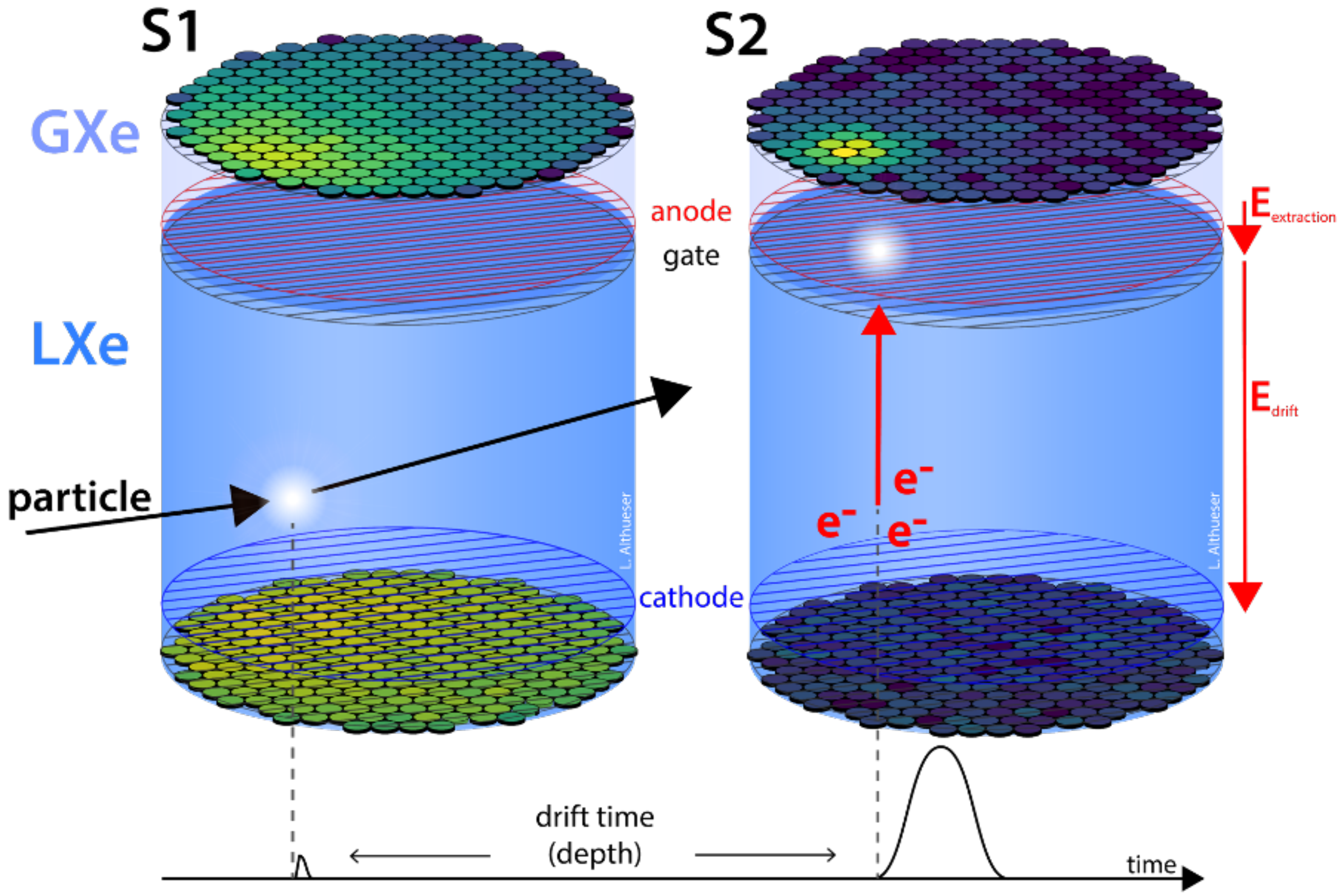
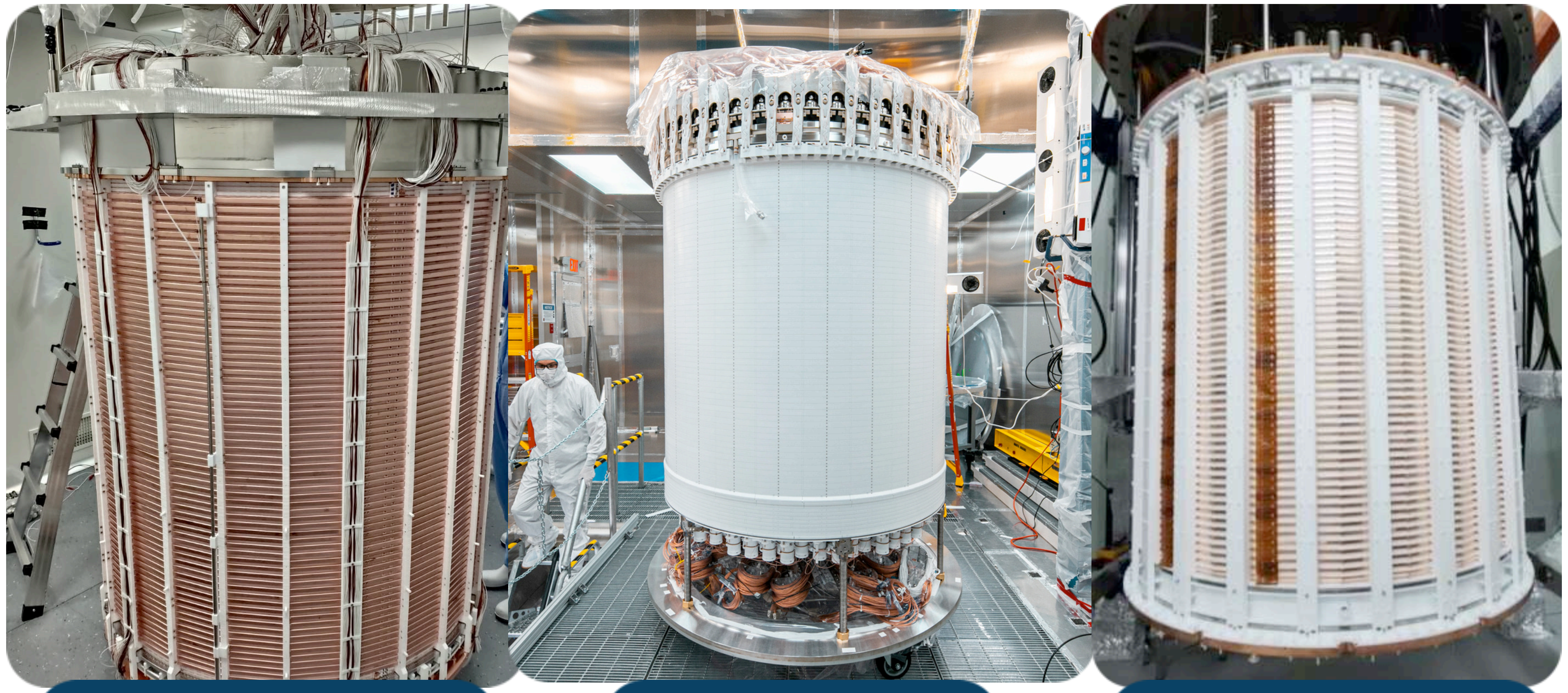
The XLZD liquid-xenon Observatory and the DARWIN R&D programme

