Karlsruhe Institute of Technology

XLZD – Towards the Next-Generation Liquid Xenon Observatory for Dark Matter & Neutrino Physics

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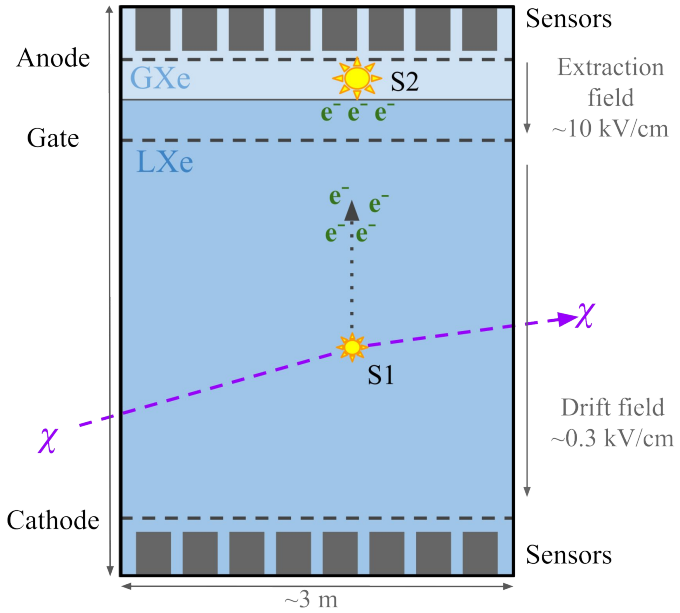
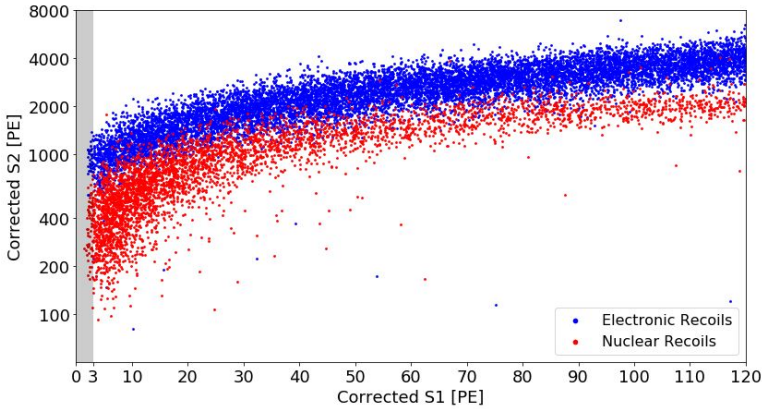
Dual-phase Time Projection Chamber (TPC)



- Initial scintillation light: S1
- Proportional scintillation signal: S2
- **Energy:** S1 area, S2 area
- **Position:** X-Y (S2 signal), Z (drift time)
- **Interaction type (ER/NR):** S2/S1 ratio



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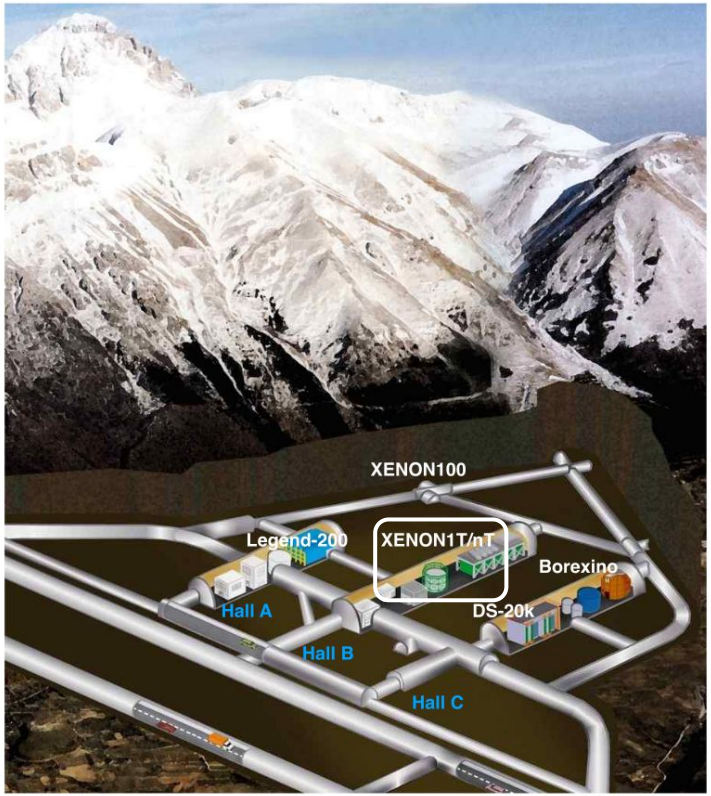
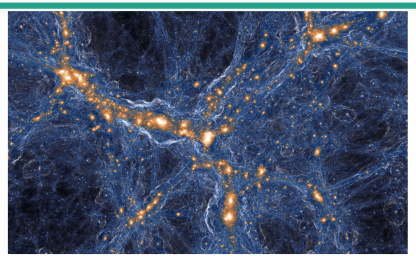


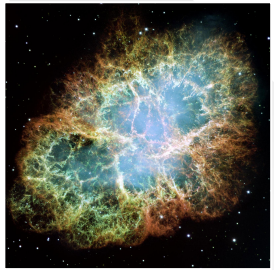
XENON dark matter direct detection experiments
at Laboratori Nazionali del Gran Sasso (LNGS)

What comes next…?

