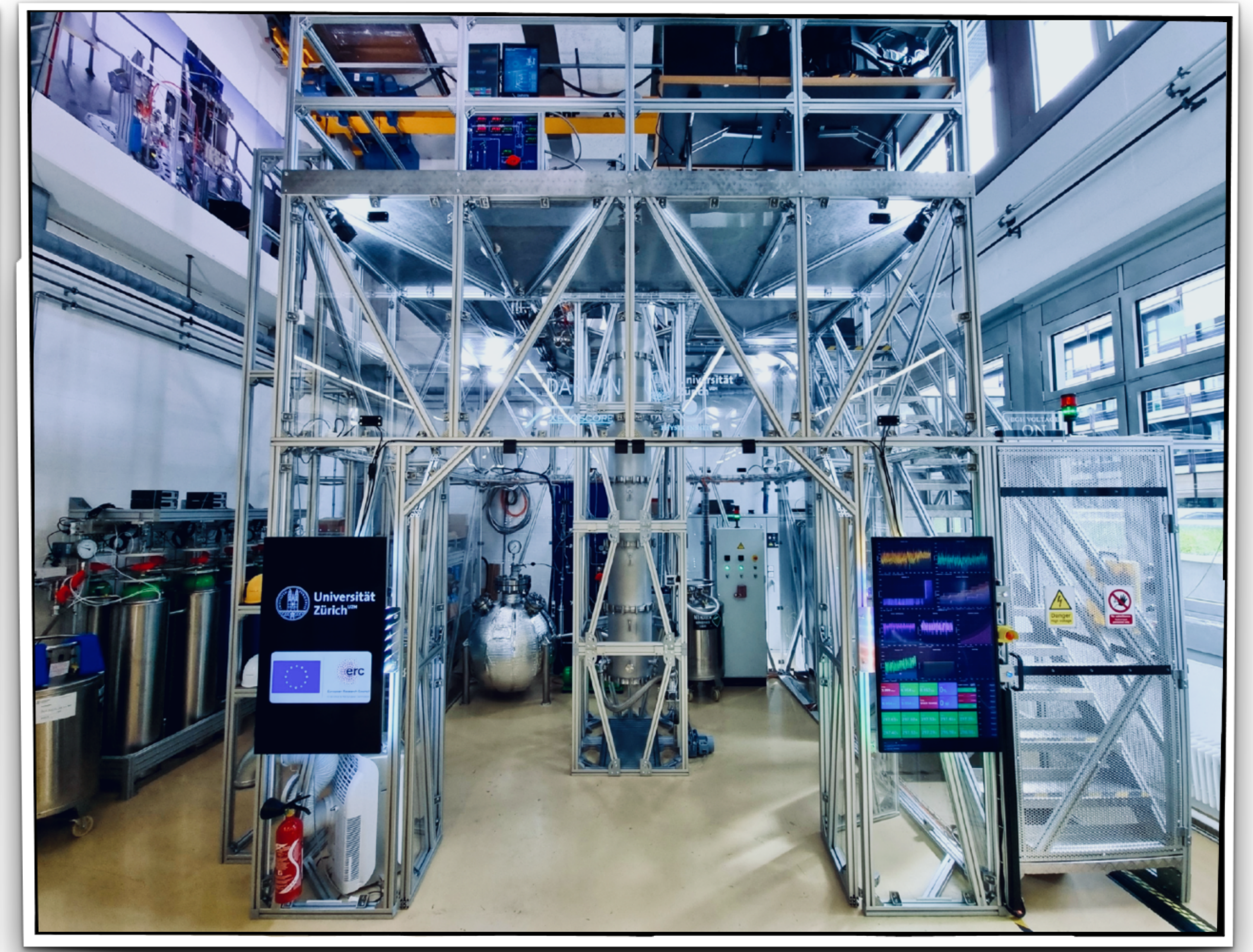
Xenoscope at UZH

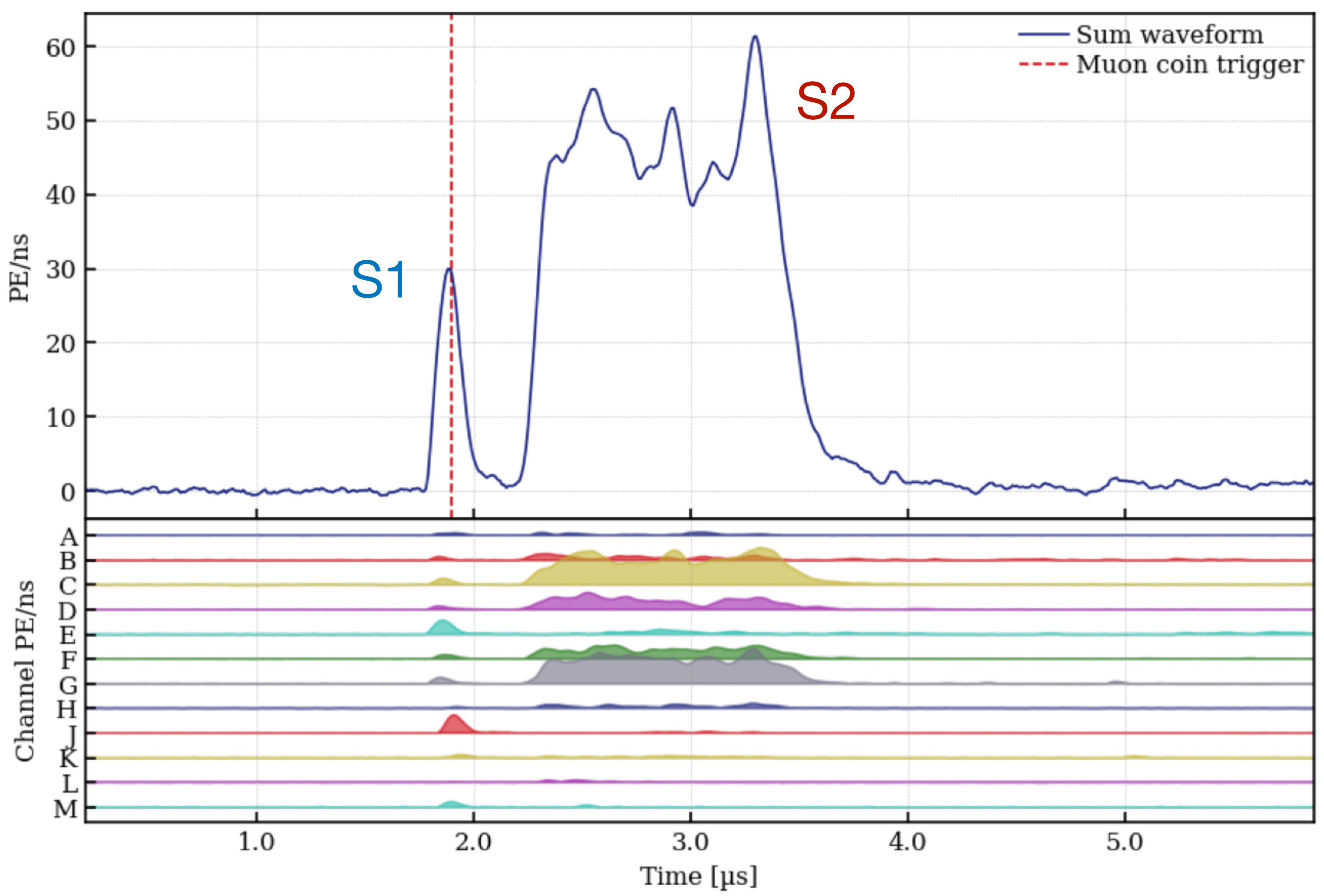
JINST 16, P08052 (2021)
Eur. Phys. J. C 83, 717 (2023)

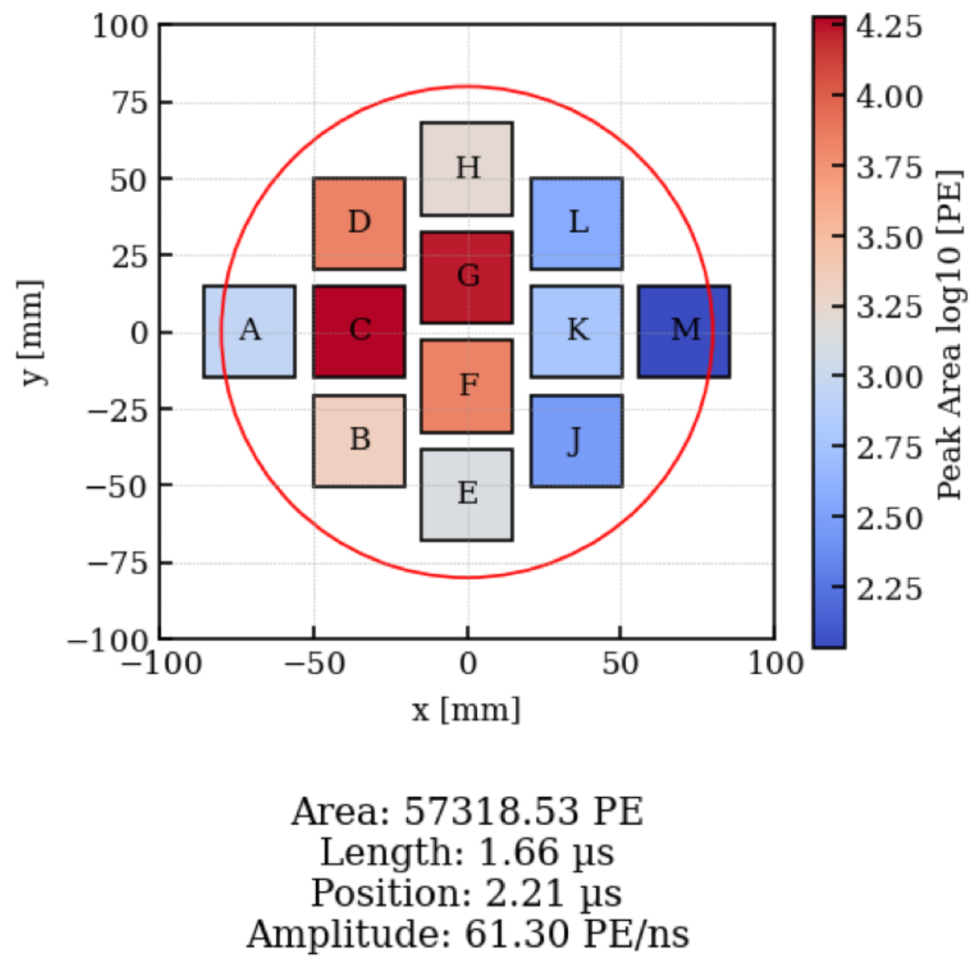
Vertical demonstrator

- Goals:
  - ➡ Electron drift over 2.6 m, ~400 kg of Xe
  - ➡ Electron cloud diffusion
  - ➡ Custom HV
  - ➡ Optical properties of Xe
- **Phase 1: purity monitor** ✔
  - ➡ 53 cm single phase PM
  - ➡ Direct charge readout from electrodes
- **Phase 2: modular TPC** ✔
  - ➡ 2.6 m dual-phase TPC
  - ➡ Proportional scintillation light readout with a SiPM tiled array