Yanina Biondi, PASCOS in Durham, 24 July 2025

KIT

Dark matter searches with Liquid Xenon TPCs





XENONnT
5.9 t @ LNGS

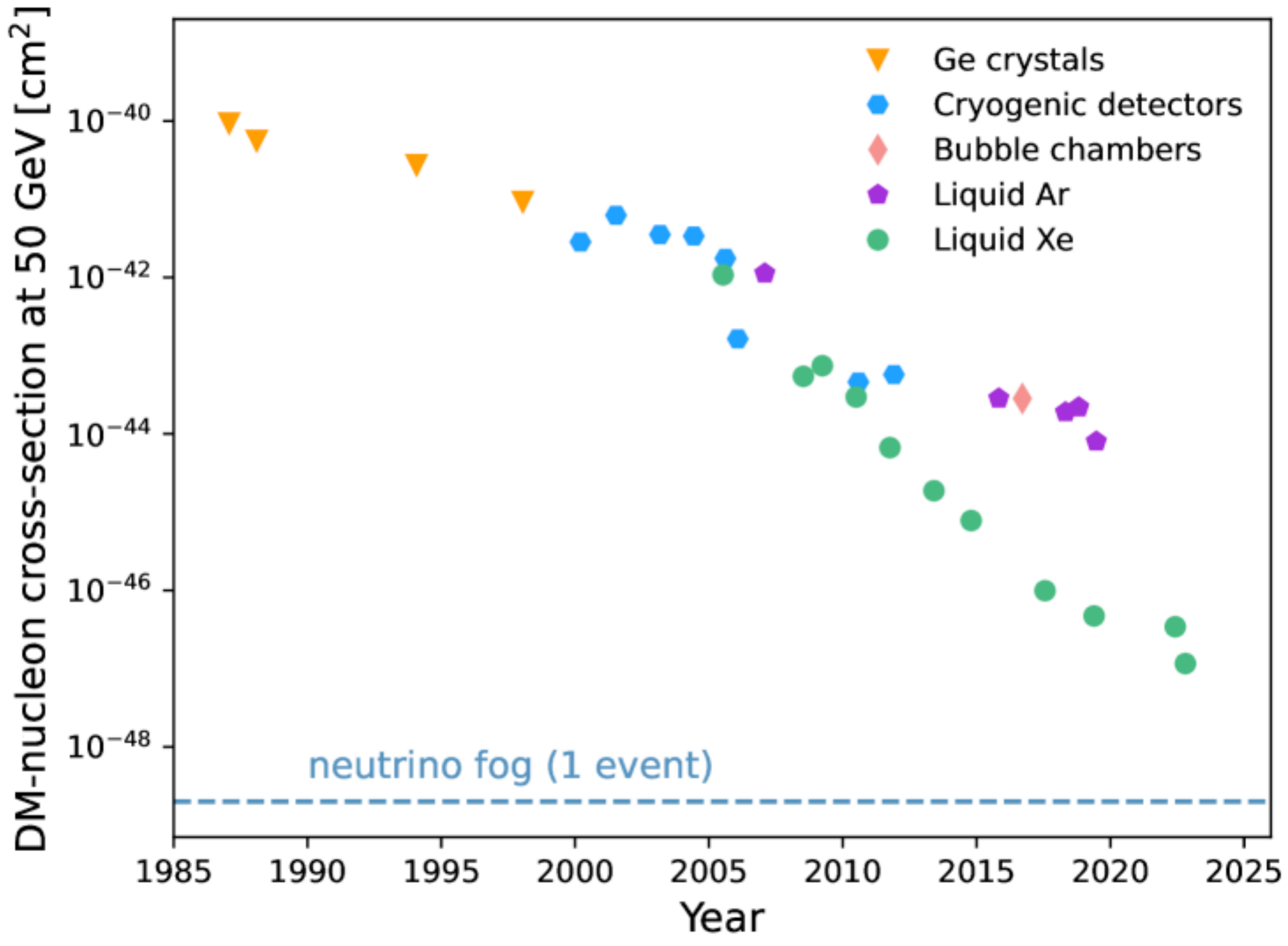
LZ
7 t @ SURF

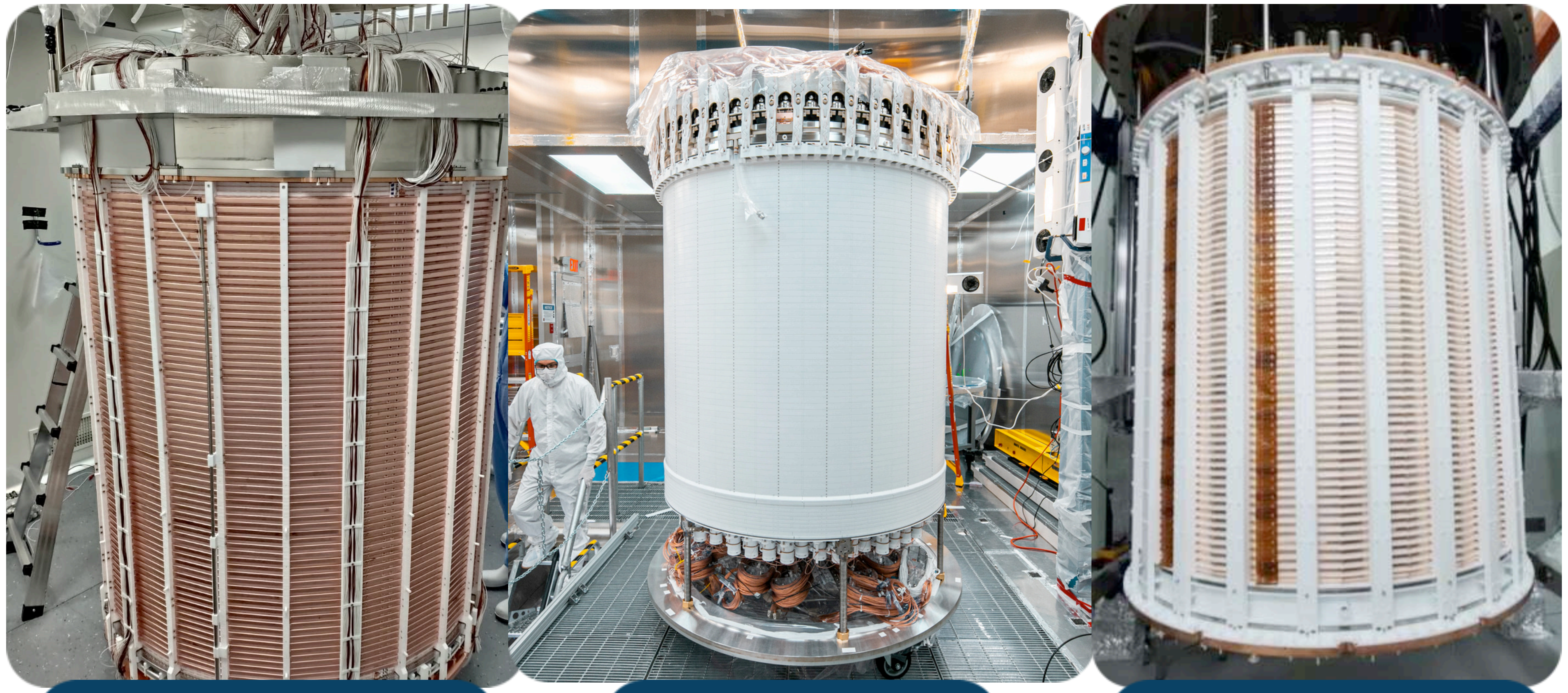
PandaX-4T
3.7 t @ JinPing

Most science data acquisition schedule to finished ~2027-2028… what then?

Dark matter searches with Liquid Xenon TPCs

WIMP: 50 GeV *Nucl.Phys.B* **1003 (2024) 116473**





XENONnT	LZ	PandaX-4T
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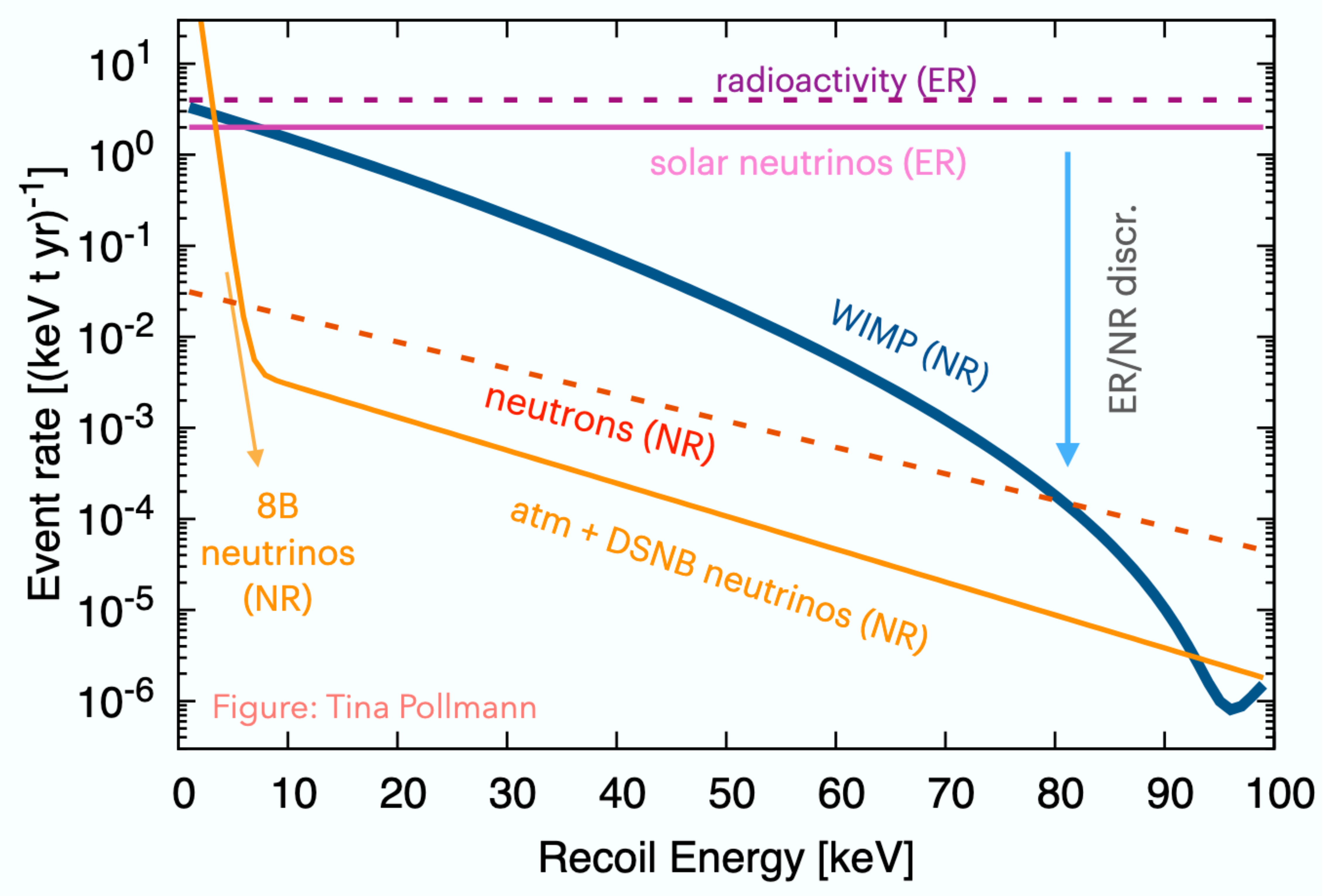
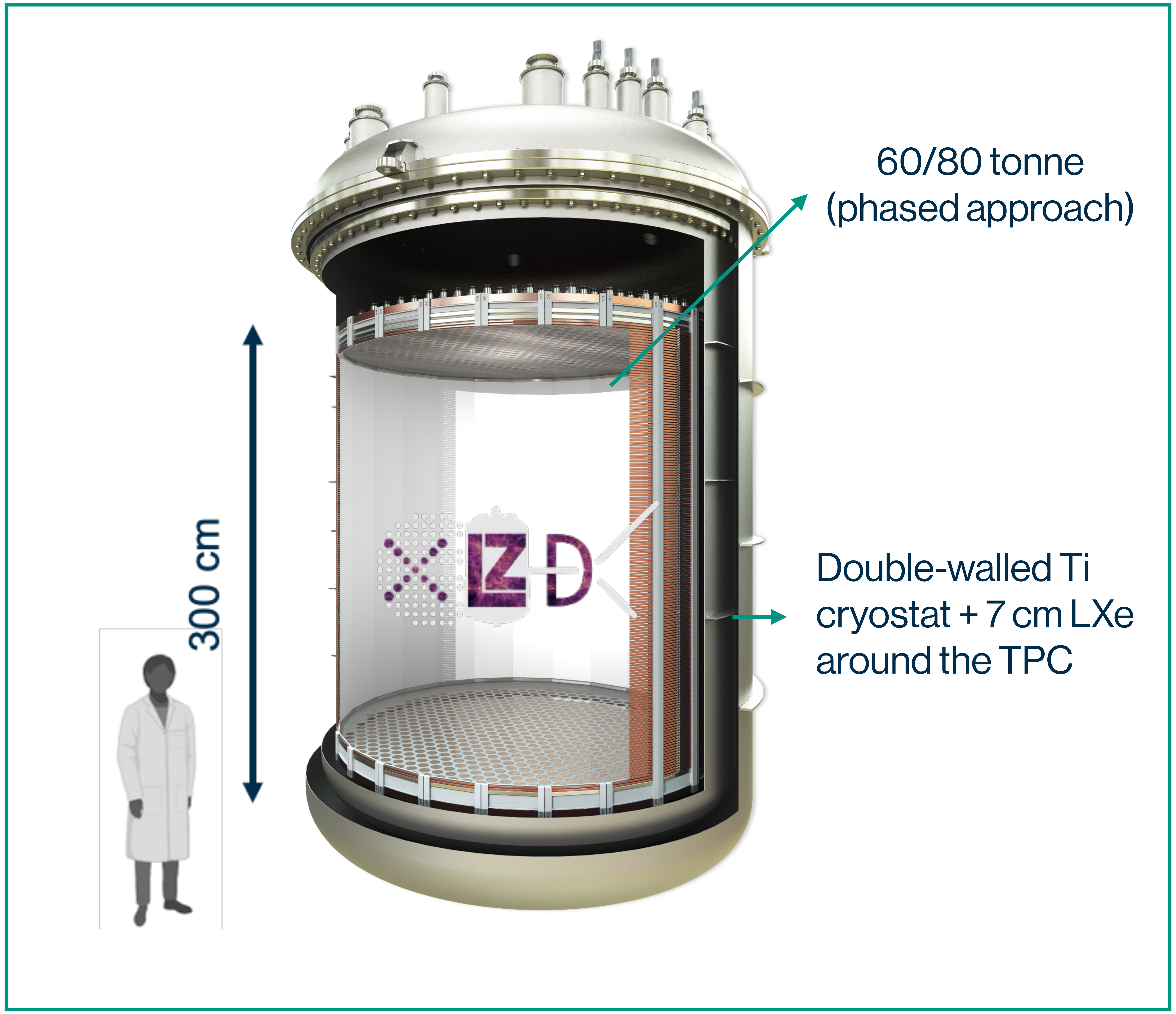
The XLZD Observatory

- ~3 m diameter x ~3 m height
- Phased approach following xenon procurement to increase to a 80 t active mass detector
- Drift field of 240-290 V/cm and extraction field of 6-8 kV/cm for optimal discrimination