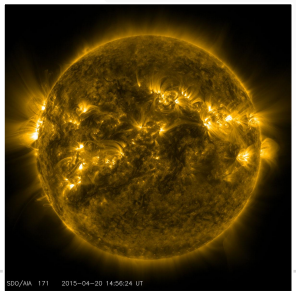
Towards the Neutrino Fog with Xenon Detectors



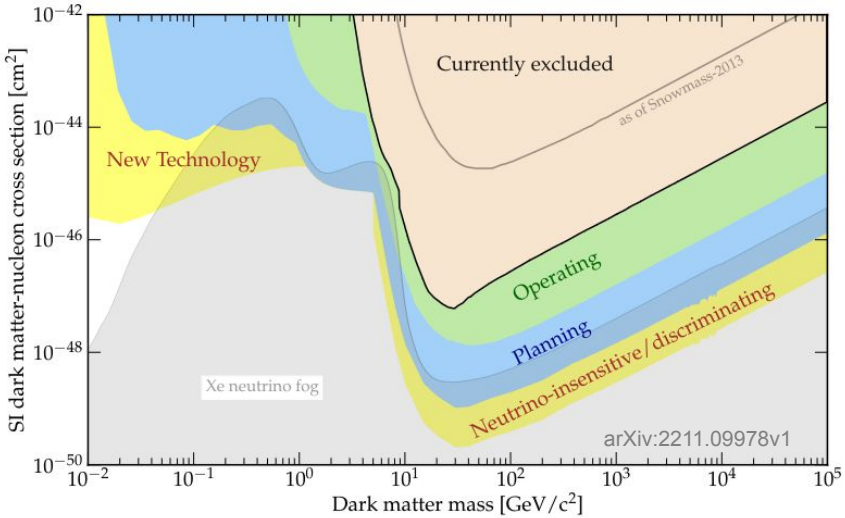
Dark Matter
- JCAP 10, 016 (2015)
- JCAP 11, 017 (2016)

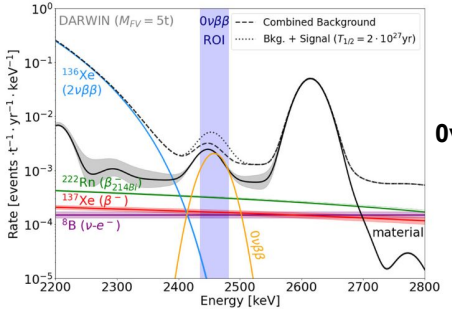


Supernova neutrinos
- Phys. Rev. D 94, 103009 (2016)
- Phys. Rev. D 105, 043008 (2022)



Solar neutrinos (pp + B8)
- Eur. Phys. J. C 80, 1133 (2020)
- Phys. Rev. D 106, 096017 (2022)
- J. Phys. G 50, 013001 (2023)





0νββ of ^{136}Xe
- Eur. Phys. J. C 80, 808 (2020)
- Eur. Phys. J. C 83, 996 (2023)

XLZD - XENON-LZ-DARWIN

- New collaboration aiming to build & operate a next-generation detector
- **XENONnT**, **LZ** - operating largest most sensitive ~6 t (active) xenon TPCs
- **DARWIN** - R&D towards ~10x larger detector: electrodes, HV, photosensors,…

- **Fall 2024:** Collaboration formed, with > 70 institutions from 15 countries
- **Design Book: out October 2024 - arxiv: 2410.17137**

Consortium launched in 2021, 1st XLZD Meeting at KIT

XENON DARWIN

xlzd.org

XLZD - XENON-LZ-DARWIN

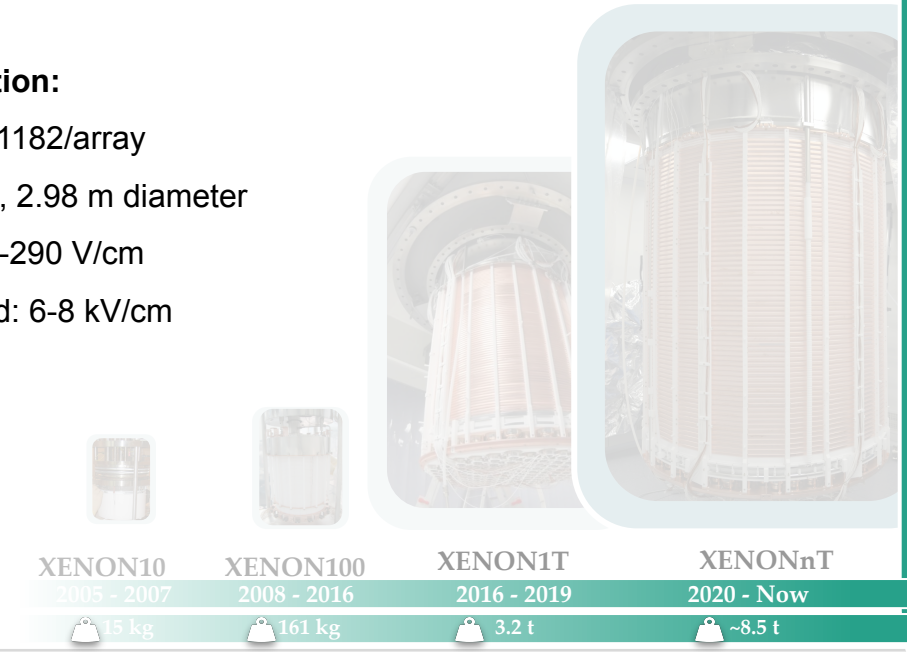
XLZD Nominal Design:

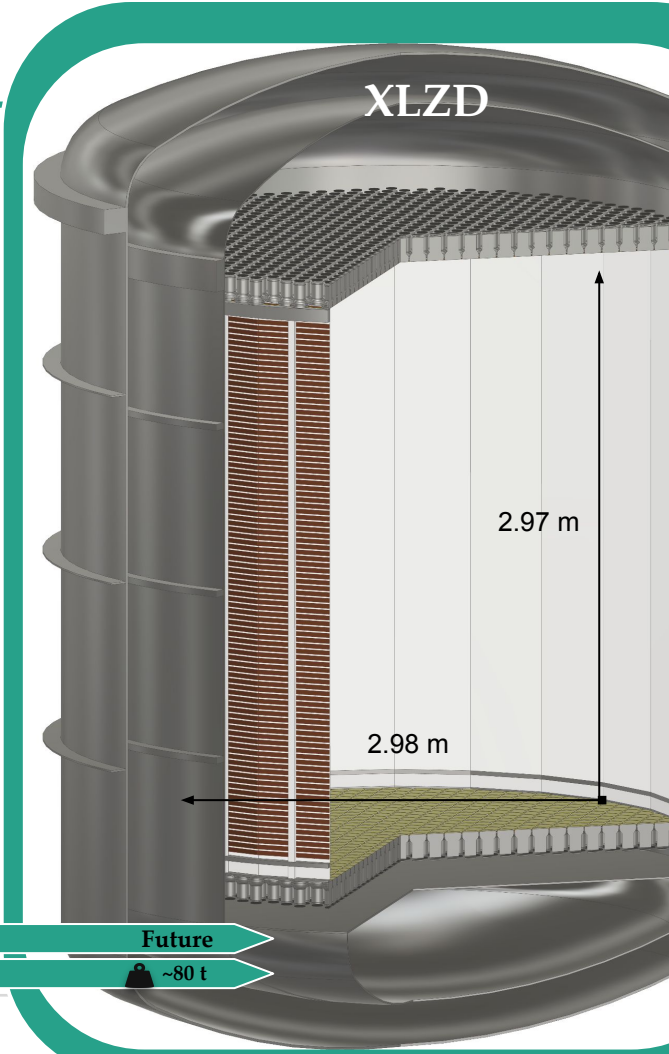
60 t liquid-xenon in TPC (~80 t total)

Option of staged approach for early science

Baseline configuration:

- 3-inch PMTs, 1182/array
- 2.97 m e- drift, 2.98 m diameter
- Drift field: 240-290 V/cm
- Extraction field: 6-8 kV/cm