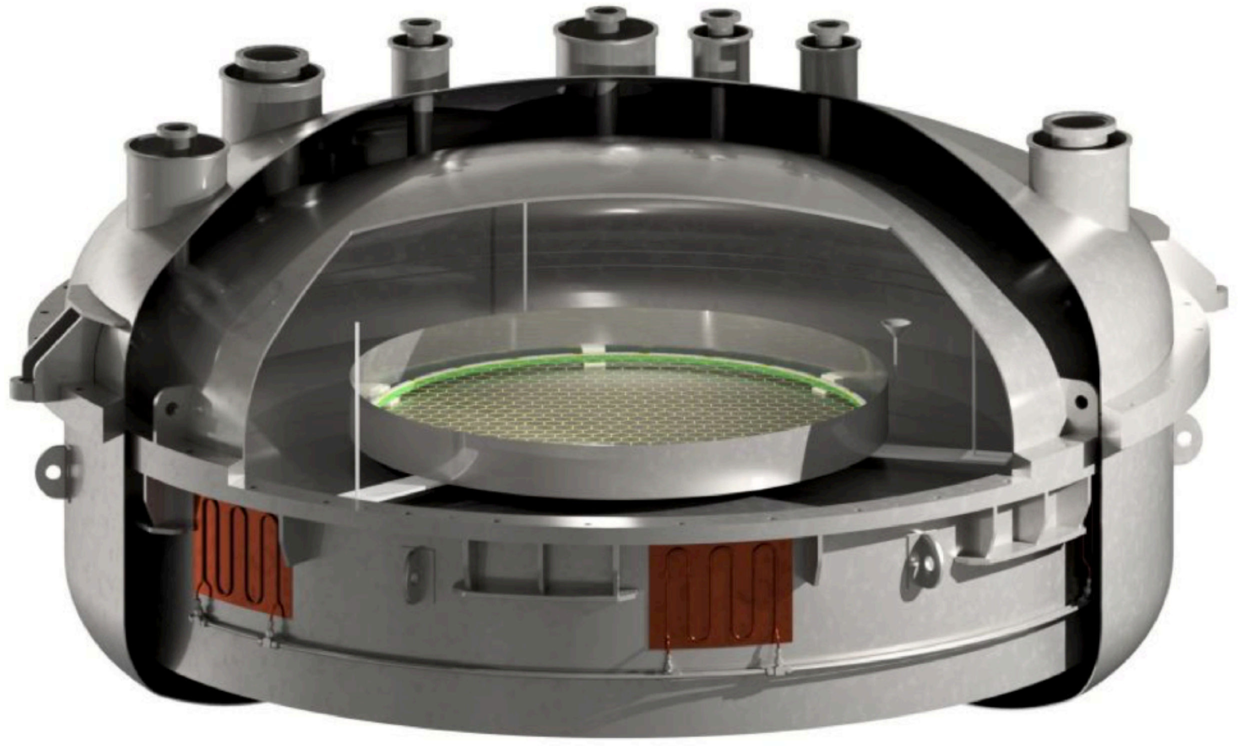




Pancake at Uni Freiburg

Full-scale ⌀ demonstrator

- Test components & concepts:
  - ➡ **Test in**: LXe, cold GXe, under HV
  - ➡ **Probe**: sagging, e⁻ emission, large-scale cooling
- 5 t stainless steel & double-walled cryostat with 380 kg of xenon
- Flat floor design and possibility of using open top vessel

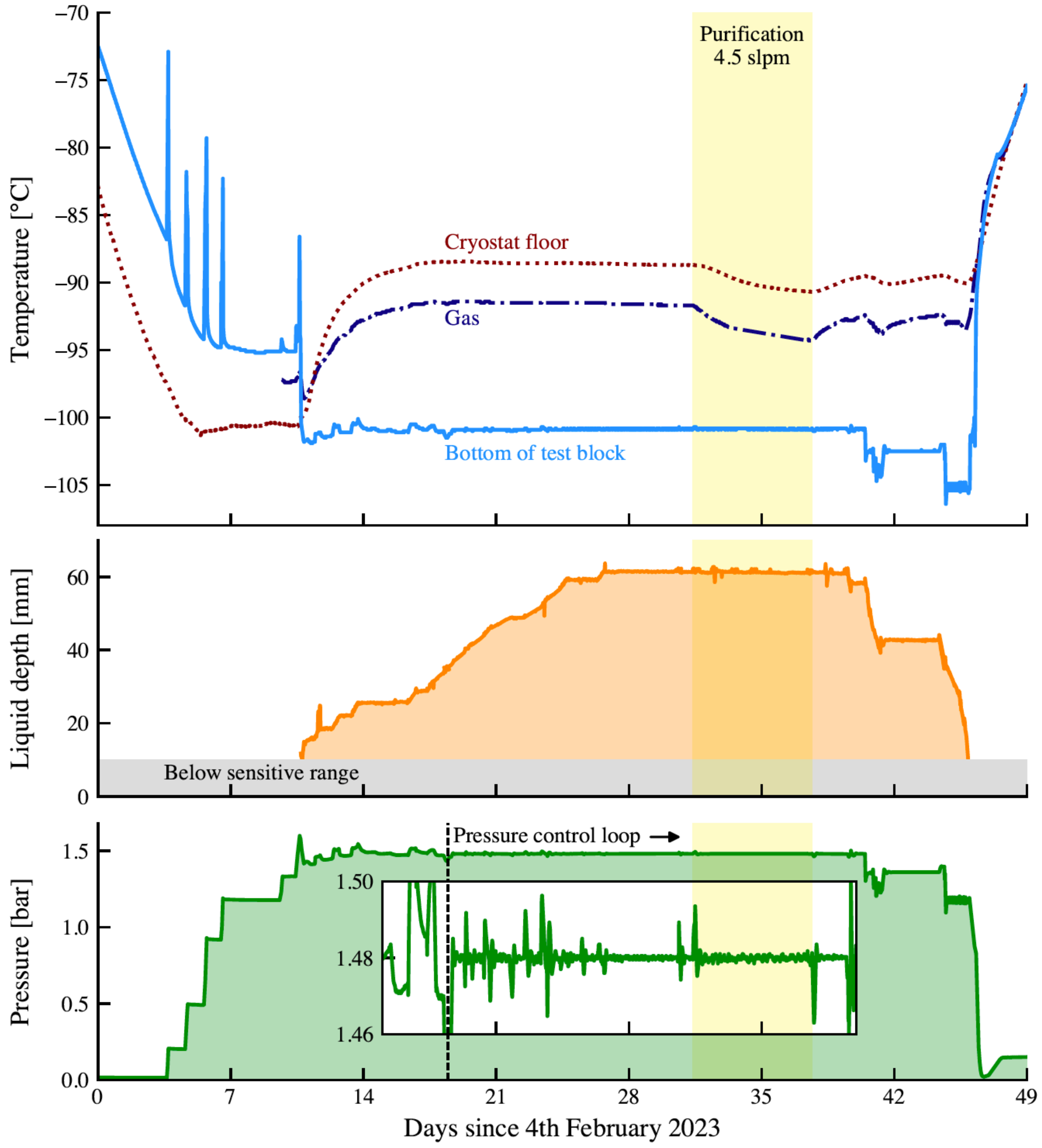


Pancake at Uni Freiburg

JINST 19 (2024) P05018

Full-scale ⌀ demonstrator

- Test components & concepts:
  - ➡ **Test in**: LXe, cold GXe, under HV
  - ➡ **Probe**: sagging, e⁻ emission, large-scale cooling
- 5 t stainless steel & double-walled cryostat with 380 kg of xenon
- Flat floor design and possibility of using open top vessel
- **Successfully commissioned** ✔
- **Instrumented with PMTs & cameras** ✔
- **Next step:** test of electrodes and HV performances