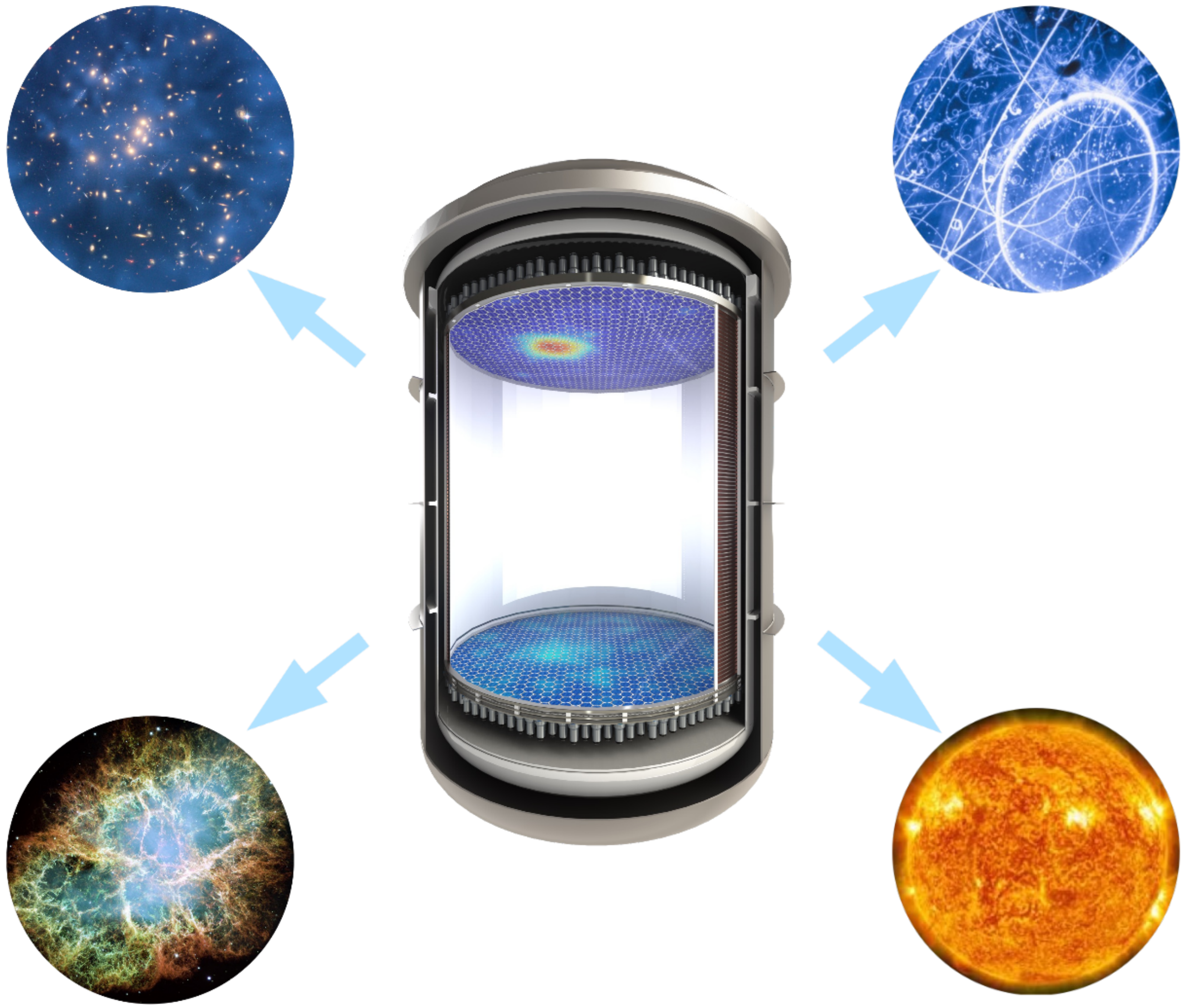
Candidate locations: LNGS, BOULBY, SNOLAB, SURF



Dark matter searches with Liquid Xenon TPCs

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



Supernovae
Early alert
Supernova neutrinos
Multi-messenger astrophysics

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

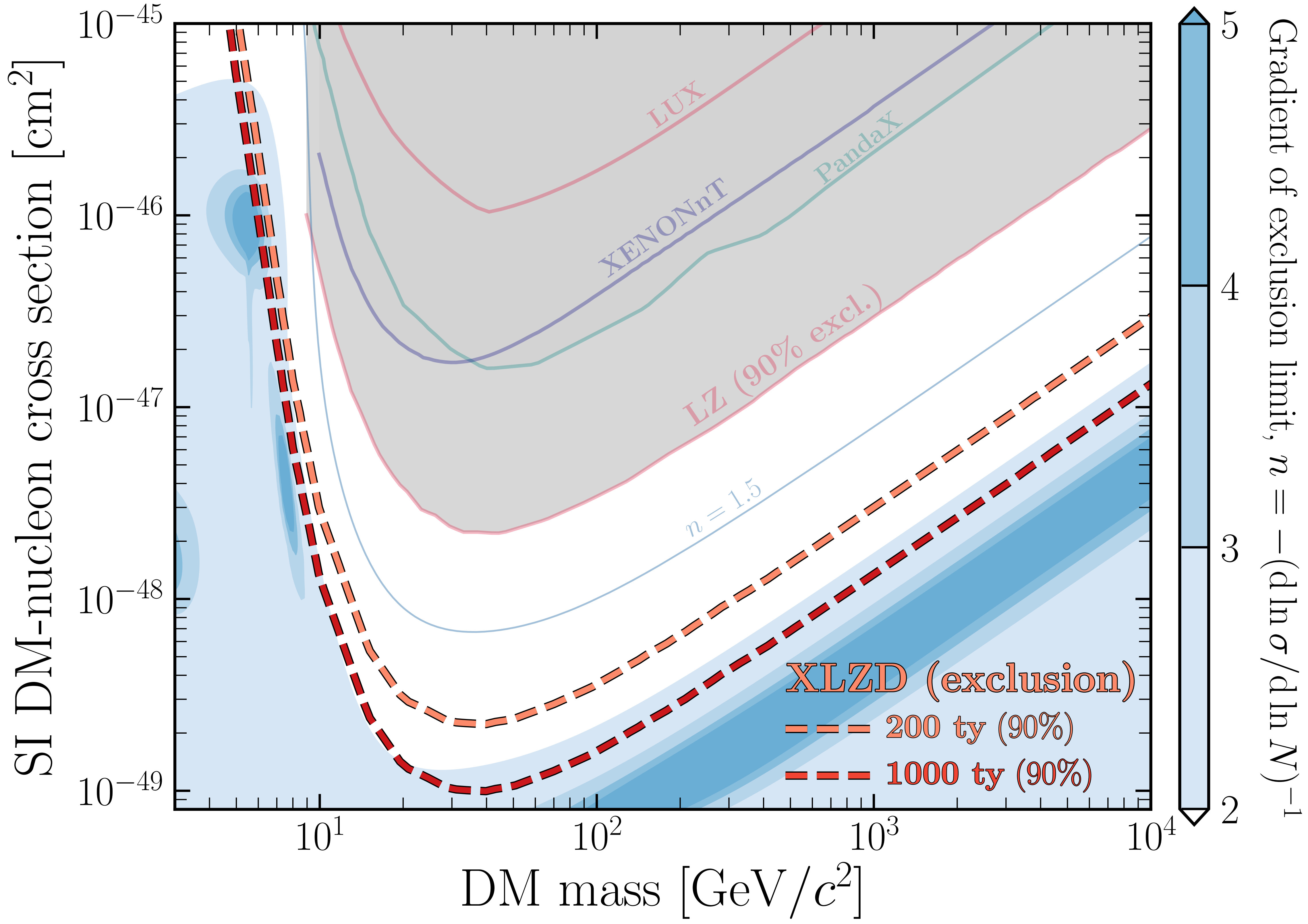
arXiv:2410.17137v2

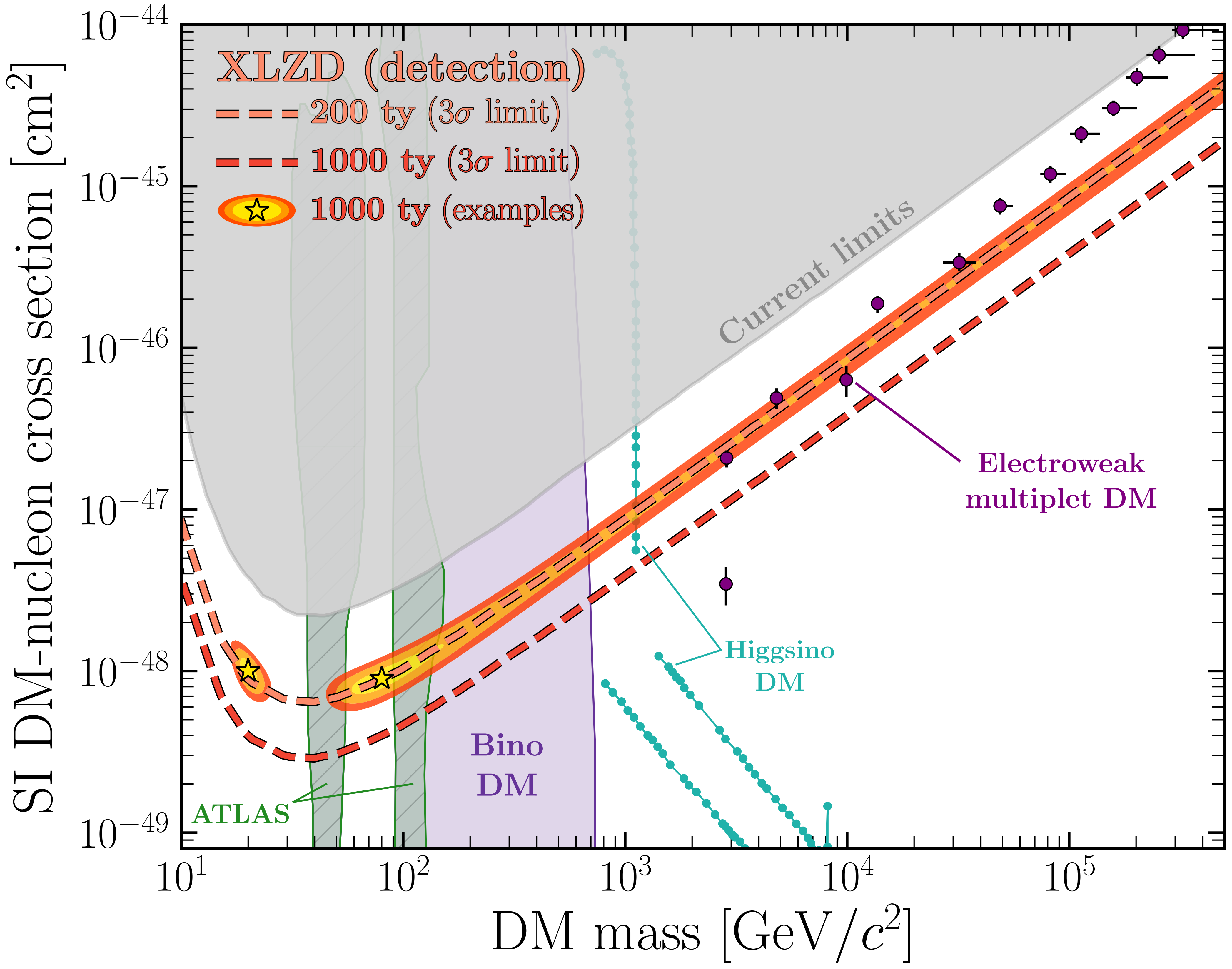
Collaboration

- **DARWIN**
  - Longstanding R&D effort with ~200 members from 35 institutions in Europe, USA, Asia, Australia
- **XLZD**
  - New collaboration to build & operate next-generation detector
  - Consortium meetings at KIT (2022), UCLA (2023), and Rutherford Lab (2024)
  - Collaboration meeting at LNGS (2025)
  - Design book submitted to publication