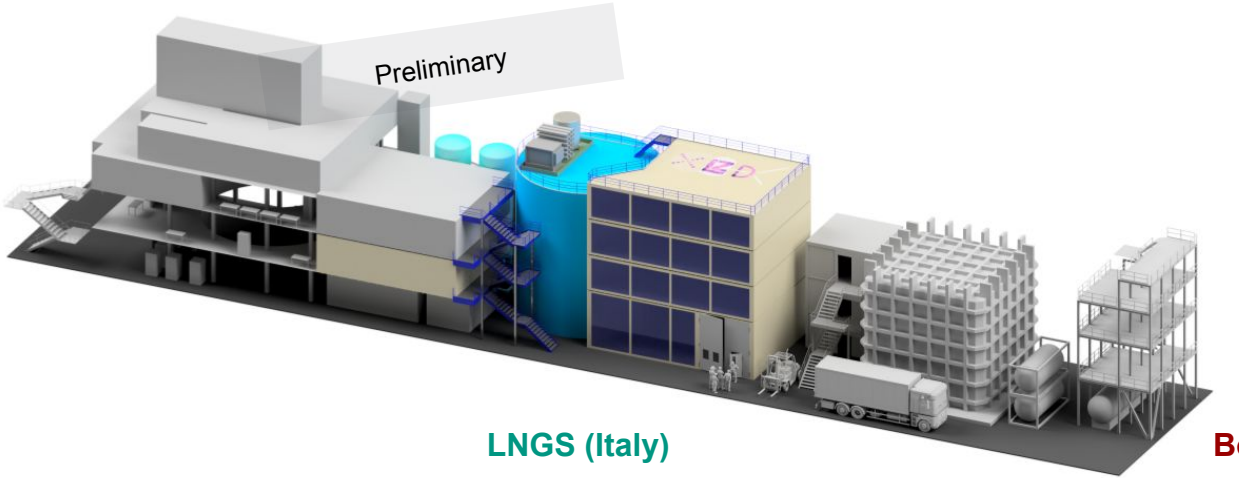




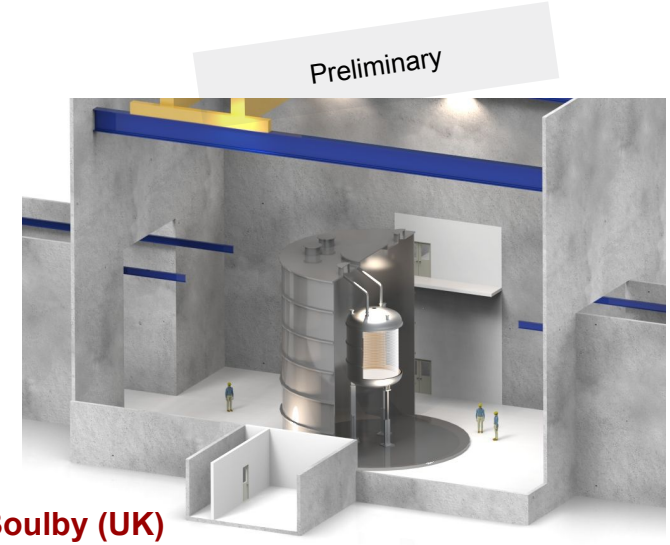
XLZD - XENON-LZ-DARWIN

XLZD Nominal Design:

- Double-walled Ti cryostat, 7 cm liquid-xenon "skin" detector around the TPC
- Neutron & muon vetoes
- Candidates for underground hosting lab: **LNGS**, **Boulby**, **SURF**
  (siting decision expected for 2026)



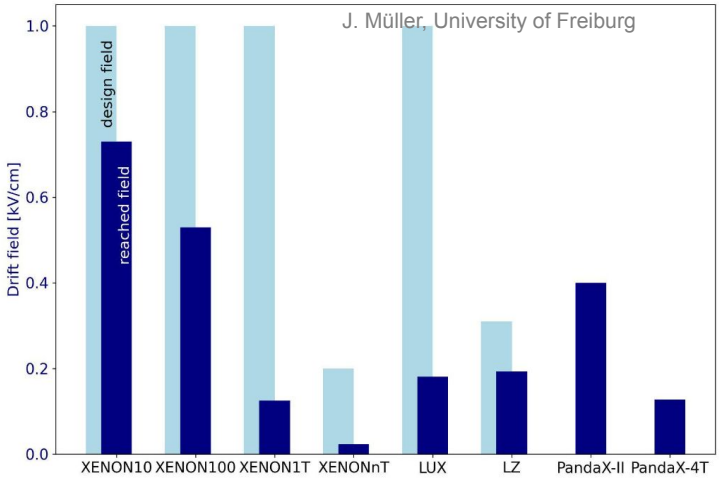
LNGS (Italy)

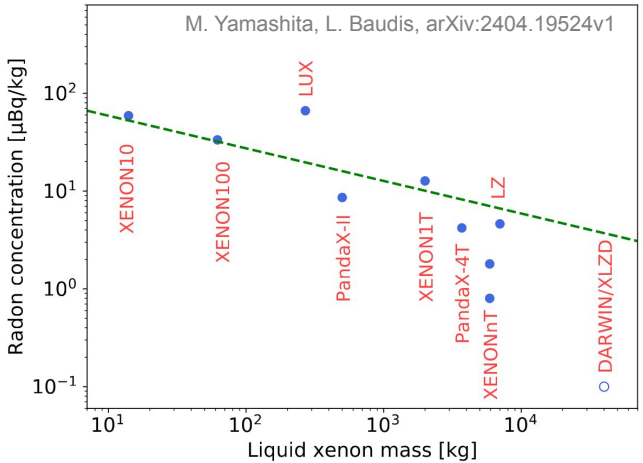


Boulby (UK)

Towards the Ultimate Xenon Detector

- **High-voltage:**
  - Electrodes design, construction & performance
  - HV feedthrough
  - Drift field homogeneity
- Xenon purity
- Light collection efficiency
- Photosensors & readout
- Background mitigation





Electrode & Detector R&D at Karlsruhe

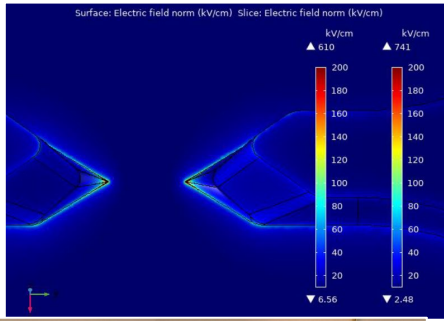
Goals

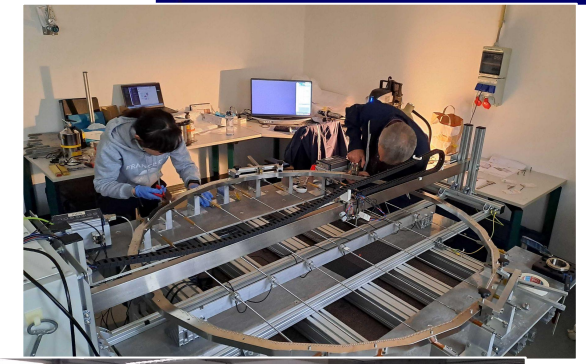
- Electrode design, production, treatment, coating & diagnostics (imaging & ML methods)
  - **Design & construction of XLZD ~3 m scale electrode prototype at KIT**
- Surface quality measurements & correlation with instabilities in liquid-xenon
- Xenon properties in HV, tritium studies

Current Work

- **Study of different electrode concepts (wires/mesh)**
  - Mechanical design
  - Electrical field, optical, mechanical simulations
  - Identification (ML) & treatment of defects
- Electrode production, assembly & qualification at ~1.5 m scale
- **Setting up to do the above also on XLZD ~3 m scale**