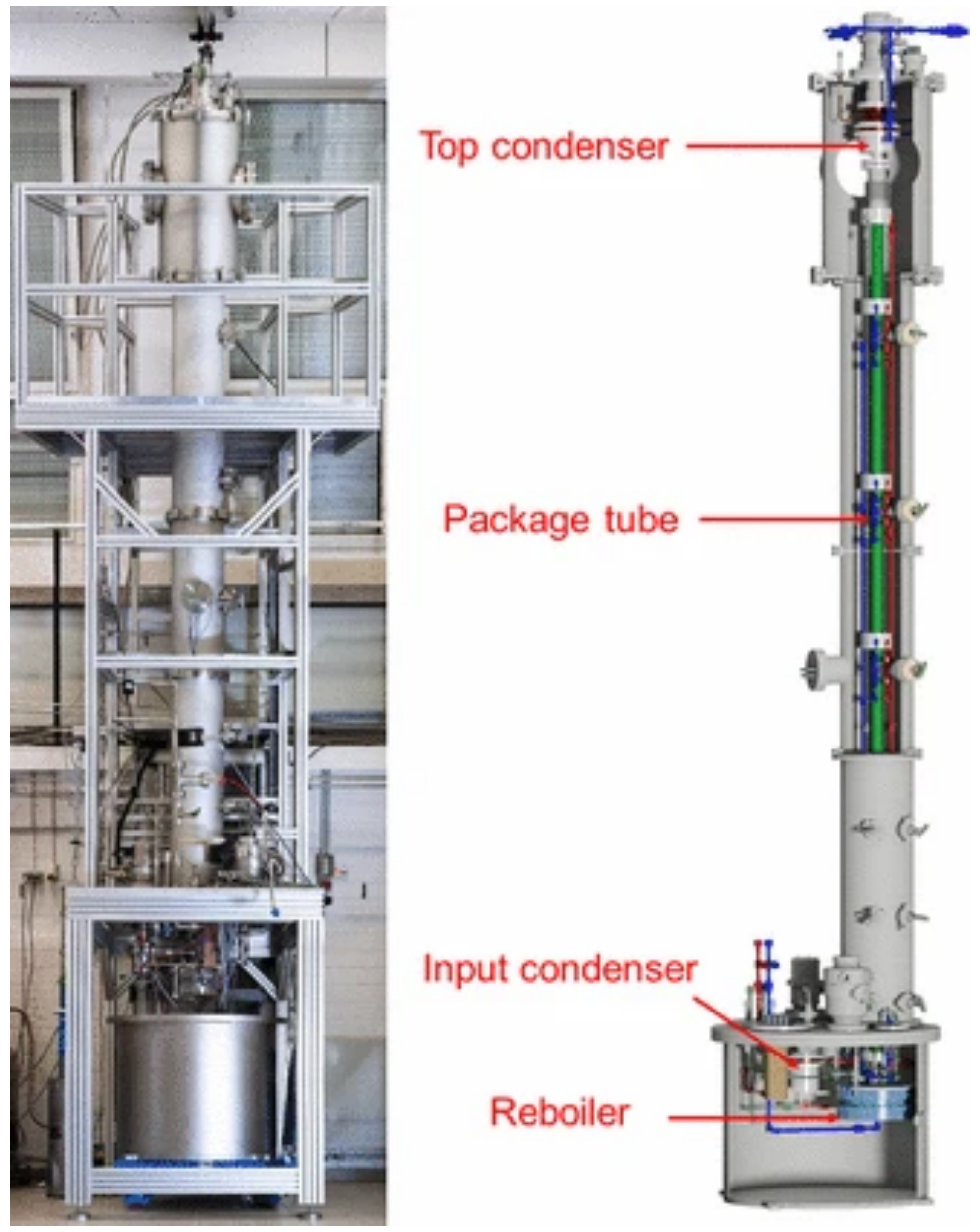


Background mitigation

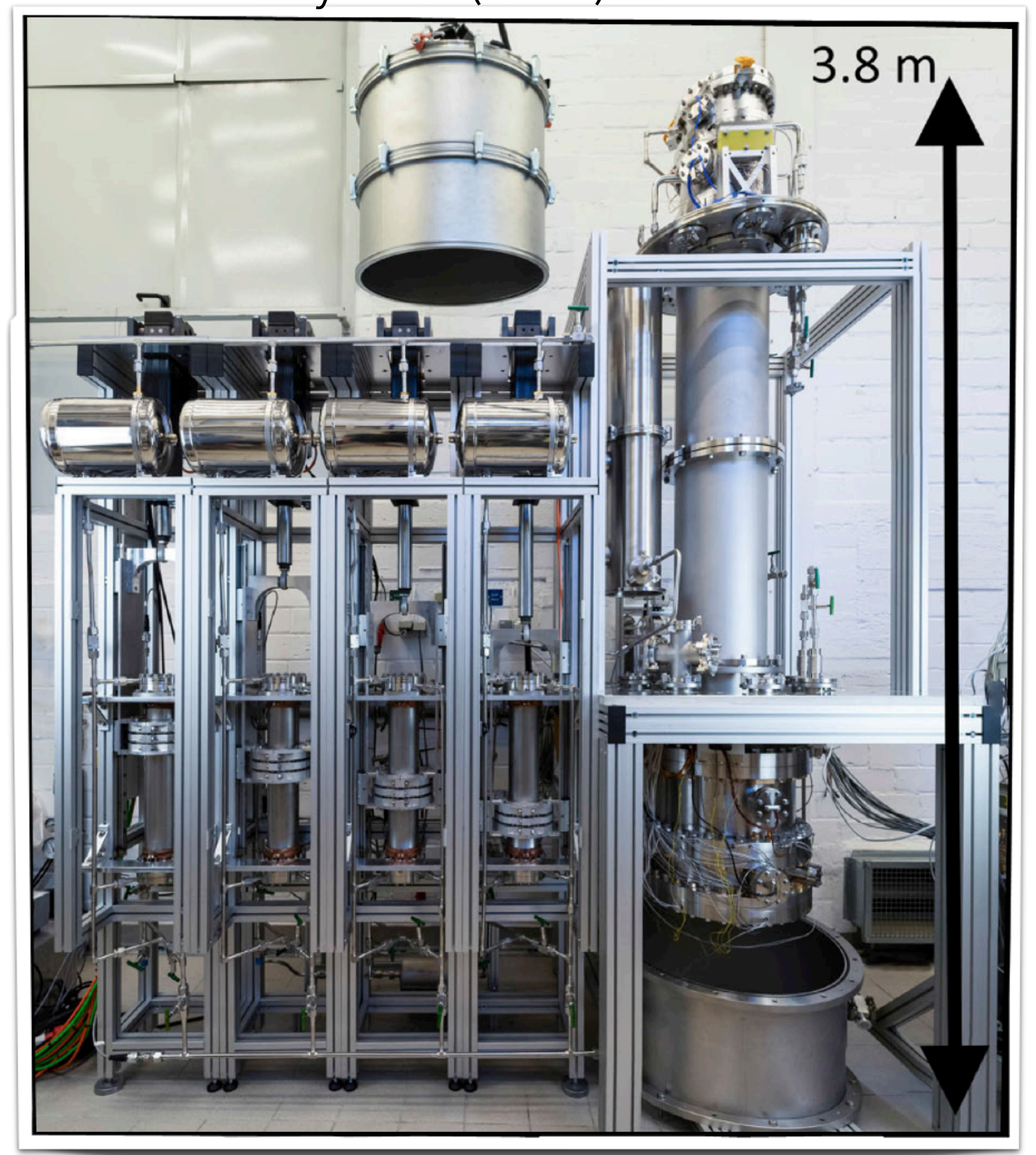
To reach background level ν-dominated

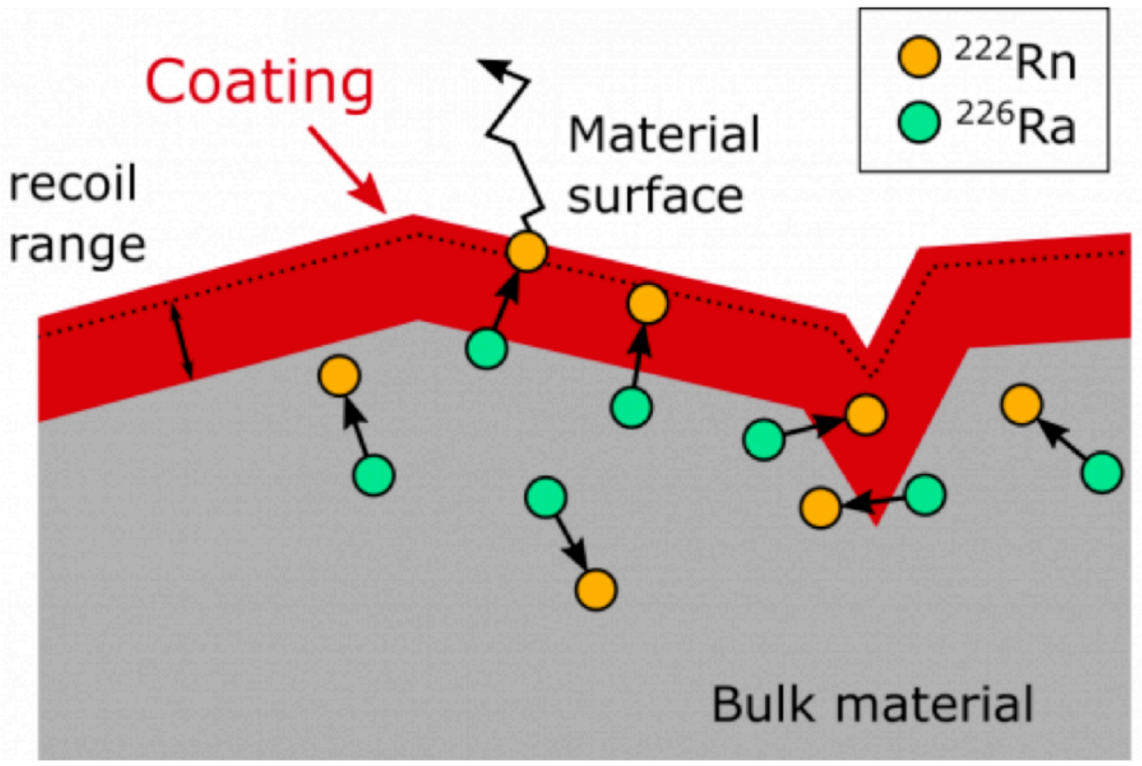
- Selection of radio-pure materials with low Rn-emanation
  - ➡ Material screening
- Reduce Xe target contamination from impurities
  - ➡ Fast LXe recirculation with radon-free filters and pumps
- Removal of intrinsic background sources
  - ➡ ^{85}Kr distillation → goal of 0.1 ppt natKr already achieved < 0.026 ppt
  - ➡ ^{222}Rn distillation → goal of 0.1 µBq/kg (achieved 0.8 µBq/kg) below ER from solar pp neutrinos. ERC LowRad
  - ➡ Coating techniques against radon emanation (electrochemical deposition of Cu)
- Study & Mitigation of accidental coincidences sources
  - ➡ Random pairing of isolated S1 and S2 signals

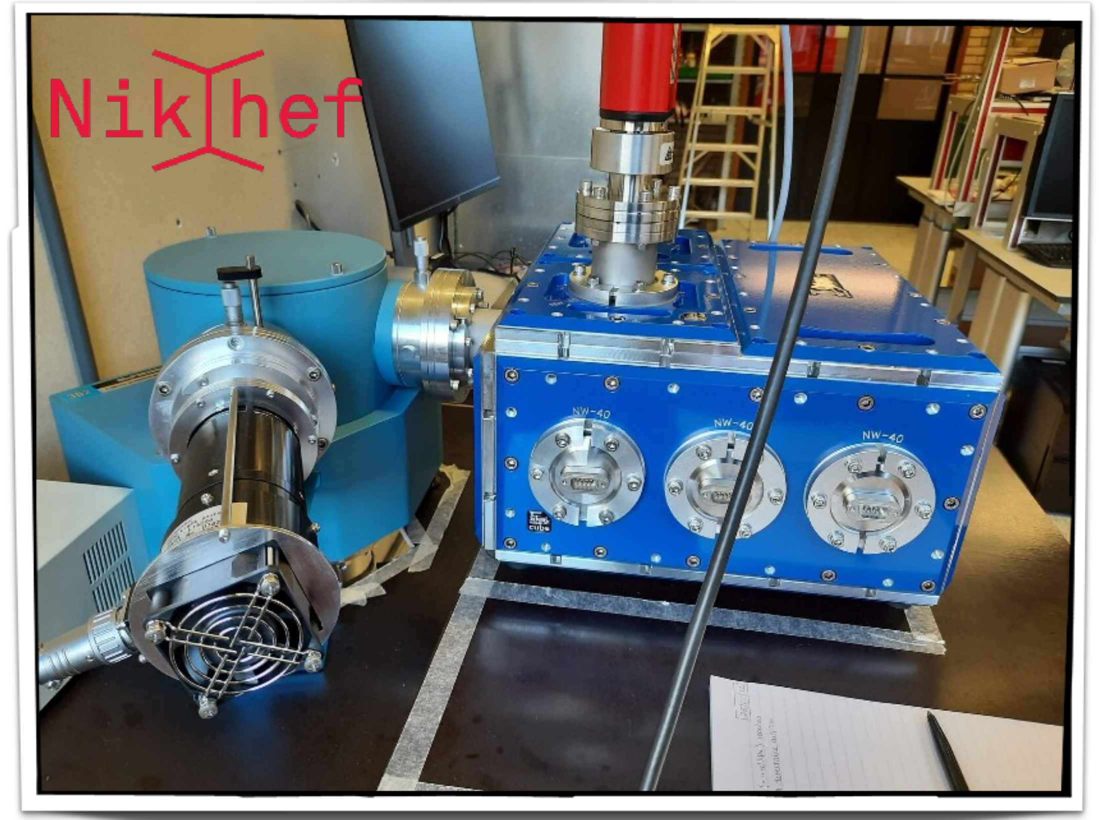
Eur. Phys. J. C (2017) 77:275



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







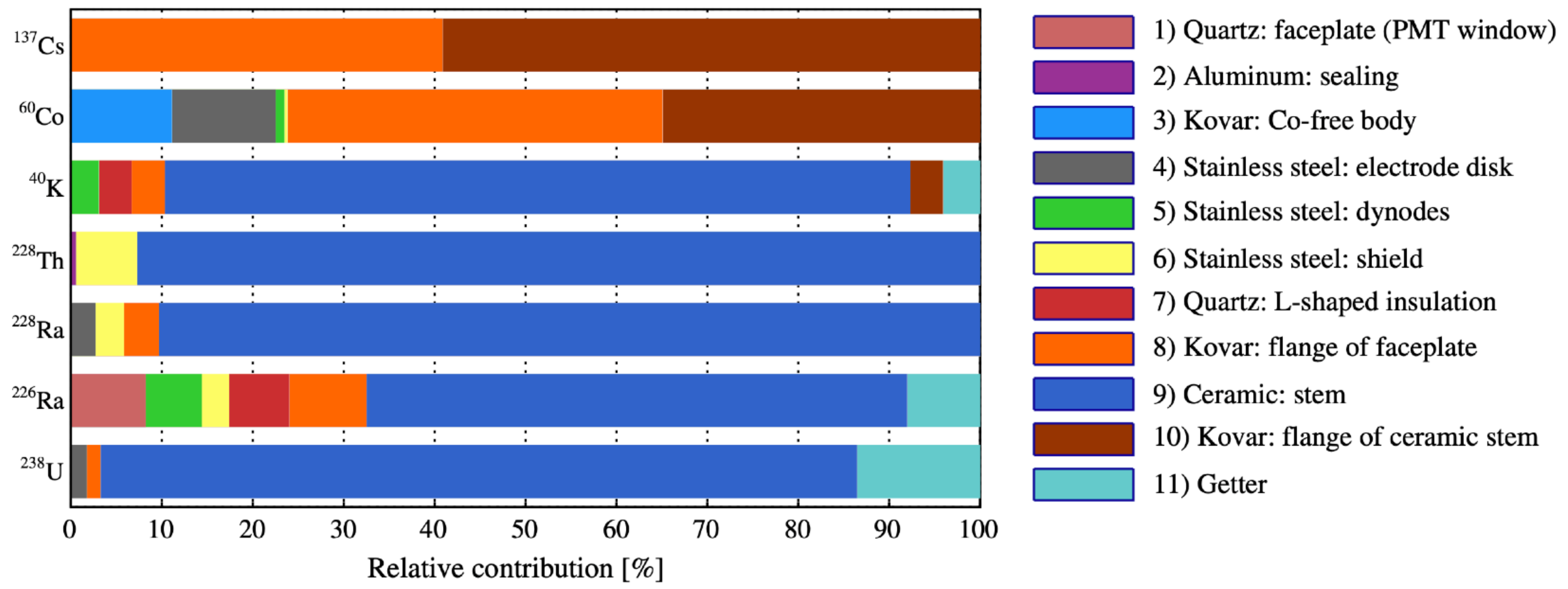
VULCAN setup: Measure optical properties of materials (Fluorescence, Cherenkov emission,…)