XZLD reach in the WIMP parameter space

Reaching the ‘neutrino fog’, after that, sensitivity gets limited by CEvNS

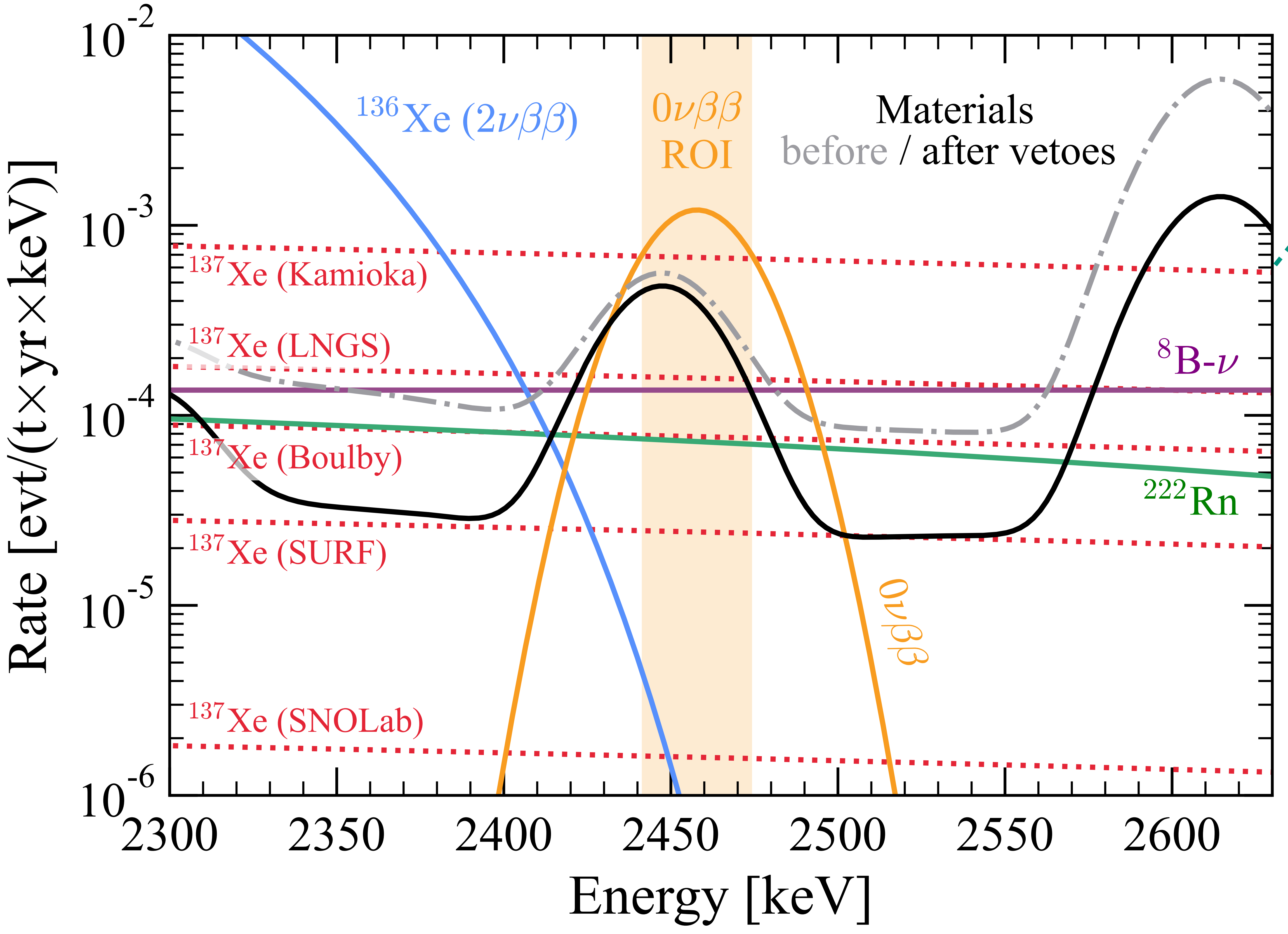




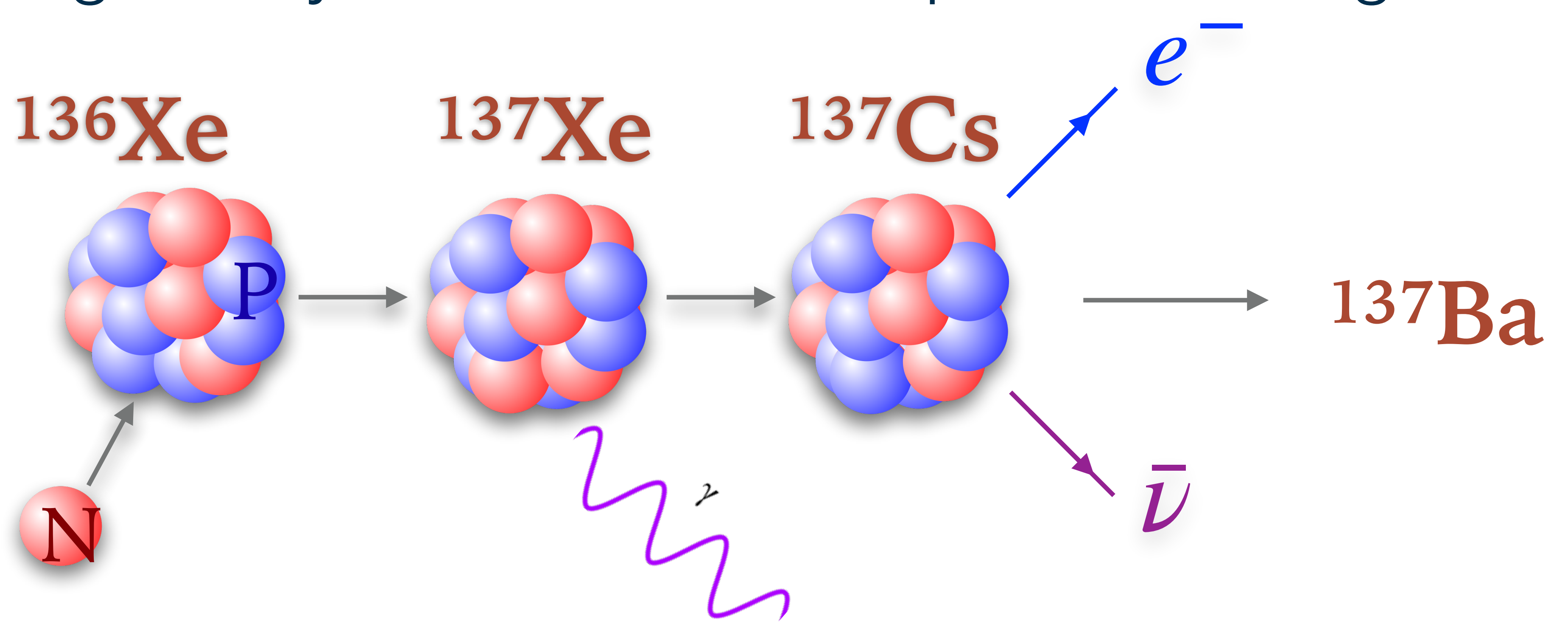
Neutrinoless double beta decay

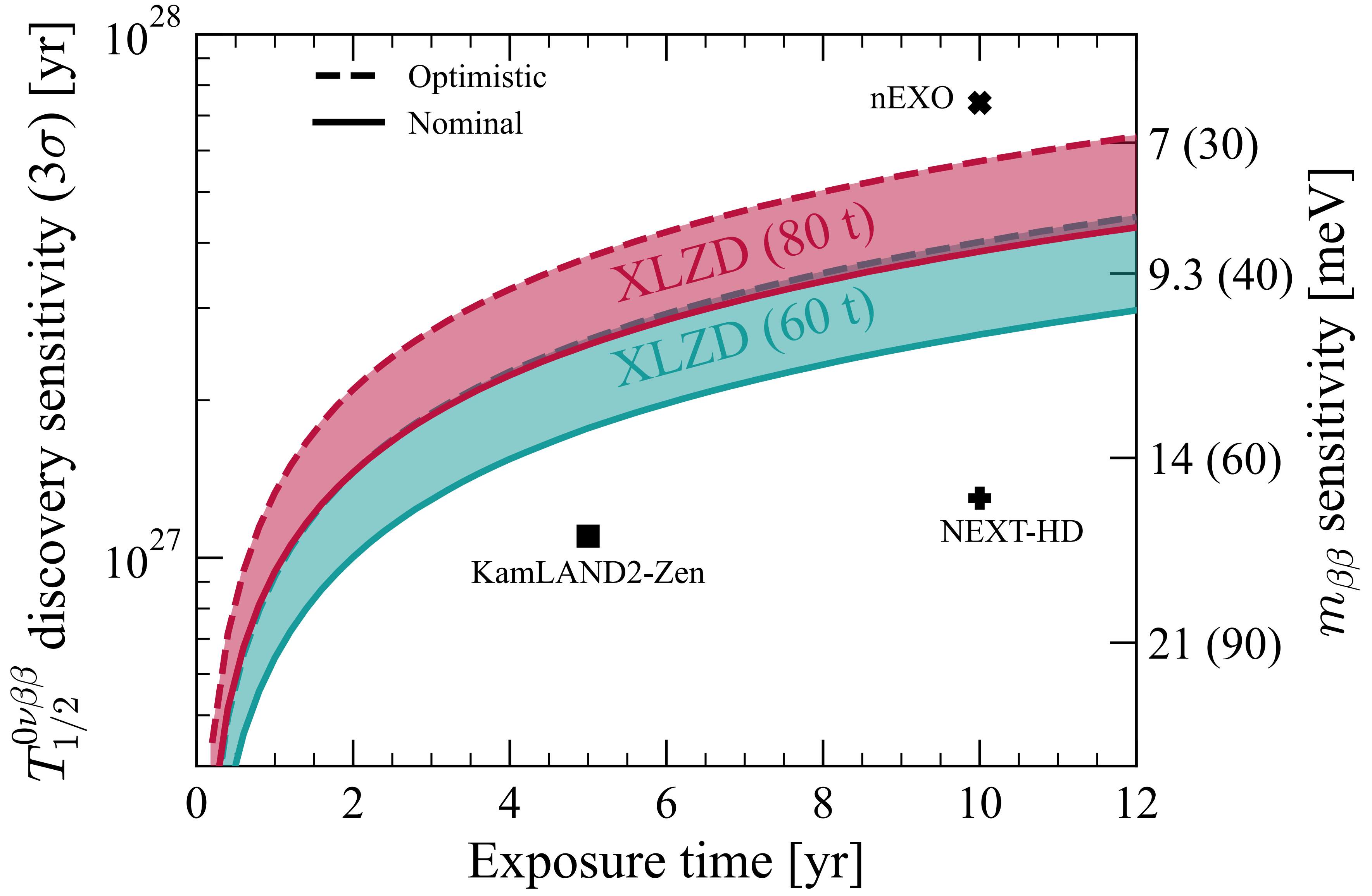
New publication!
J. Phys. G: Nucl. Part. Phys. 52 045102

Access to this channel through the natural abundance of ^{136}Xe (~8.9%)