Multiple local test facilities: **bHiVE**, **HiCUTIE, MOTION**





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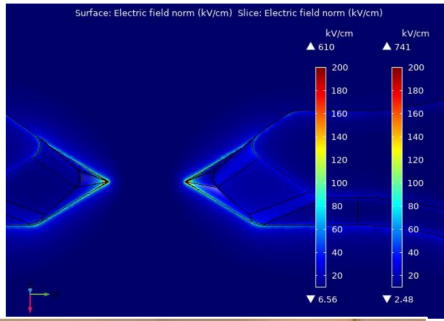

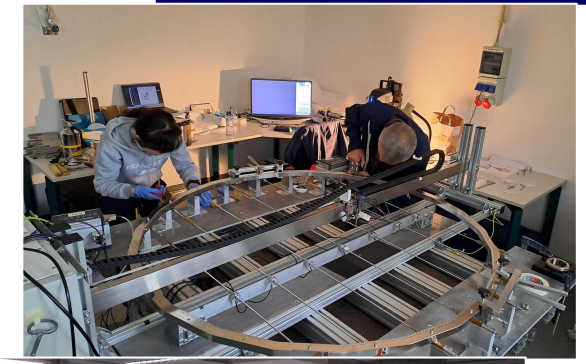

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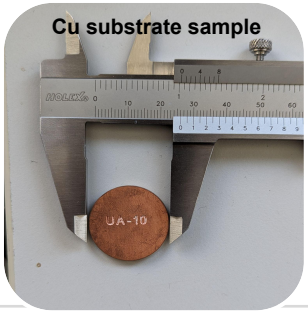
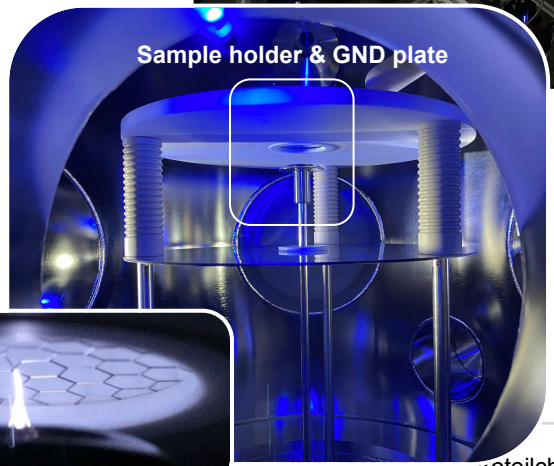
Multiple test facilities: **bHiVE**, **HiCUTIE, MOTION**

Check out the poster

bHiVE - bite-sized High Voltage setup for Electrodes

- Study electron & photon emission from electrode samples
- Form better understanding of electrode properties that cause emission
- **Explore emission mitigation techniques**
  - **Electrode coating** - Au, Cu (MPIK HD), Al/MgF_2 (U. Alabama)
  - **SS treatment methods** - citric, nitric acid, etc…
- Couple HV data, microscopy, camera imaging to simulations & theory





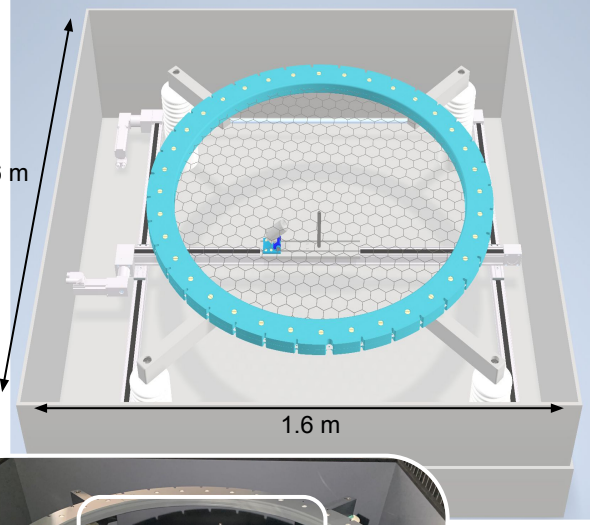
HiCUTIE

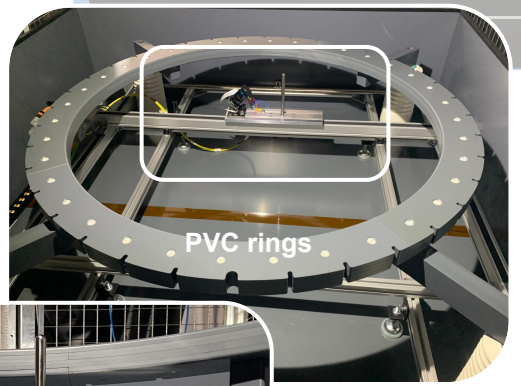
Assess performance of full-scale electrodes before insertion into a detector

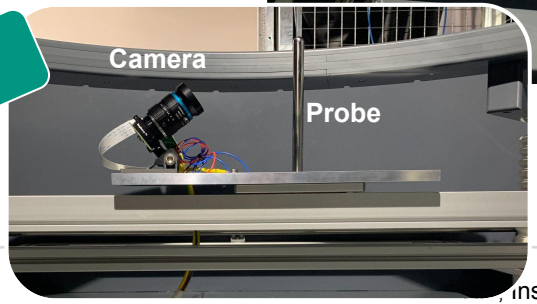
- ➢ Use localized high field in gaseous Ar to identify defect locations