Photosensors

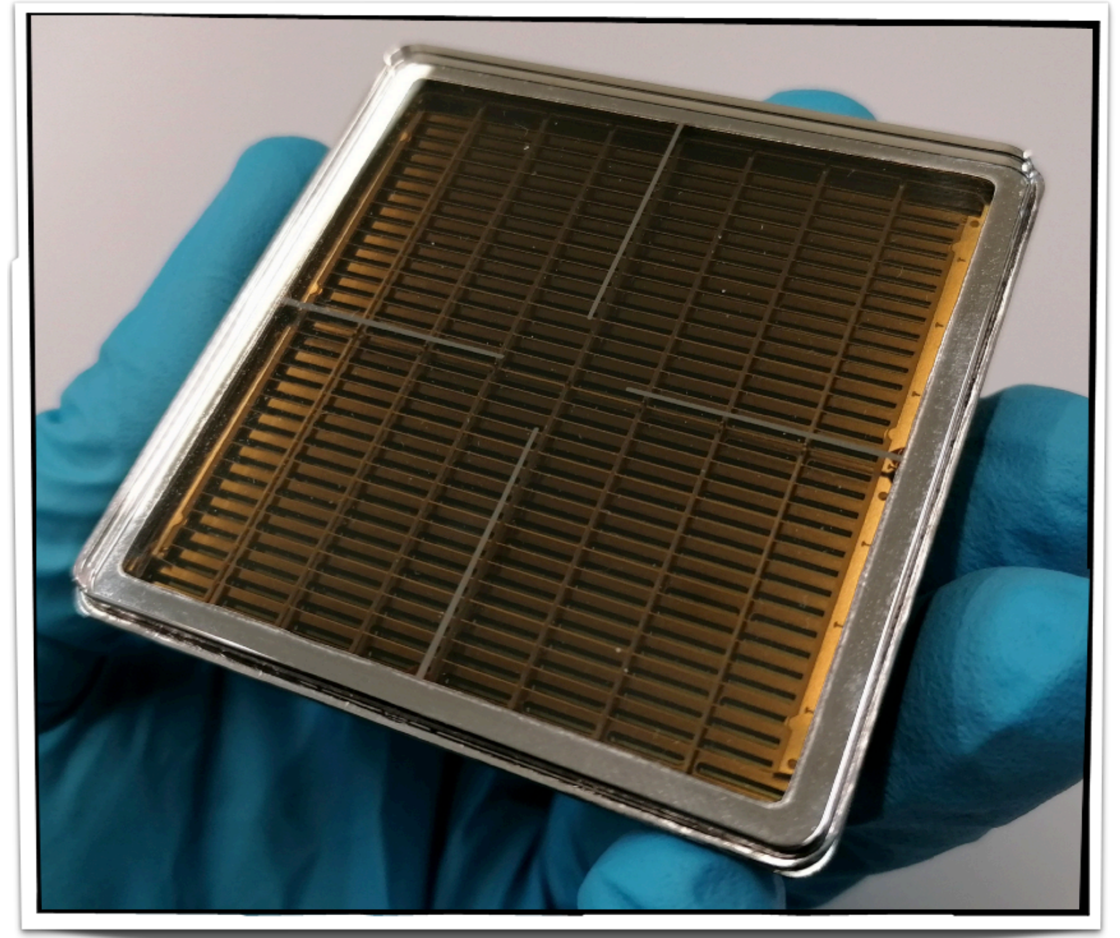
Eur. Phys. J. C (2015) **75**: 546

Nominal design with PMTs

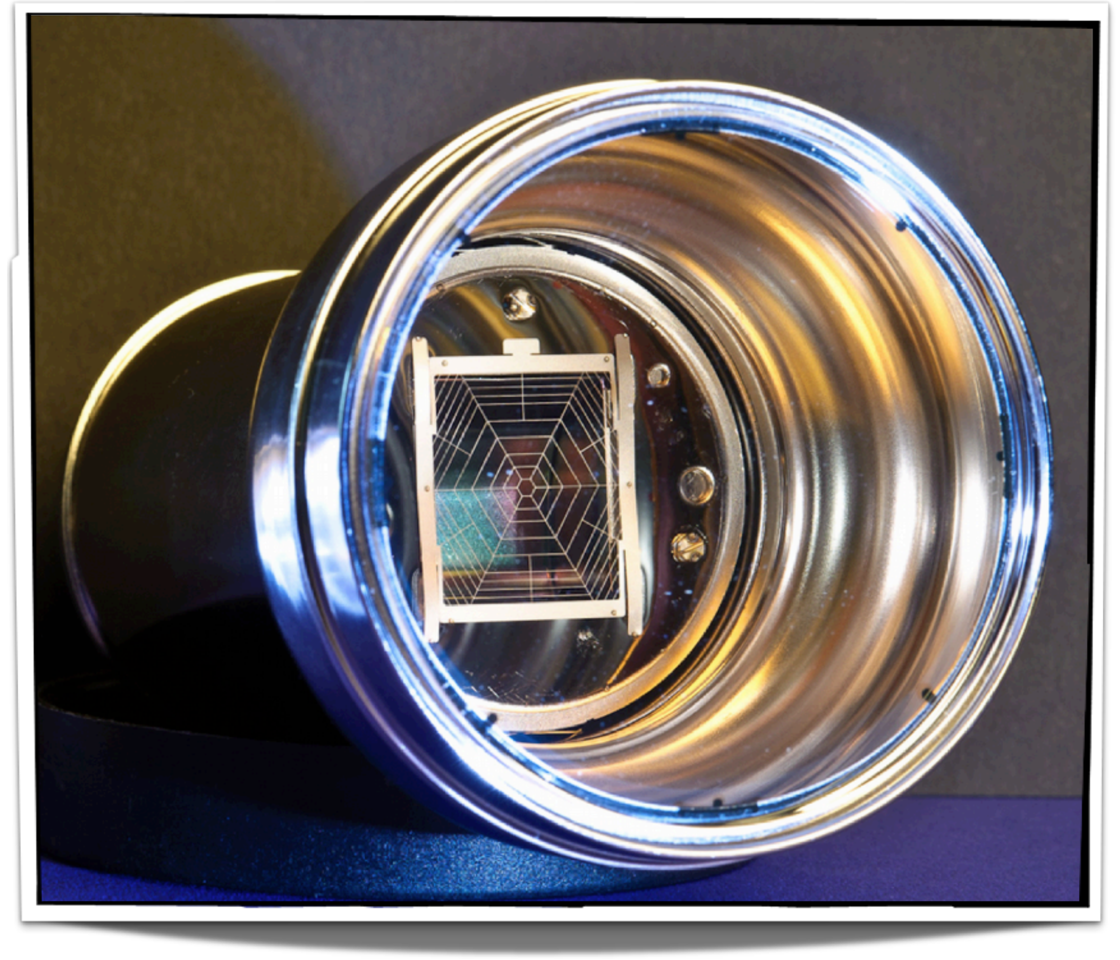
- Established technology, low dark count rate (~0.02 Hz/mm^2), high QE (30-40%)
- Radiopurity improvement on 3″ PMTs, but still contribute via several decay chains.
- Testing of Square 2″ PMT, lower buoyancy and sub-ns rise time
- Characterisation of SPE response, dark counts, light emission, after pulsing
- R&D & Study of other photosensors