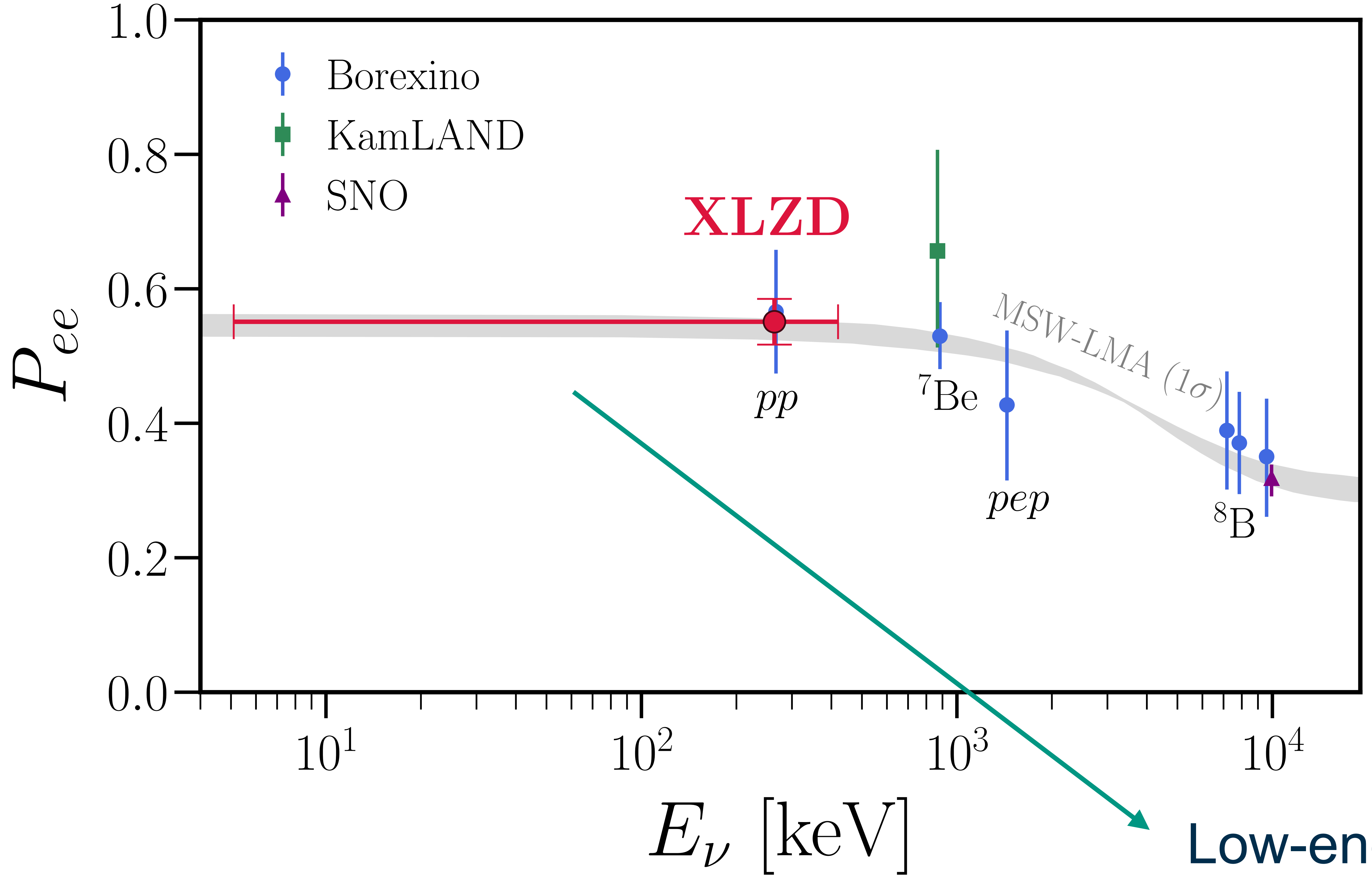


Cosmogenically created ^{137}Xe is a potential background





Solar neutrinos: neutrino-electron scattering

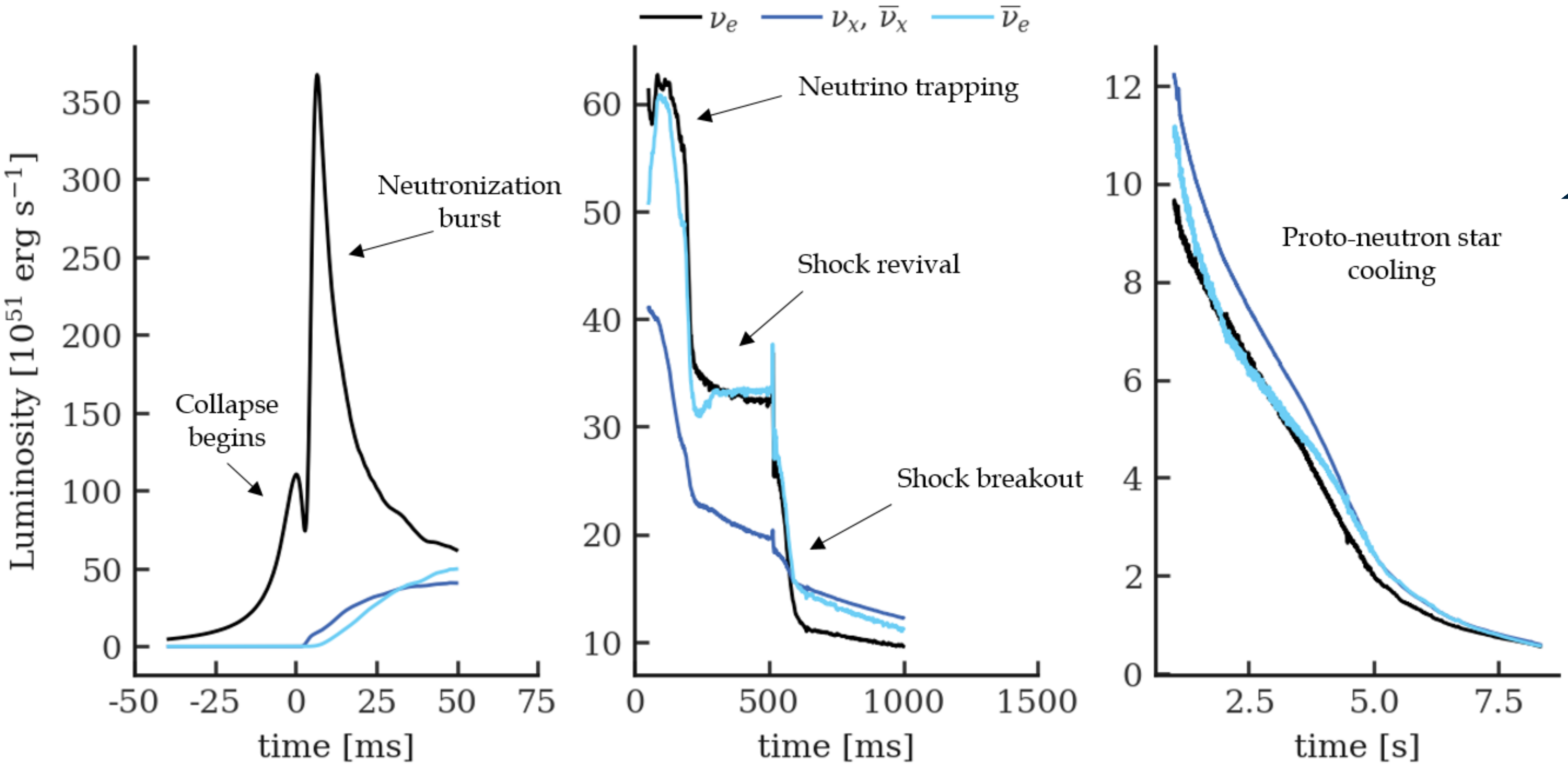


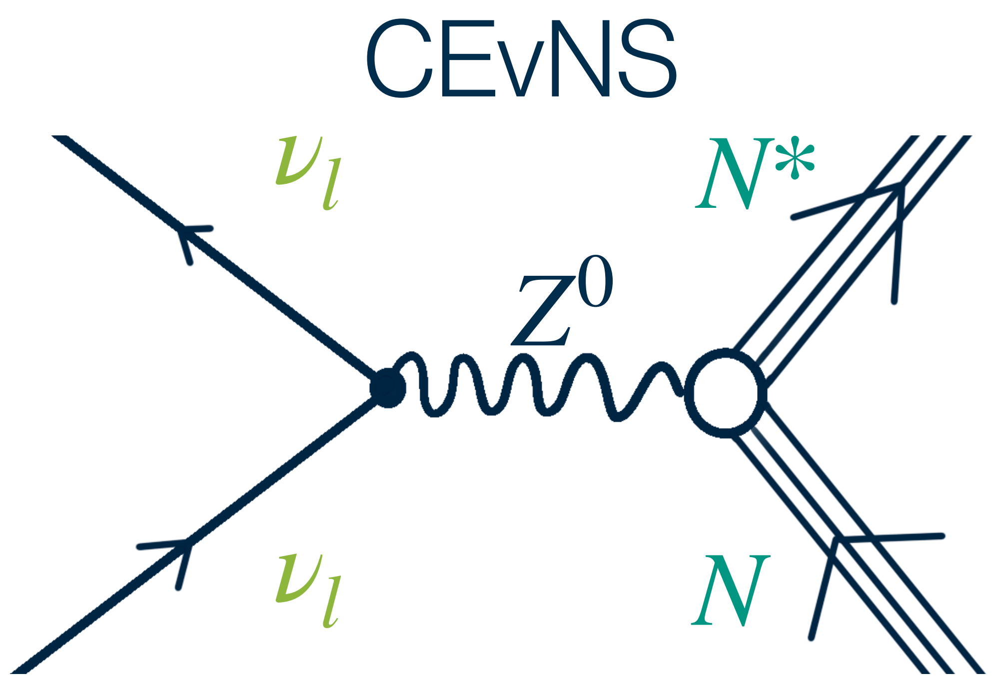
- Constrain low-energy survival probability to 5%
- Independent measurement of the weak mixing angle
- Prove neutrino-electron non-standard interactions

Low-energy range not previously explored

Core collapse supernova

Neutrino emission from core collapse supernova

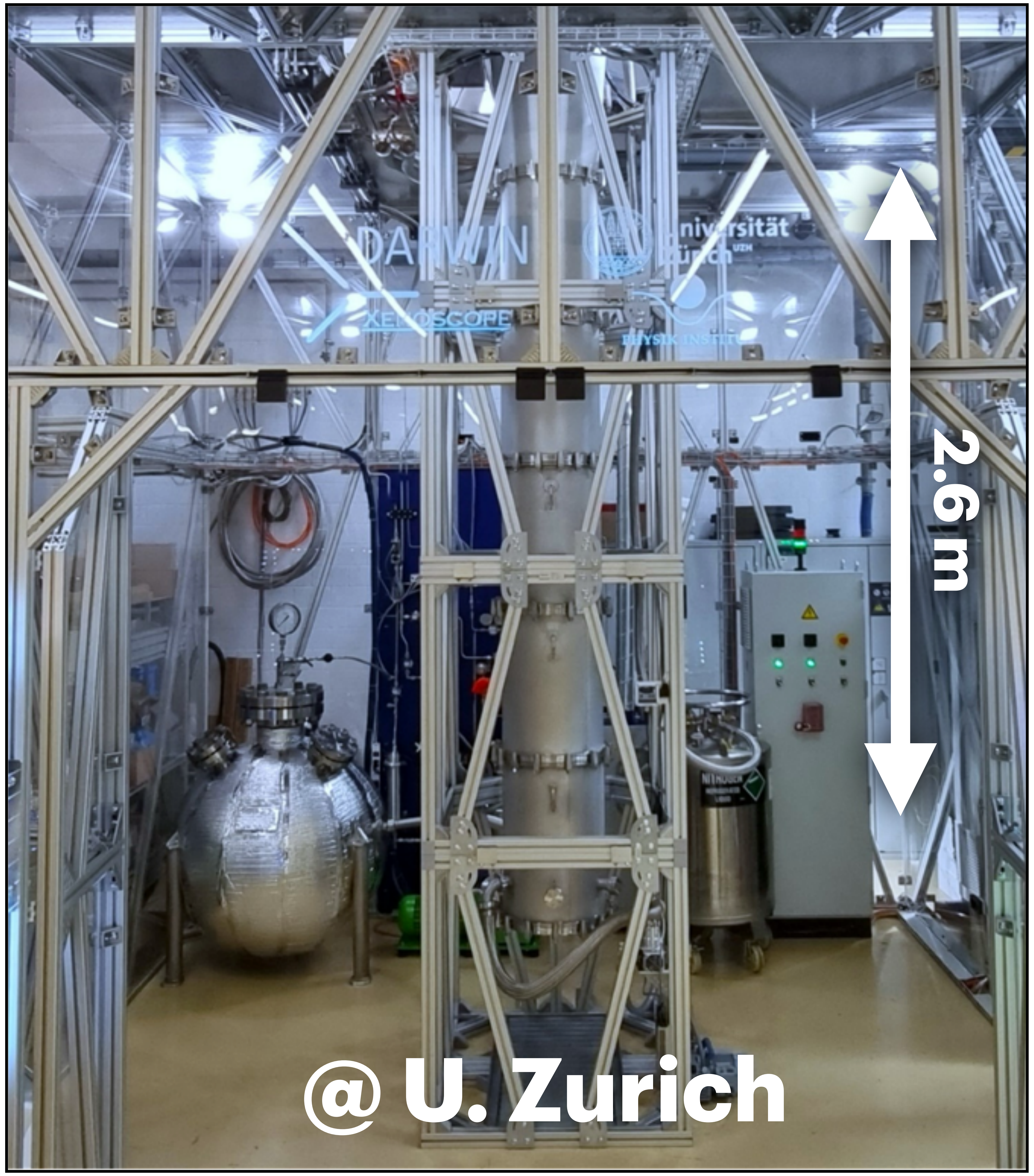




Flavour independent detection of neutrinos in XLZD from all stages from core collapse to cooling