HiCUTIE - High-voltage Coordinate Unit for Targeted Inspection of Electrodes

- ➢ **Prototype** ~1 m scale, then expand to ~3 m
  - ○ Hardware & software R&D
  - ○ Electrode on potential & grounded probe
  - ○ ITEM x-y linear motion system
  - ○ Camera & LED for imaging inspected locations
  - ○ Dedicated control software
- ➢ Ongoing commissioning





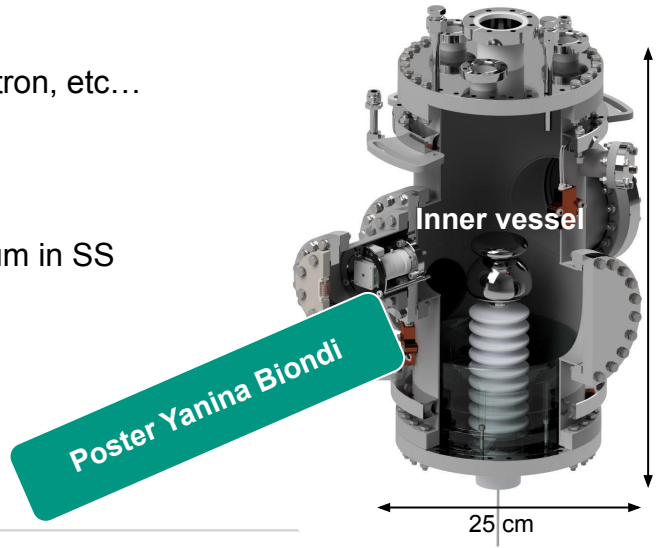


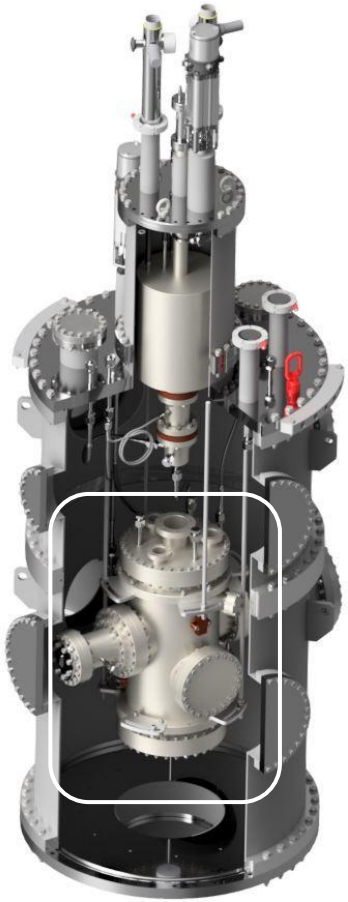
Poster Anna Götz

MOTION - Liquid-xenon TPC for HV Applications

- **80 kg liquid-xenon TPC** with up to -200 kV voltage biasing
  - Port access for diagnostics of HV components (feedthrough, electrodes, couplings)

- **Monitoring of systematics:** effects of purity, surface, pressure…
- Surface quality vs. voltage breakdown in xenon
- SiPMs to monitor cathodic emission, single electron, etc…
- Camera for monitoring discharges
- Studies with tritium:
  - Calibration & removal, permeation of tritium in SS





Poster Yanina Biondi

Summary

XLZD (XENON-LZ-DARWIN) - New international collaboration

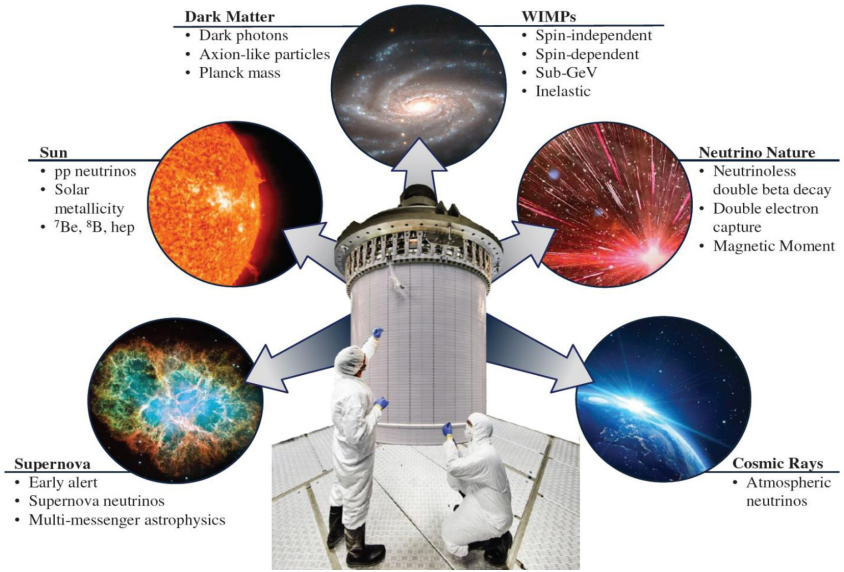
- ➢ Aim to build & operate ≥ 60 t liquid-xenon TPC
- ➢ Explore WIMP parameter space down to the “neutrino fog”
- ➢ Search for 0νββ-decay
- ➢ Observe solar & SN neutrinos & more …