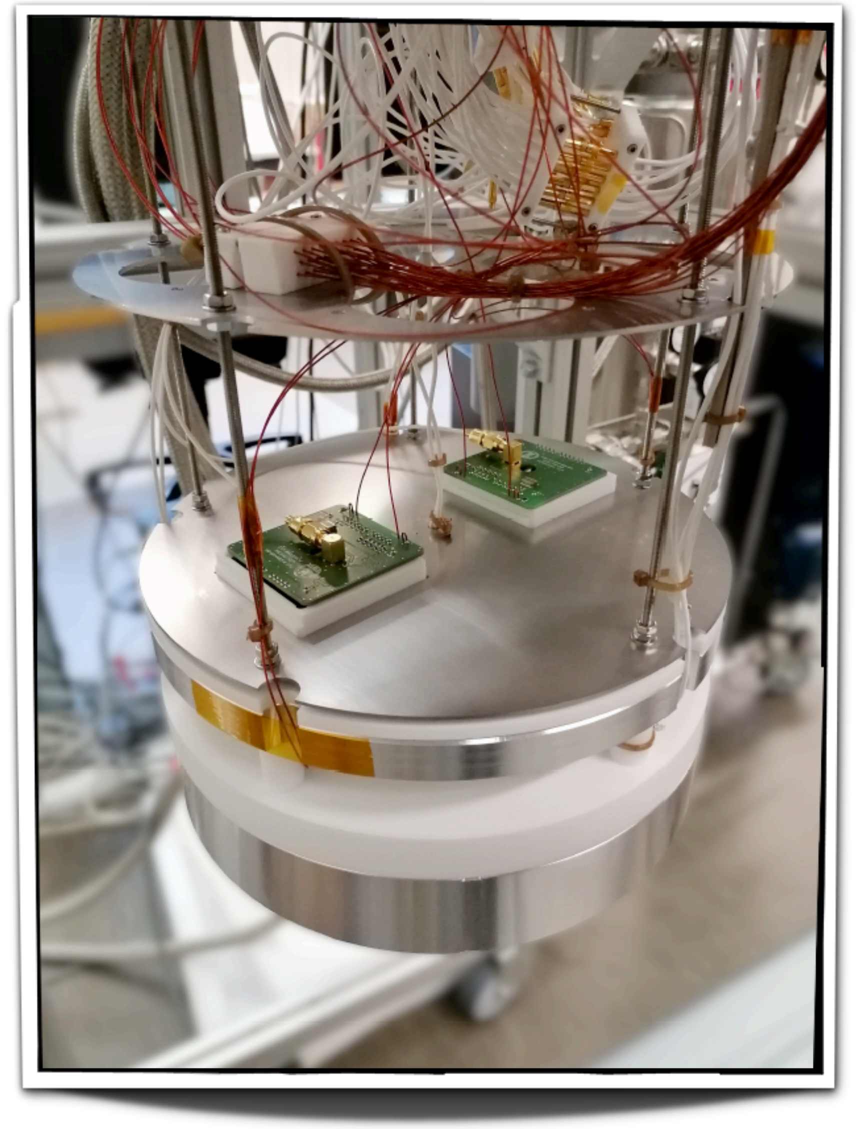


Hamamatsu R12699-406-M4



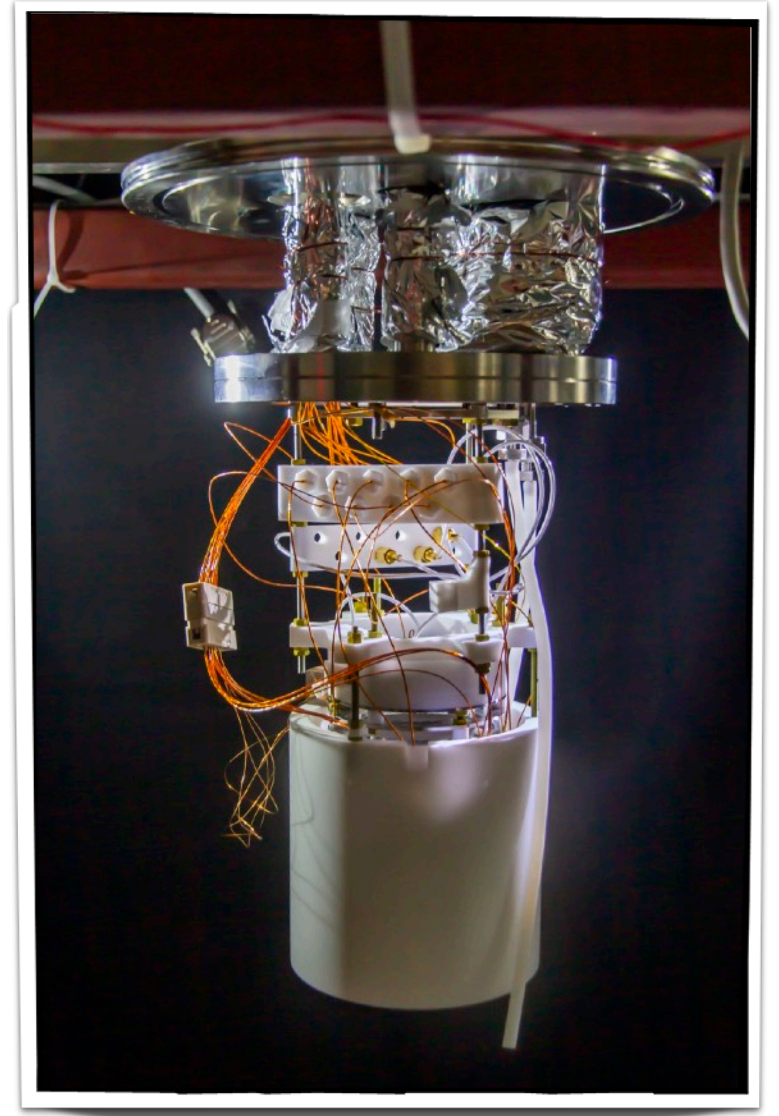
Hamamatsu R111410-21





MarmotX

Universität Zürich^{UZH}



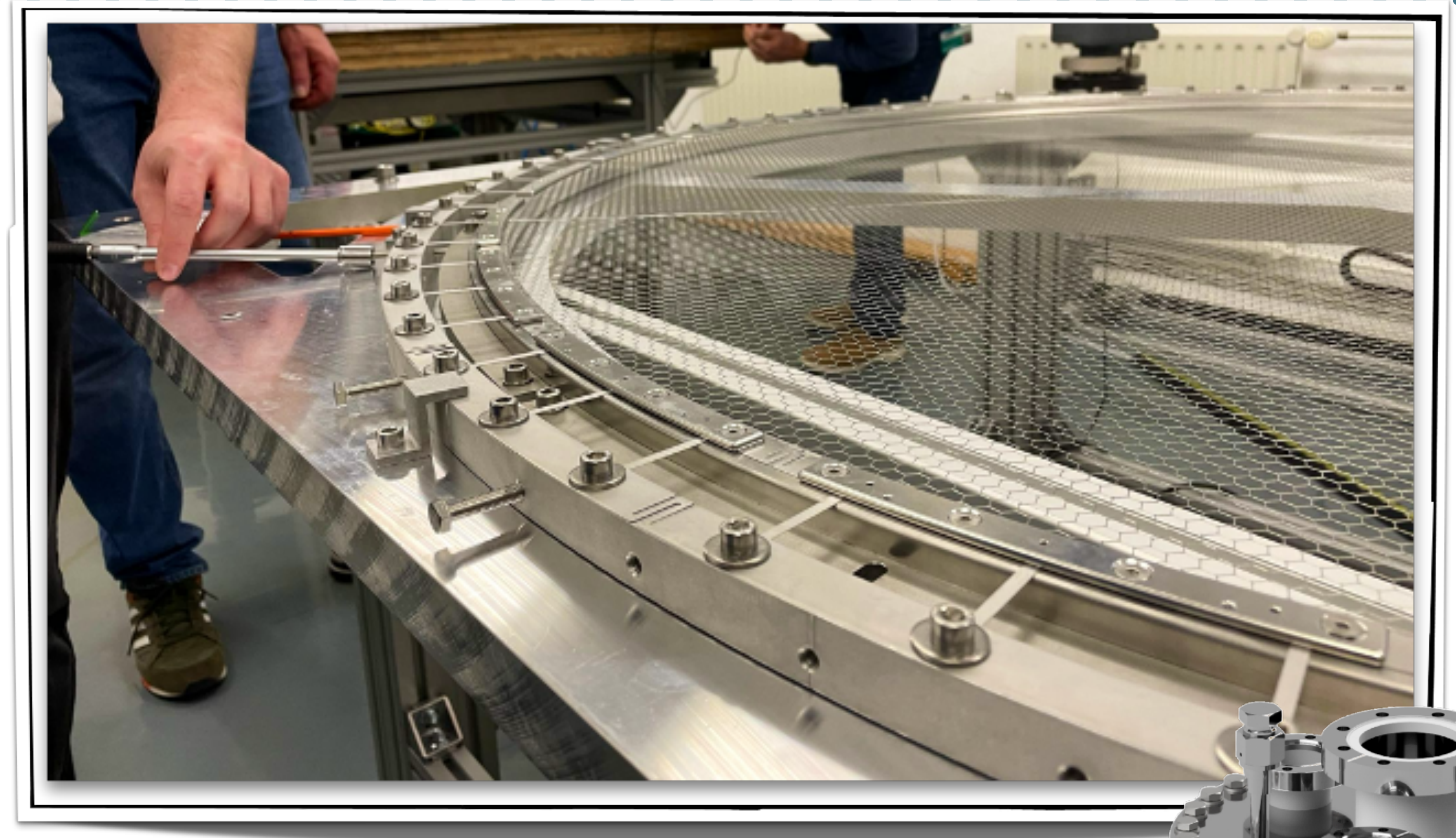
XAMS

Nikhef

Electrodes & HV Supply

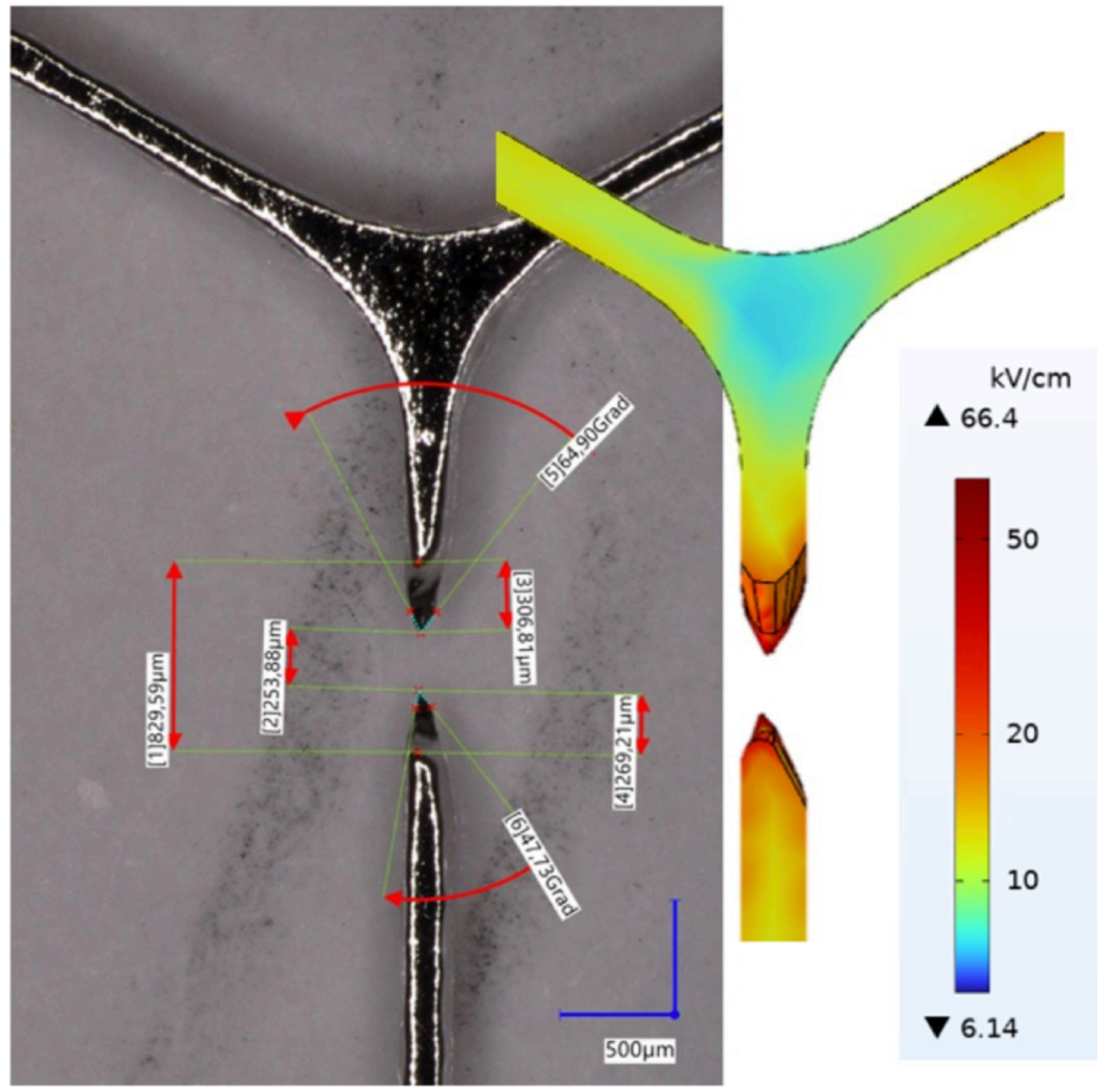
Efficiency and Robustness

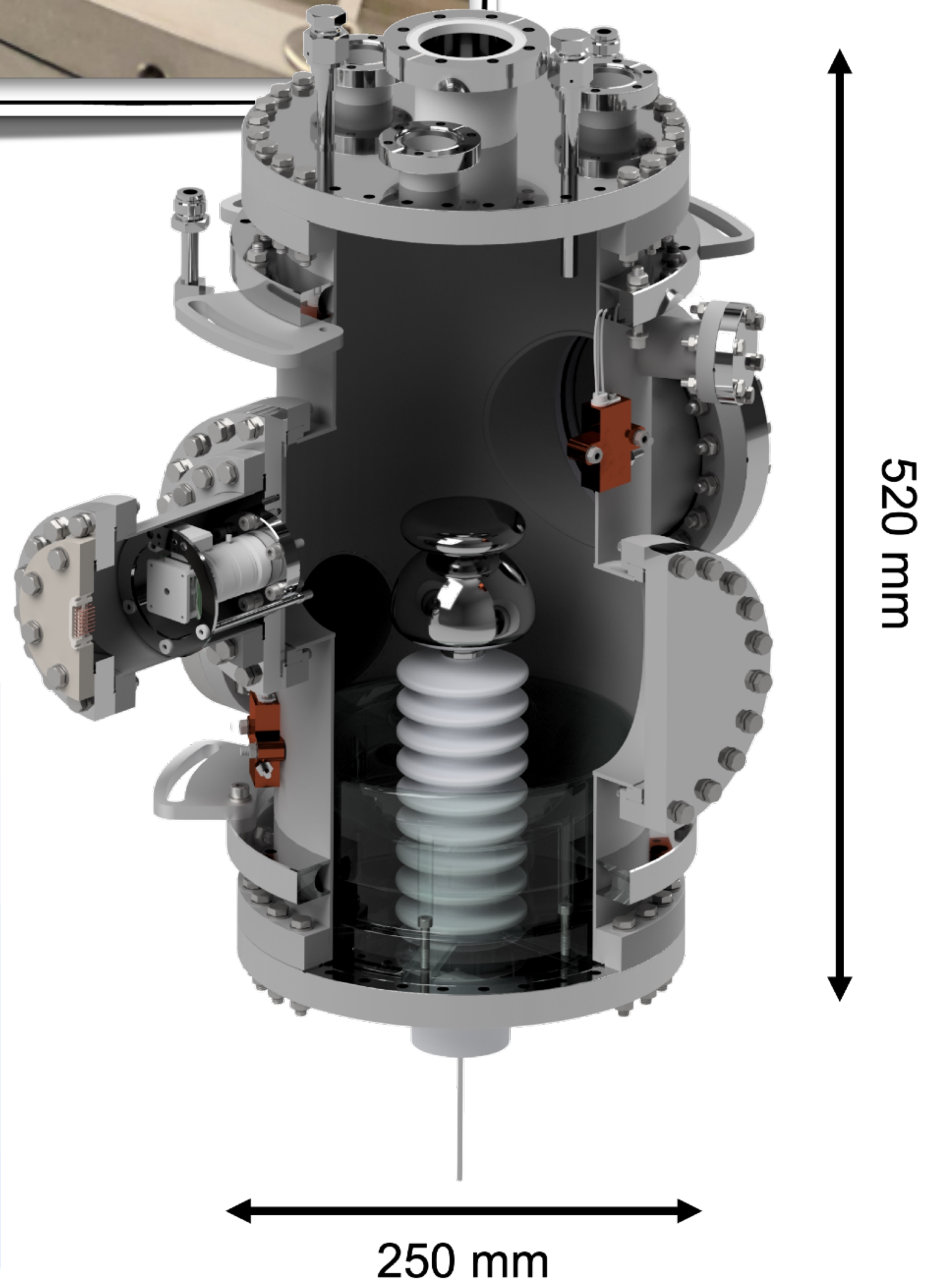
- Electrical Field, optical & Mechanical simulations
  - ➡ Effects of electrode geometries on light collection efficiency
  - ➡ Mechanical design & stability; 2D/3D simulation studies



- Identification & Treatment of Features
  - ➡ Investigate stretching, sagging and flatness of meshes
  - ➡ Automatic feature detection with ML and repair with laser welding
  - ➡ Electrode surface treatment and coating

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





Summary