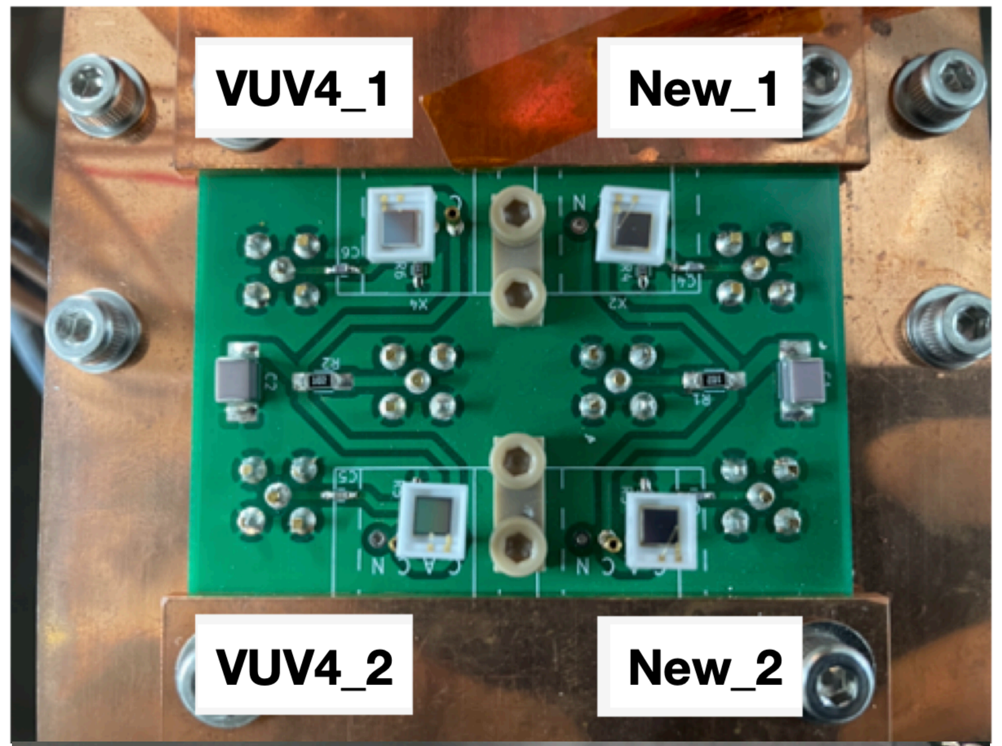
M. Kara PhD Thesis

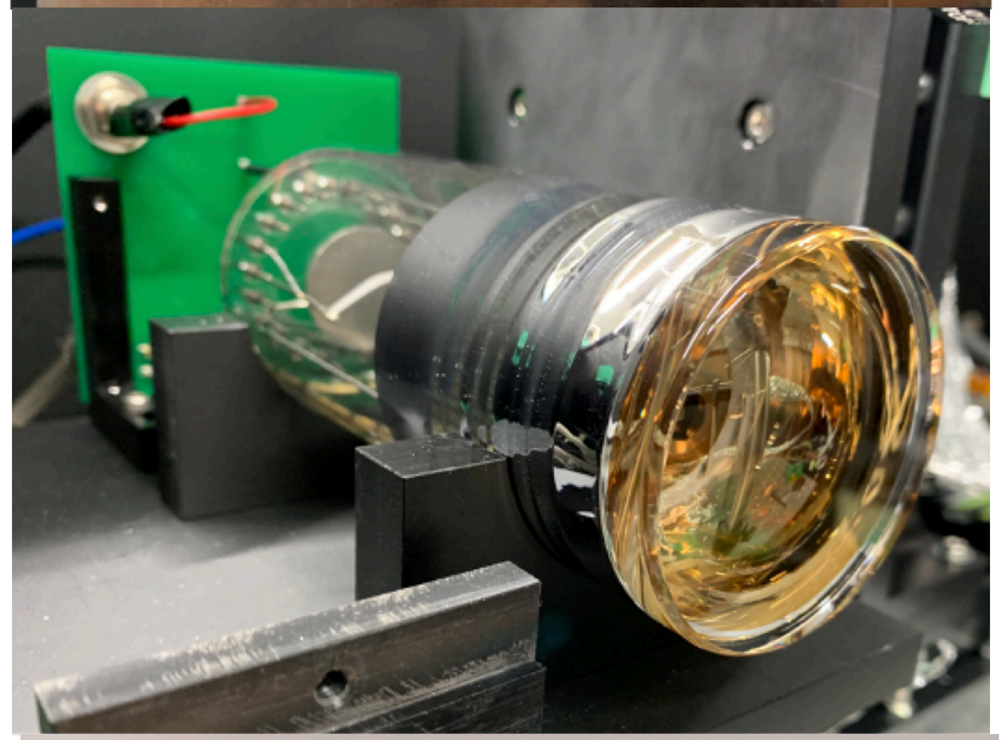
Large scale demonstrators

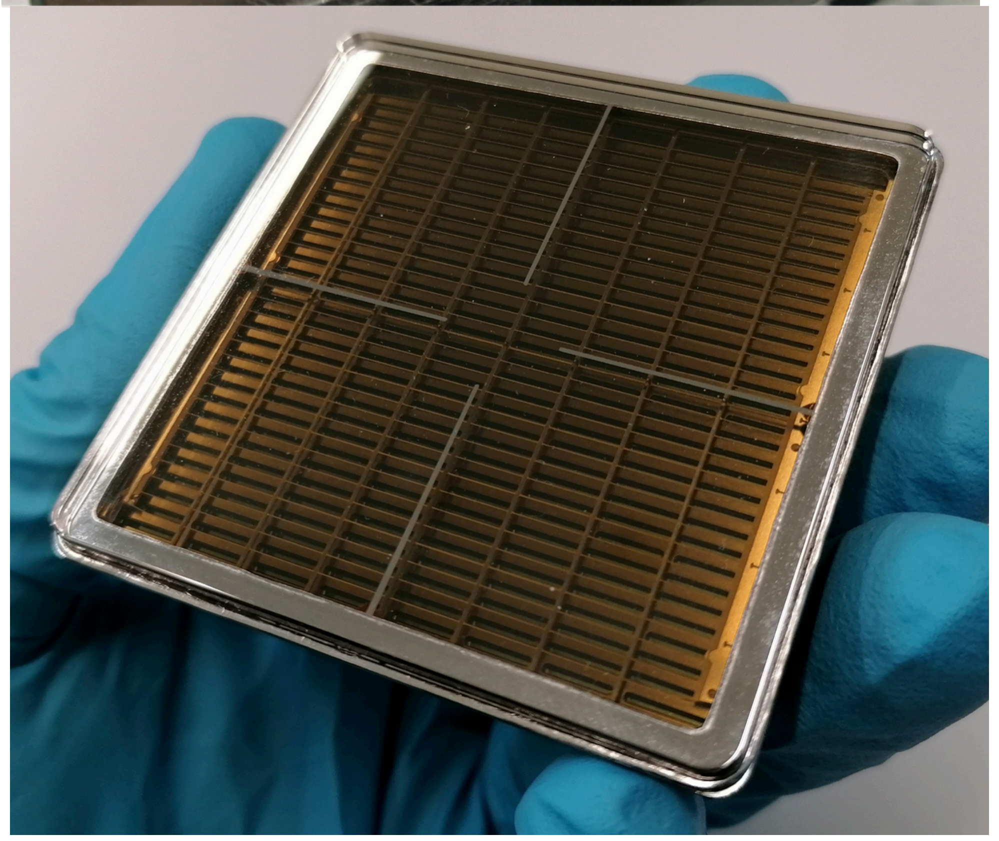


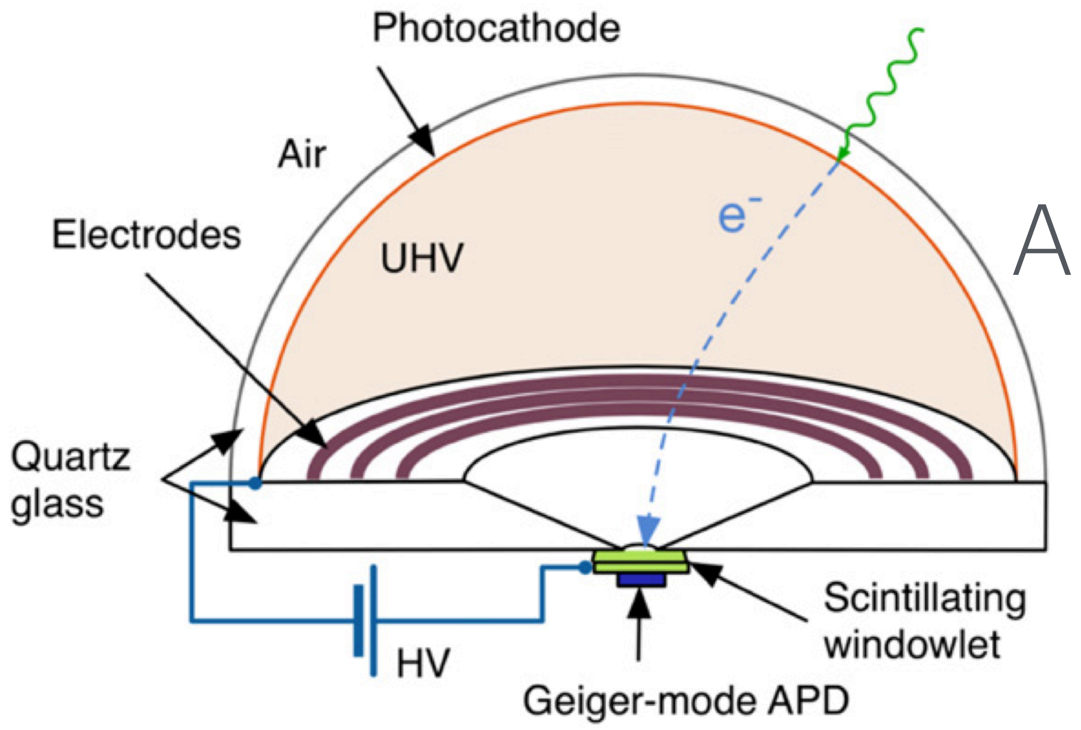
Photosensors

- Baseline design consists of 3” PMTs, but other options are being explored
- Characterisation of Square 2” PMTs → lower buoyancy and sub-ns rise time
- New VUV SiPM development - reduced DCR of VUV4 SiPM by a factor of ~7
- VUV Setup (@ LXe temperature / Vacuum)
- Absolute QE measurement including position dependence using 2D linear stage under vacuum at LXe temperature
- Digital SiPMs development for DARWIN (high fill factor, cold electronics, low dark count)