R&D Efforts Towards XLZD

- ➢ Large-scale demonstrators (**U. Freiburg**, **U. Zurich**)
- ➢ Test R&D setups:
  - ○ HV feedthrough, electrode development & testing - **KIT**
  - ○ Xenon purity - **U. Münster**
  - ○ Photosensors - **U. Zurich**
  - ○ Background mitigation - **MPIK**

  …& more…

Design Book - arxiv: 2410.17137
xlzd.org

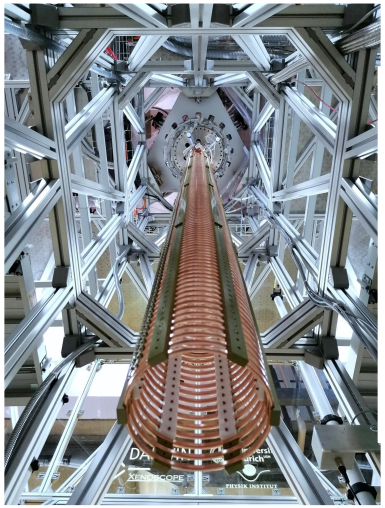


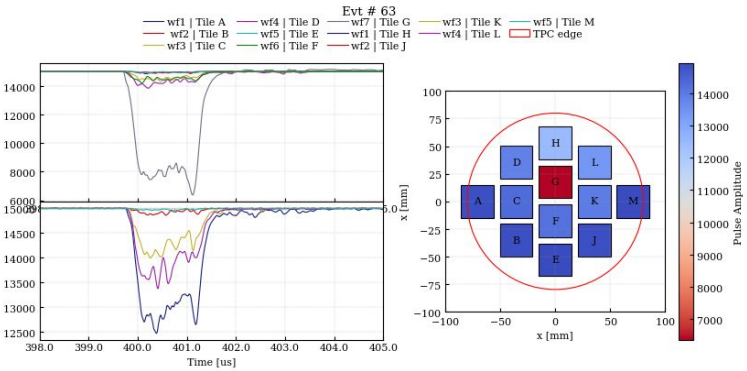
Additional Materials & Backup

Xenoscope at the University of Zurich

- **Vertical demonstrator:**
  - Electron drift over 2.6 m ,~400 kg of xenon
  - Custom HV
  - Electron cloud diffusion
  - Optical properties of Xe

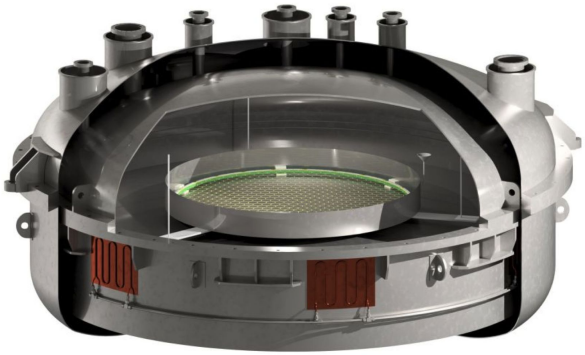
- Purity monitor ✓
- **TPC** - commissioning
  - 173 shaping rings - 16 cm ∅
  - Top SiPM array
  - HV up to 50 kV
  - Levelling system



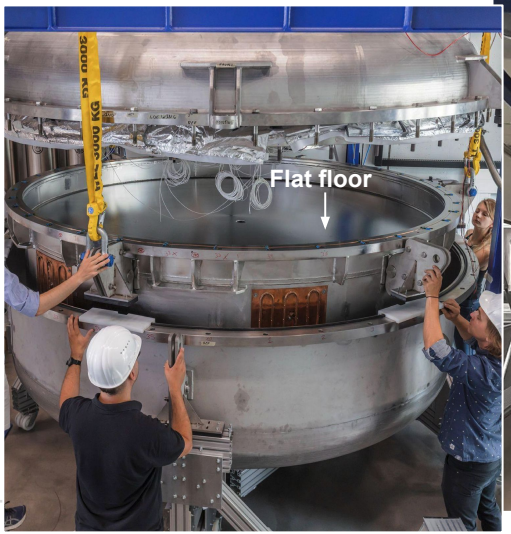


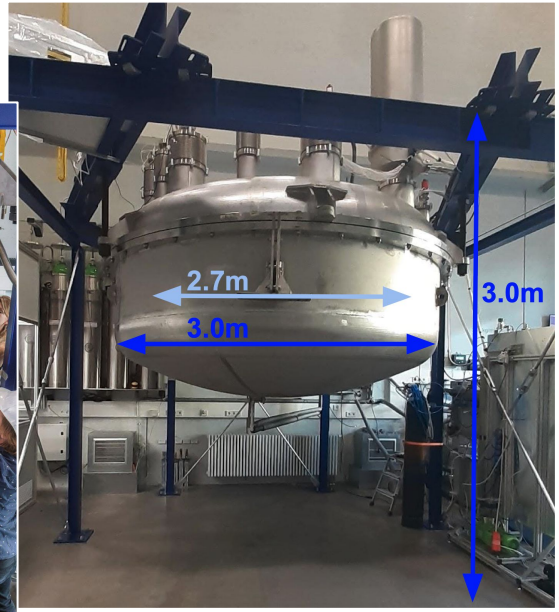
JINST 16, P08052 (2021), Eur. Phys. J. C 83, 717 (2023)