DARWIN - R&D efforts towards the ultimate LXe astroparticle observatory (XLZD)

- Several large-scale demonstrators, as well as R&D setups to tackle the technical challenges:
  - ➡ Electric fields
  - ➡ Xenon purity
  - ➡ Photosensors
  - ➡ Background mitigation

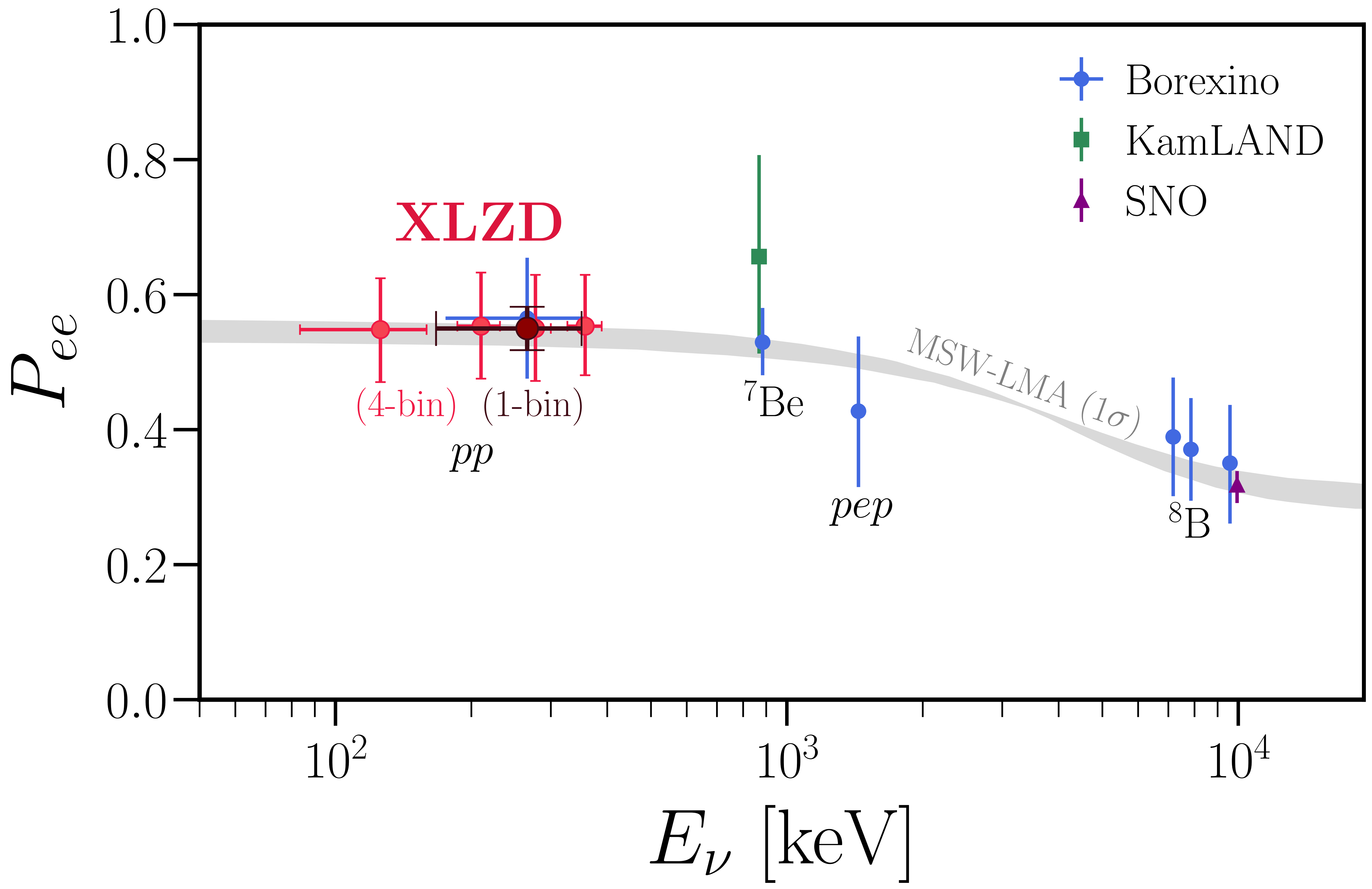
XLZD (XENON-LZ-DARWIN): new international collaboration

- Aim to build & operate ≥ 60t LXe TPC
- Explore WIMP parameter space down to the "neutrino fog"
- Broad physics program with solar & Sn neutrinos, $0\nu\beta\beta$-decay and other Double-Weak decay processes, and more…

Back-up

Solar pp-neutrino

- Precise measurements of electronic solar neutrino survival probability and electroweak mixing angle using pp neutrino



$0\nu\beta\beta$ of ^{136}Xe Projection Sensitivity

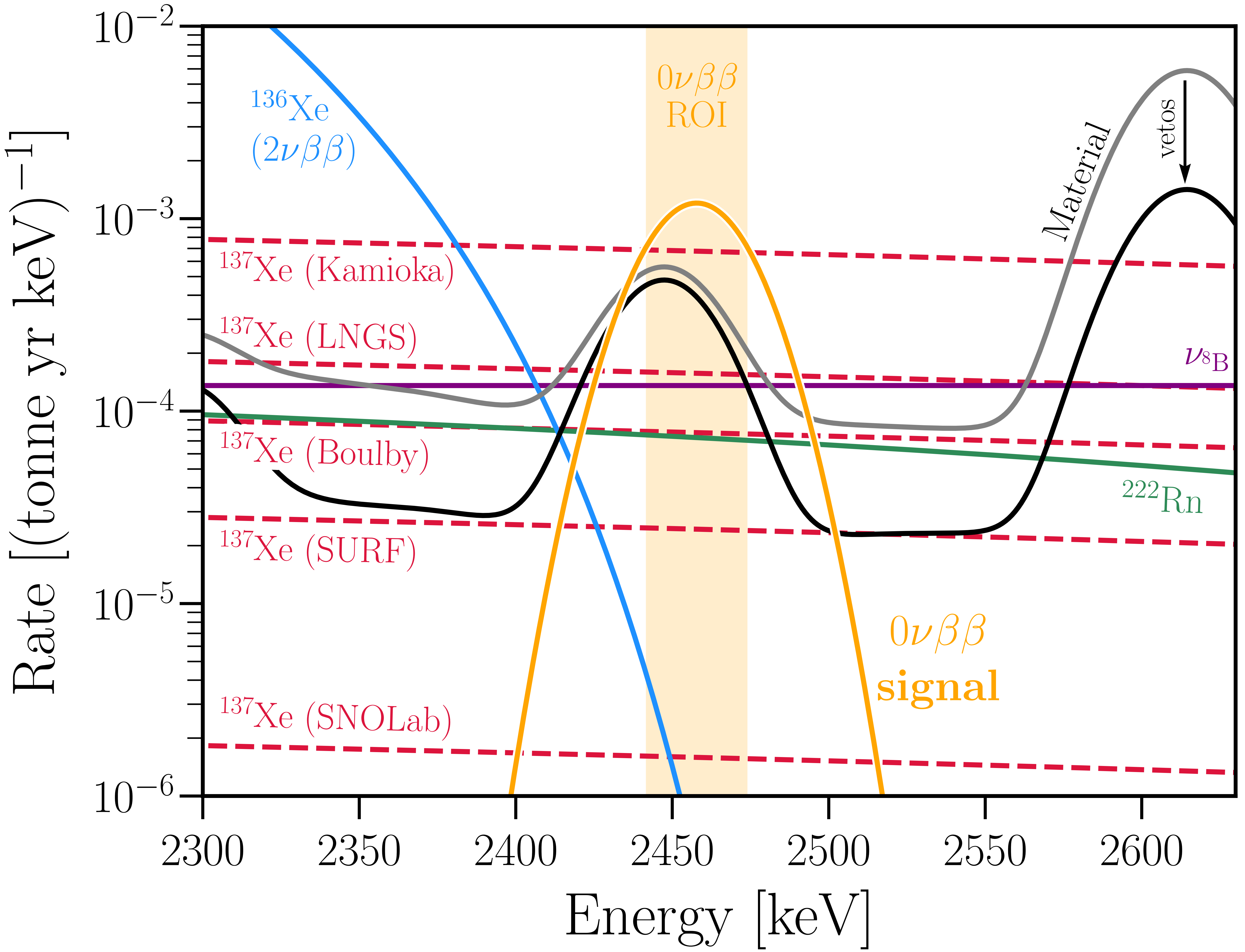
Background consideration for different scenarios