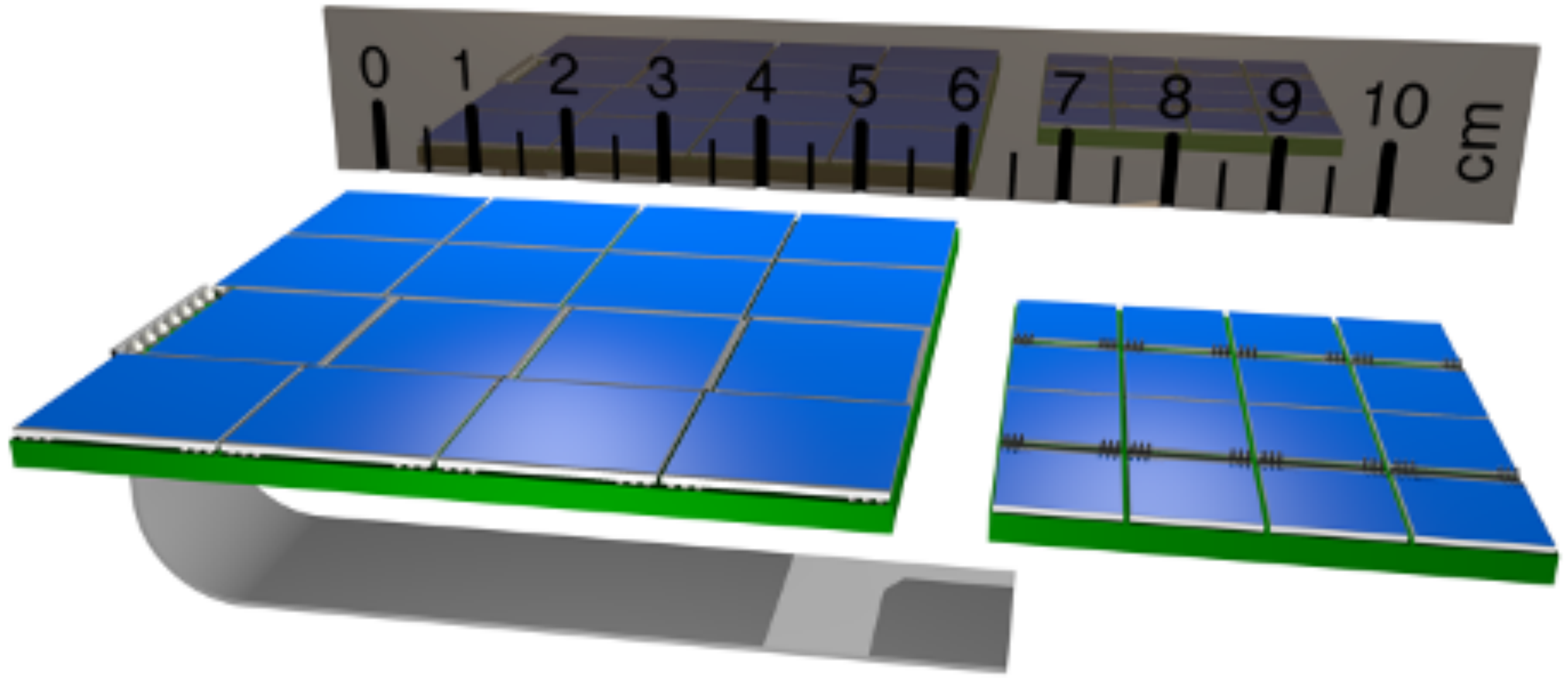




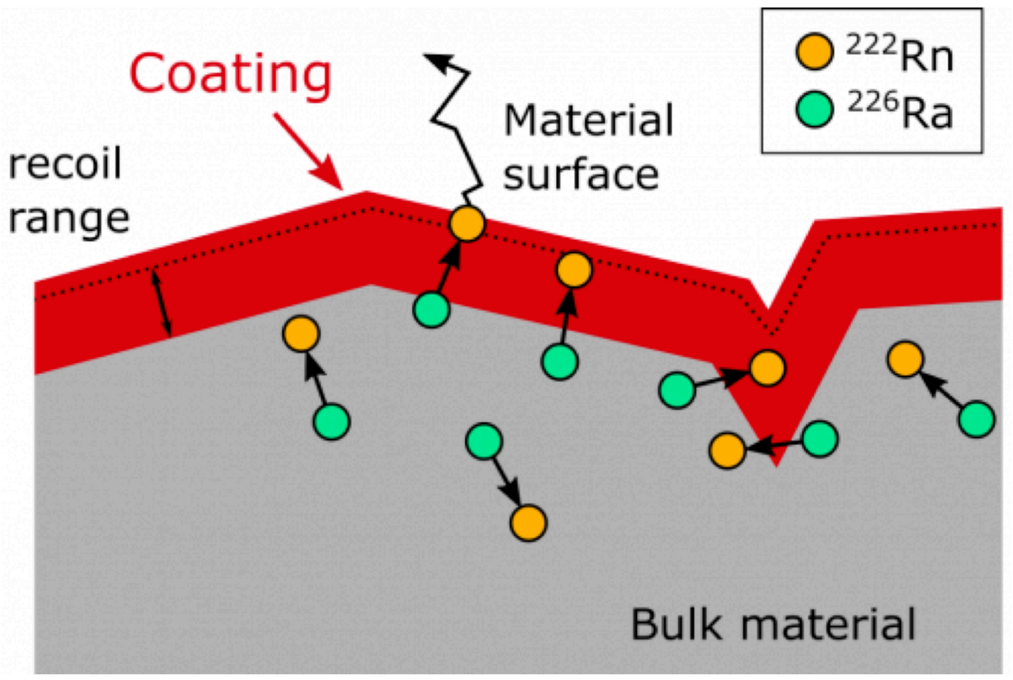




ABALONE



Xenon cleanliness



R&D for xenon purity levels that allow exploring the neutrino fog

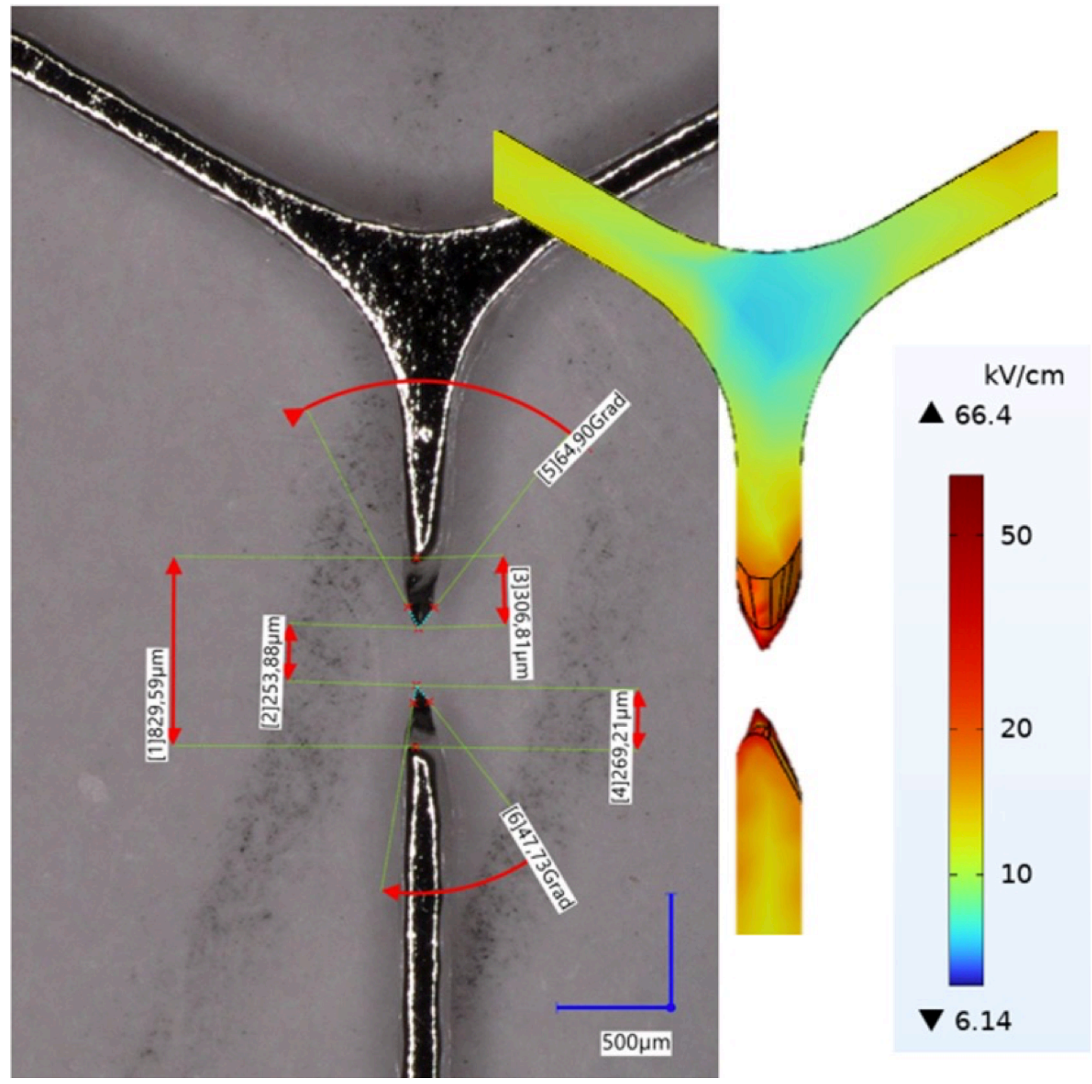
- ^{85}Kr distillation → goal of 0.1 ppt natKr already achieved <0.026 ppt
- ^{222}Rn distillation column → goal of 0.1 µBq/kg (achieved 0.8 µBq/kg) below ER from solar pp neutrinos
- Cryogenic Xe distillation system with novel heat pump concept
  - Rn removal and quasi loss-less ^{85}Kr removal system and impurity monitoring
- Radon emanation suppression by surface coating

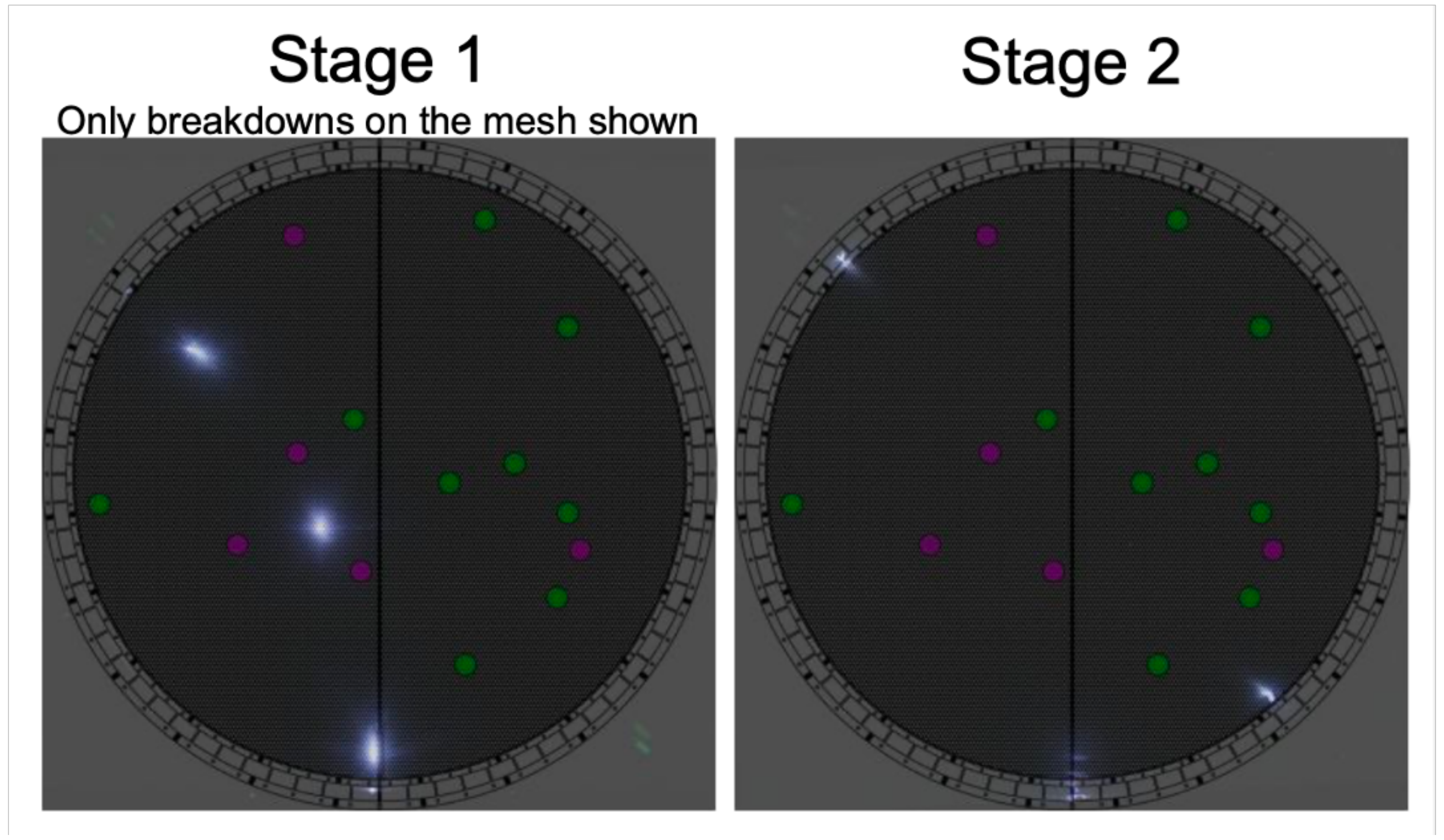
Eur. Phys. J. C (2017) 77:275
Eur. Phys. J. C (2022) 82:1104