Pancake at the University of Freiburg



- **Test full-scale components & concepts**
  - **Test in**: LXe, cold gXe, under HV
  - **Probe**: sagging, e- emission, large-scale cooling
- 5 t stainless steel & double-walled cryostat
- Successfully commissioned ✓
- Instrumented with PMTs & cameras ✓
- **Tests of electrode performance**

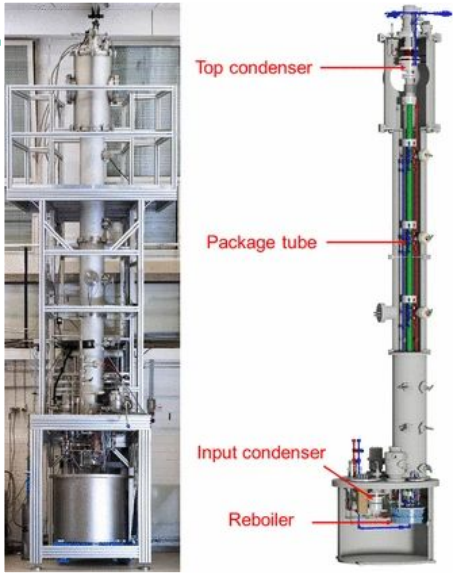


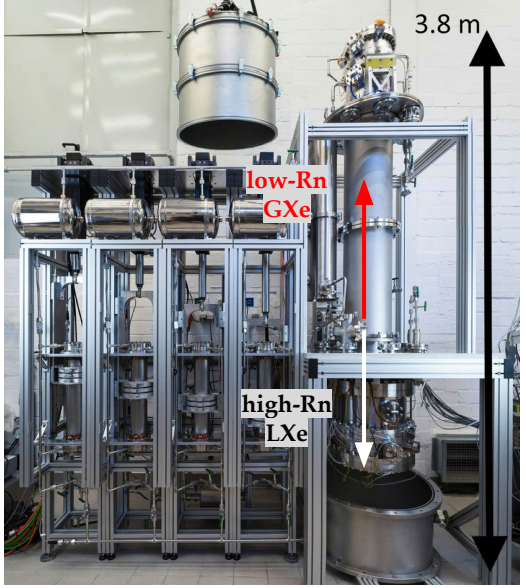


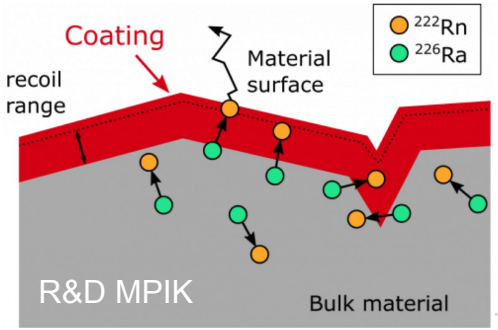
JINST 19 (2024) P05018

Background mitigation

- **^{85}Kr distillation** - goal of 0.1 ppt ^{nat}Kr
  Achieved <0.026 ppt
- **^{222}Rn distillation** - goal of 0.1 μBq/kg
  Achieved ~0.8 μBq/kg
- U. Münster - LowRAD (ERC AdG)
- **Cu coating** against radon emanation
  Electrochemical deposition of Cu
- **Material screening:**
  Radio-pure materials with low Rn-emanation





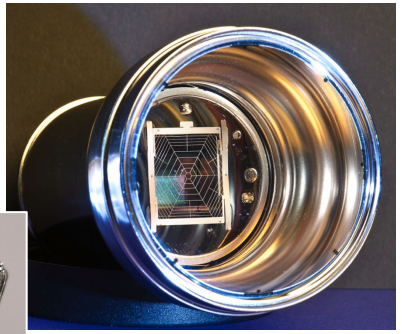


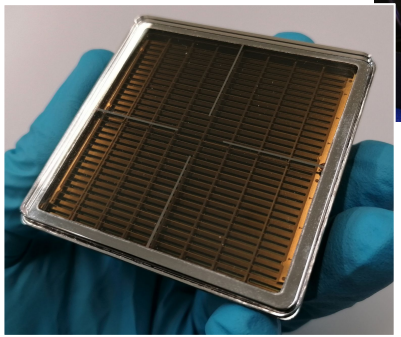
Photosensors

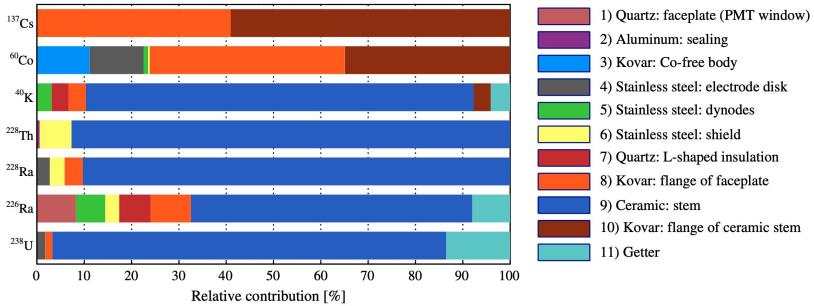
Baseline Design with PMTs

- Established technology, low dark count rate (~0.02 Hz/mm^2), high QE (30-40%)
- Radiopurity improvement on 3” PMTs

- **UZH** - testing square 2” PMTs - lower buoyancy & sub-ns rise time
- Characterisation of SPE response, dark counts, light emission, afterpulsing
- R&D & study of other photosensors…







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