- External bkg from screening → Nominal
- x1/3 reduction factor → Optimistic

- ^{137}Xe production at LNGS → Nominal
- ^{137}Xe production at SURF → Optimistic

- BiPo Tagging efficiency 99.95% → Nominal
- BiPo Tagging efficiency 99.99% → Optimistic

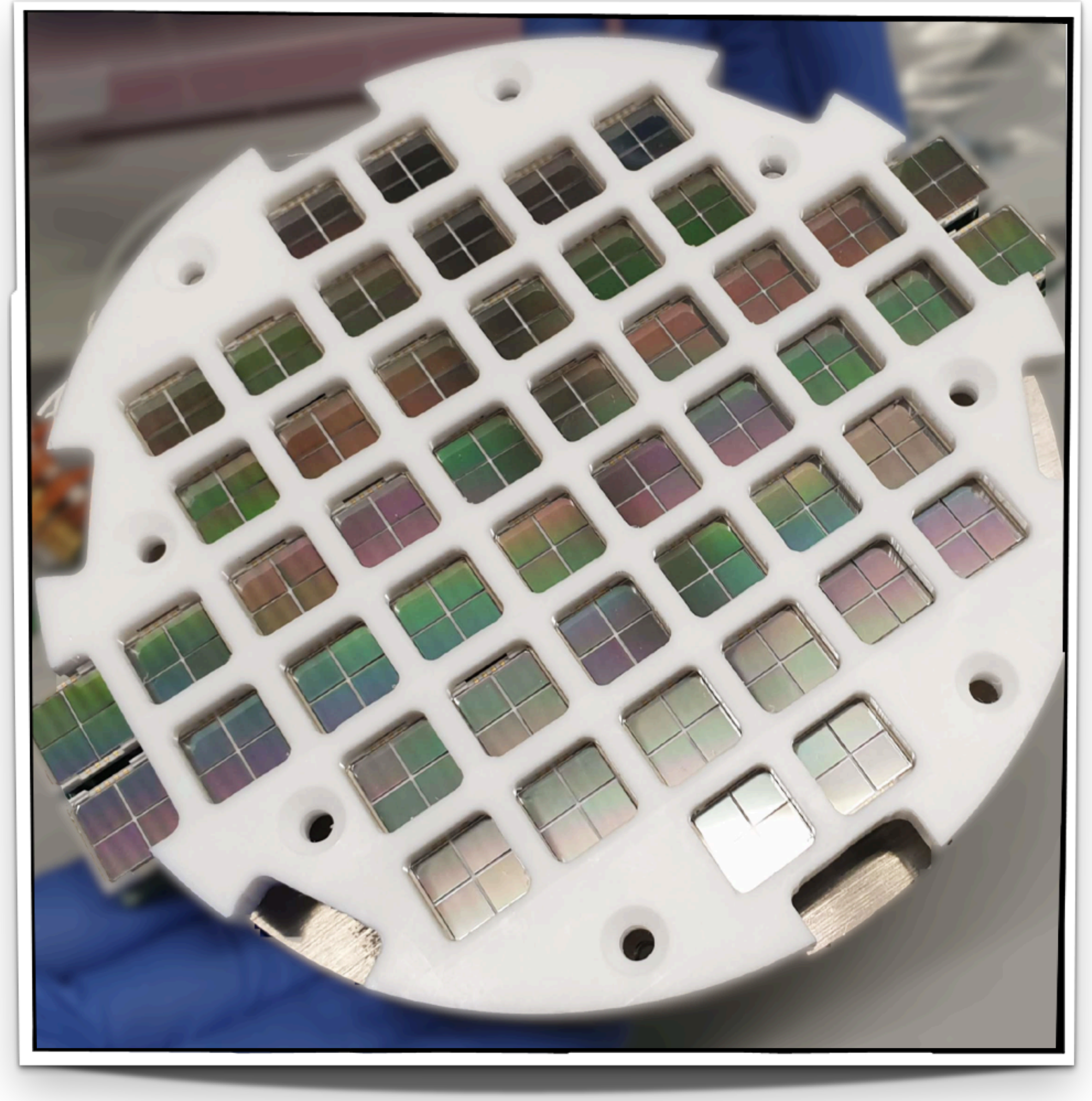
- Energy Resolution @ $Q_{\beta\beta}$: 0.65% → Nominal
- Energy Resolution @ $Q_{\beta\beta}$: 0.60% → Optimistic

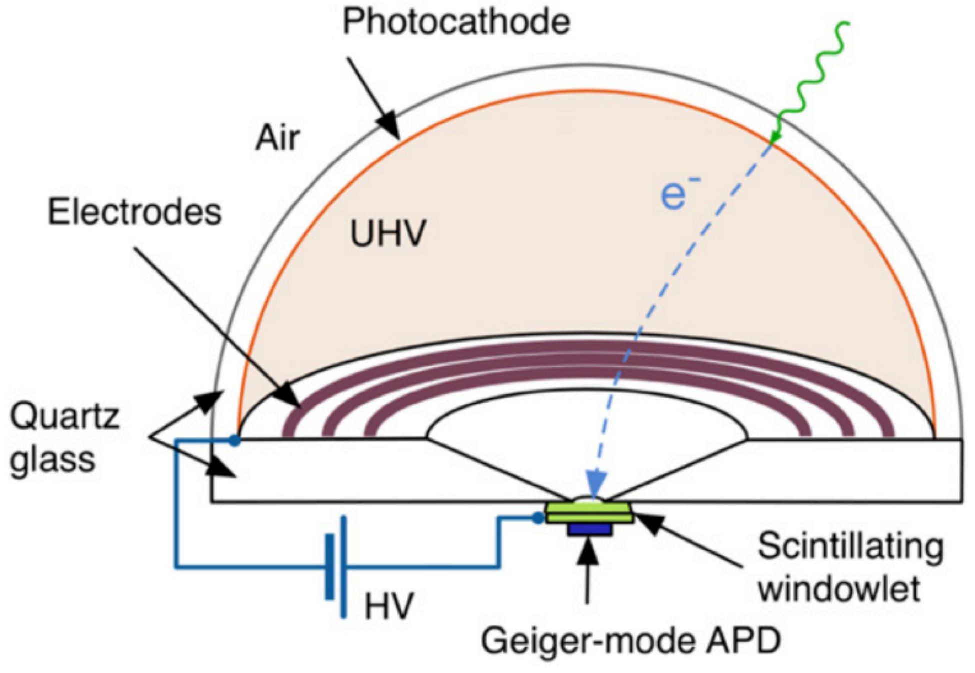


Other Photosensors

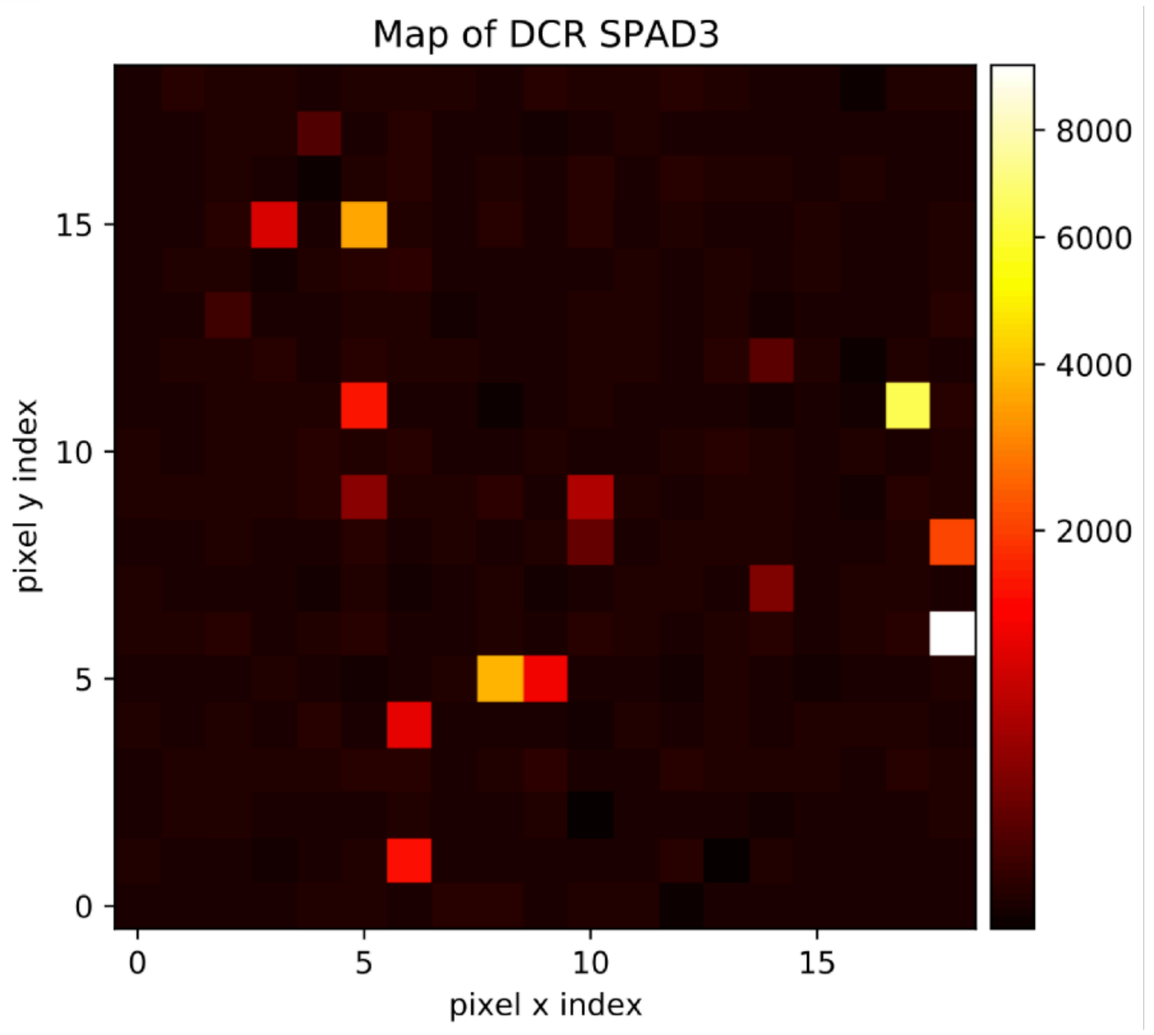
- 12x12 mm² MPPC of VUV4 SiPMs
  - ➡ Low radioactivity
  - ➡ Cheaper
  - ➡ Higher buoyancy
  - ➡ Higher dark count rate
- Digital SiPMs
  - ➡ Can turn off single pixels
  - ➡ Output already digitised
- LDC VUV SiPMs
- Hybrid sensors (Abalone,…)