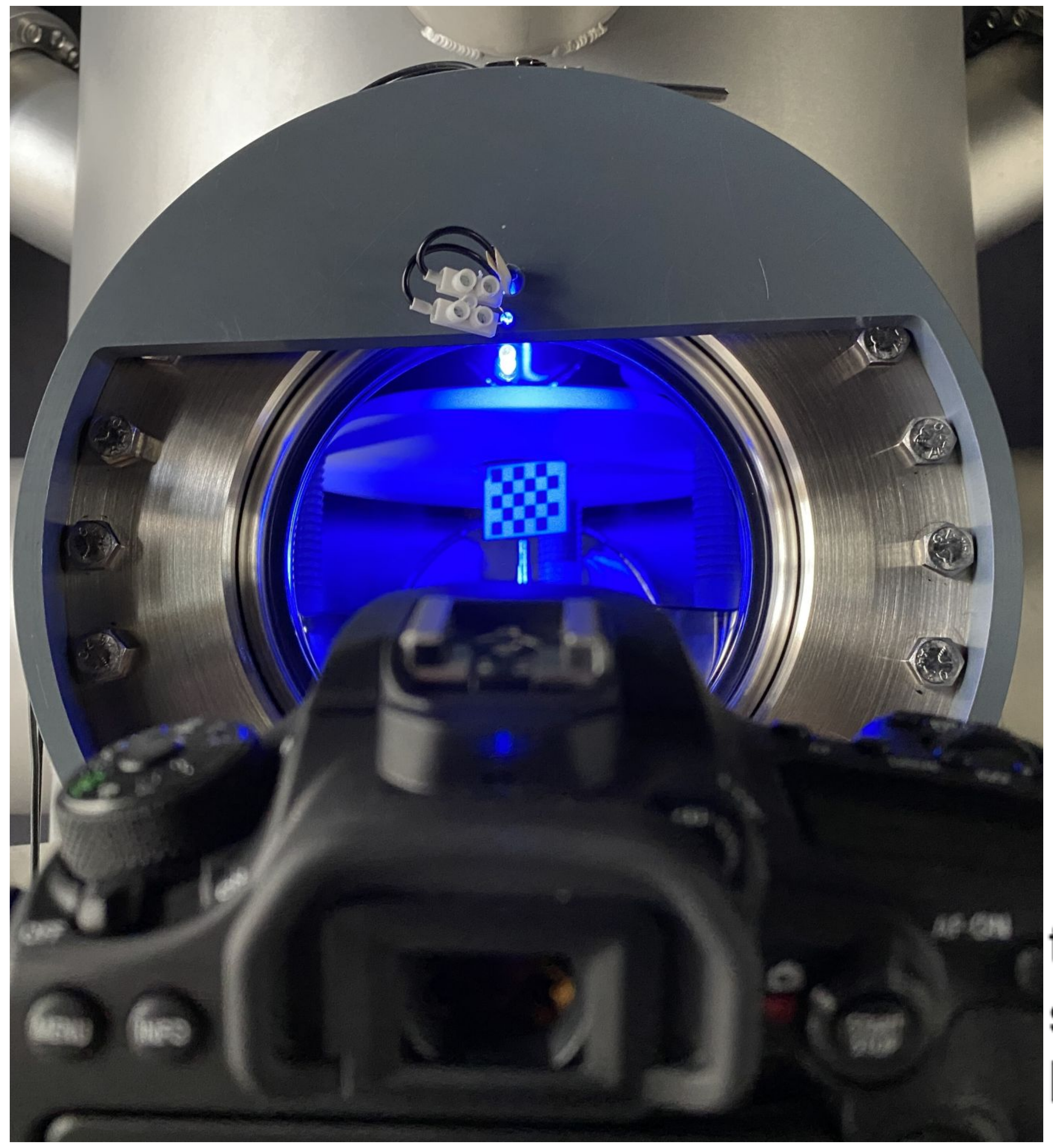
XLZD Electrodes

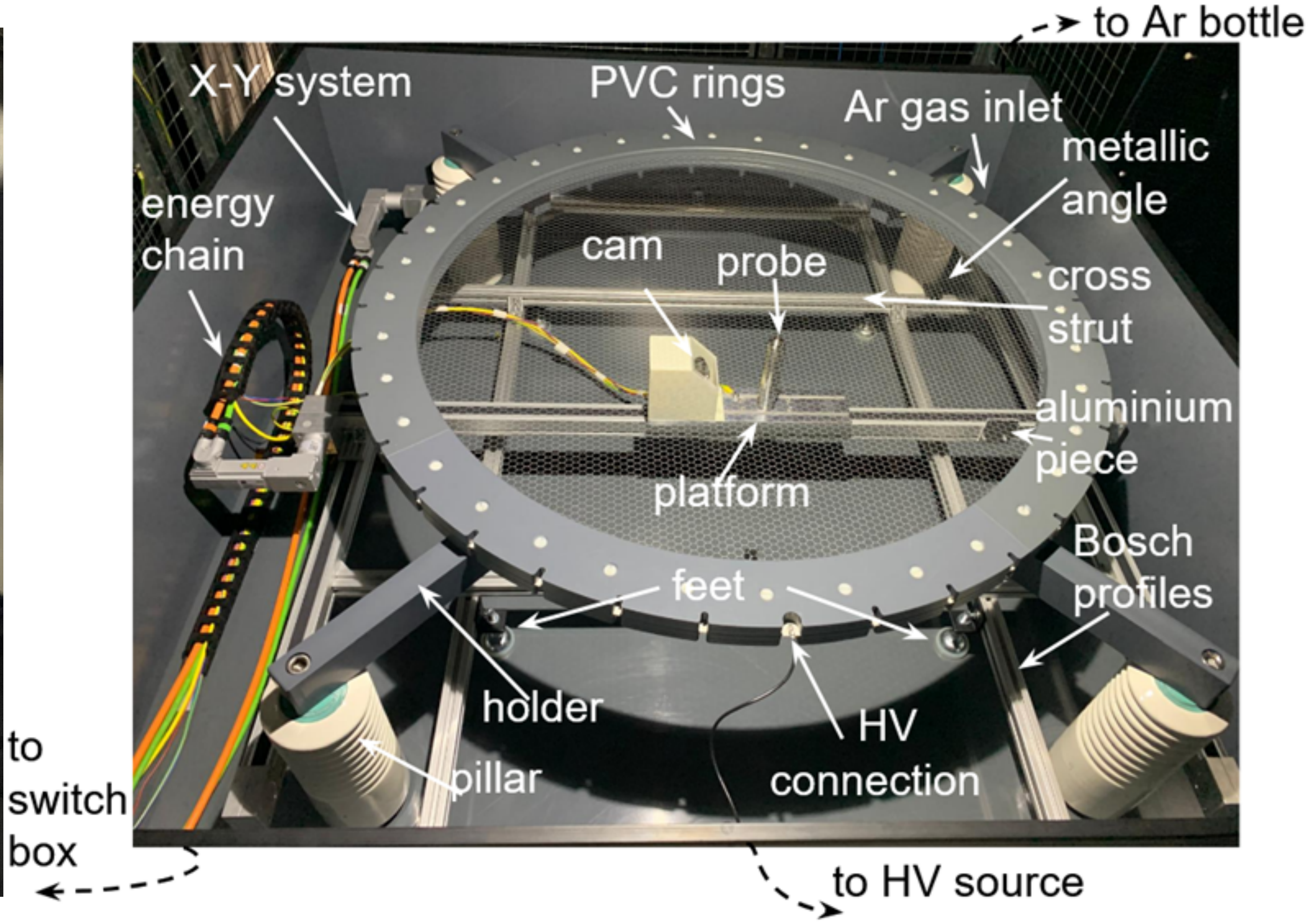
Production and quality assessment of >3m electrodes in air, vacuum and gas argon

- 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
  - 2D scanning system of 1.5 m and soon 3 m grids
  - Detect glow in gAr indicating defects in mesh - diagnostics: optical imaging

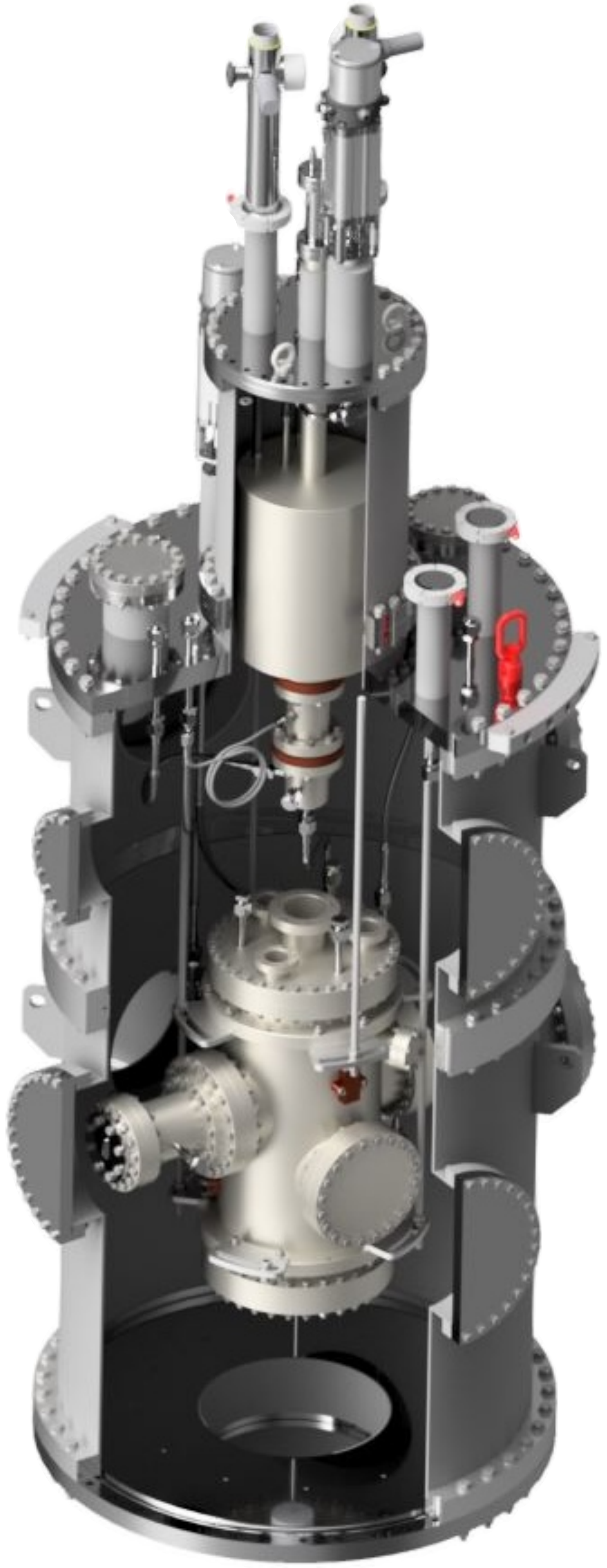








Liquid xenon properties and high voltage



- Liquid xenon time projection chamber hosting up to **80 kg at KIT**
- Power supply of up to **-200 kV** to bias the cathode
- Diagnostics of **HV** components (feedthrough, electrodes, couplings)
- Monitoring of **systematics**: effects of purity, surface, pressure...
- **SiPMs** to monitor cathodic emissions, luminescence, electron trains
- **Camera** for monitoring of discharges
- Studies with tritium solubility, **calibration** and removal, and permeation studies of tritium in SS

Henry solubility

$$H_s^{cc} = \frac{c_l}{c_g}$$

Diffusion law

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial z}\left(D_{zz}\frac{\partial c}{\partial z}\right)$$

Conclusions and outlook

- XLZD (XENON-LZ-DARWIN): New international collaboration to build and operate a 60- to 80 tonne scale LXe TPC
- DARWIN: Active R&D collaboration for next generation LXe TPC for WIMP direct detection down to the neutrino fog
- TPC of ~3 m dimensions and 60/80 tonne of active mass
- Reaching the neutrino fog, but exciting physics available!
- Rich R&Ds program to tackle the technical challenges