48 12x12 mm² VUV4 MMPCs @ UZH





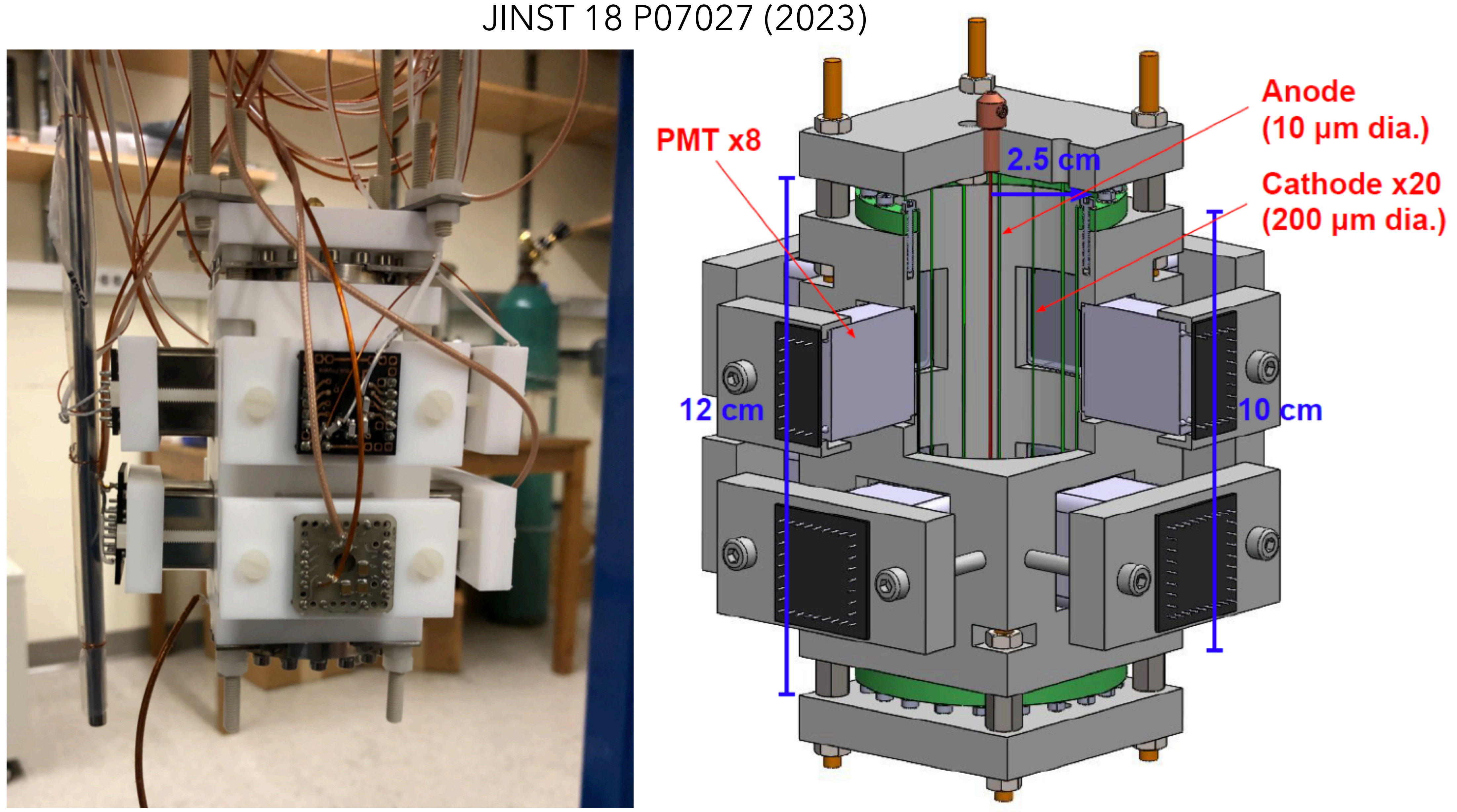
JINST 17 C01038 (2022)

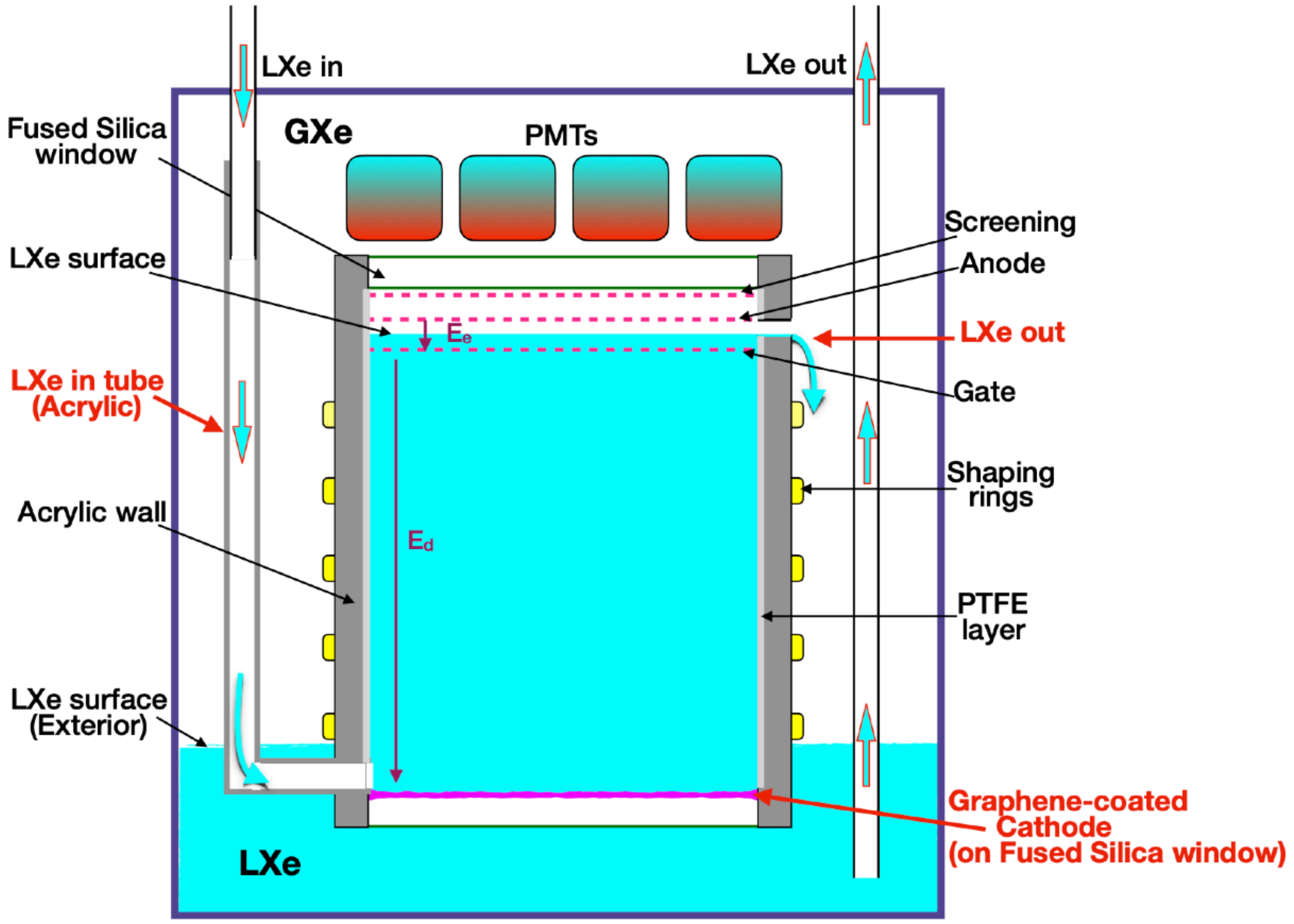


Alternative designs

- Single phase TPC
  - ➡ Simplified TPC design, no liquid level control required
  - ➡ Reduce single electron emissions
- Hermetic TPC
  - ➡ Prevent radon impurity diffusion into inner volume
- 4π coverage with photosensors

JINST 18 P07027 (2023)





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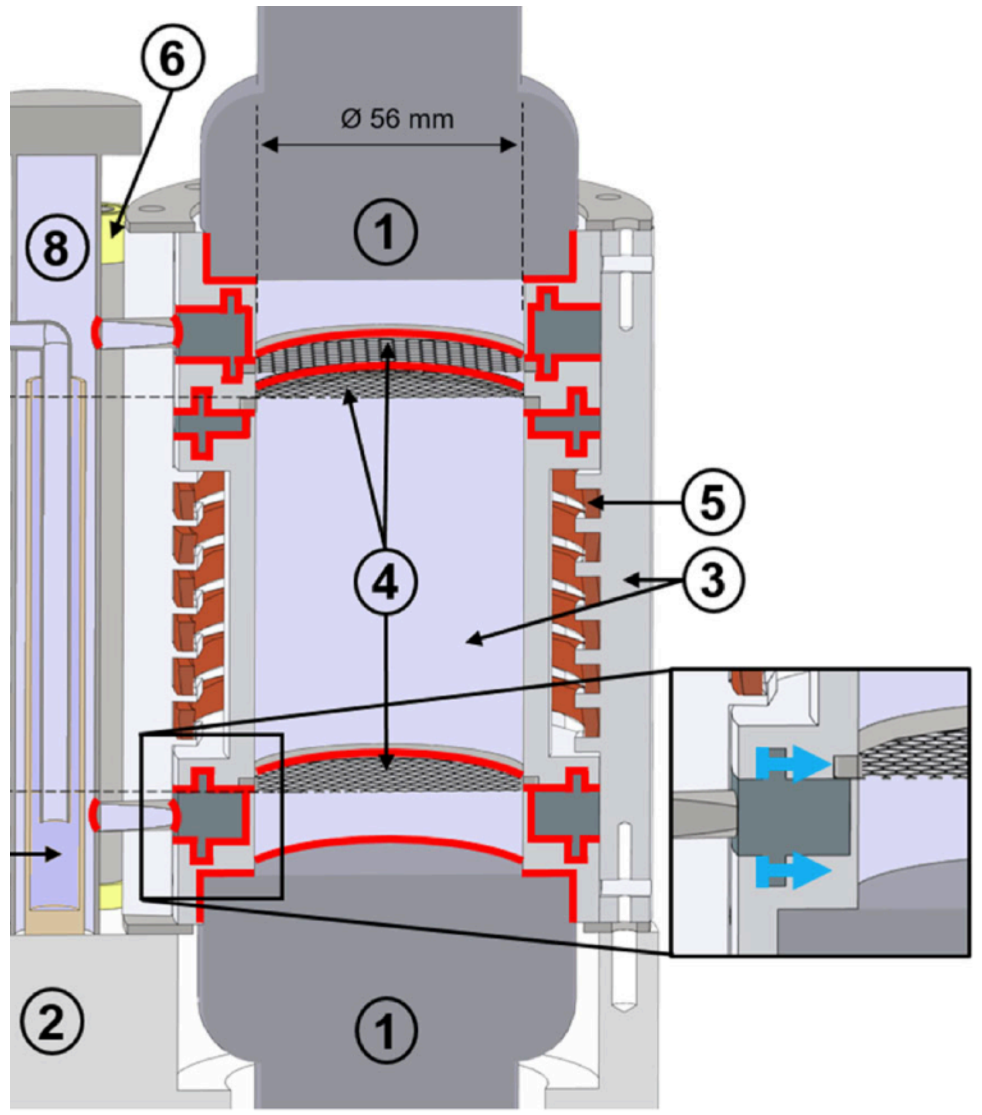

Eur. Phys. J. C (2023) 83:9