DARWIN/XLZD
The Future of Direct Dark Matter Detection

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Annual Meeting of the Swiss Physical Society – 13.09.2024

Universität Zürich[UZH]

DARWIN & XLZD

Liquid xenon based detectors have leading sensitivity towards WIMP-nucleon interactions for $m_\chi > 1\,\mathrm{GeV/c^2}$

XENON-LUX-ZEPLIN-DARWIN

- Focus years of experience in liquid xenon (LXe) detector technology.
- Combine forces and resources in a new collaboration to achieve a common goal.

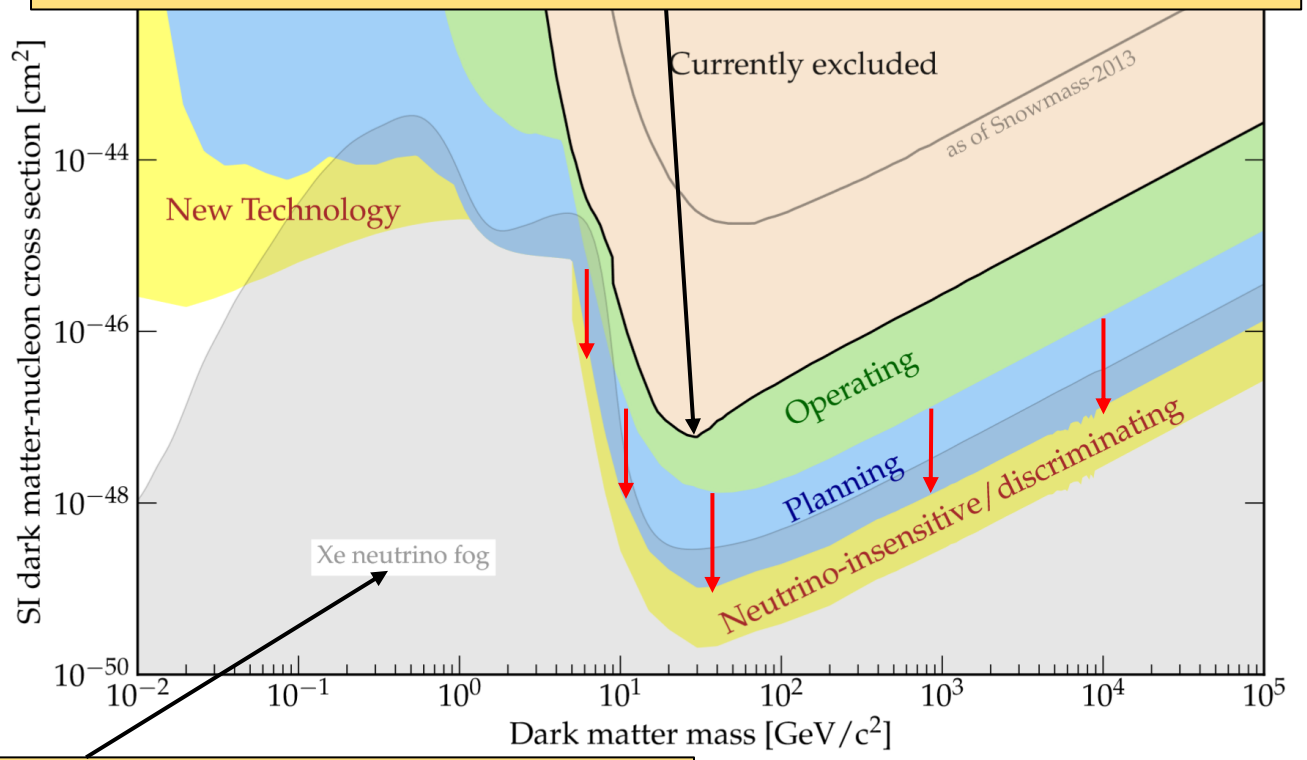
→ WIMP search down to the neutrino fog

DARWIN

- Ongoing R&D for the next generation LXe detectors.
- Two large scale demonstators currently in operation.

Snowmass Cosmic Frontier Report (2022), arXiv:2211.09978v1

Current-gen about 1 order of magnitude from neutrino fog



ν-nucleus interactions become irreducible background

XLZD Baseline Design

XENONnT

Mass:	8.6 t
Max. *e*-drift:	1.5 m
Location:	LNGS

LUX-ZEPLIN

Mass:	10 t
Max. *e*-drift:	1.5 m
Location:	SURF

- ~3 m diameter
- ~2400 3”-PMTs
- Drift field up to 240-290 V/cm
- Extraction field up to 6-8 kV/cm

Mass:	78 t
Max. *e*-drift:	~3 m
Location:	*LNGS, SURF, Boulby, …*

XLZD Baseline Design

Science channels

Dark matter
- WIMPs
- Axion-like particles
- …

Neutrino physics
- *CEvNS*
- Solar neutrinos
- Supernova neutrinos
- $o\nu\beta\beta$-decay of ^{136}Xe
- …

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- ~2400 3”-PMTs
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Mass:	78 t
Max. *e*-drift:	~3 m
Location:	*LNGS, SURF, Boulby, …*

Challenges

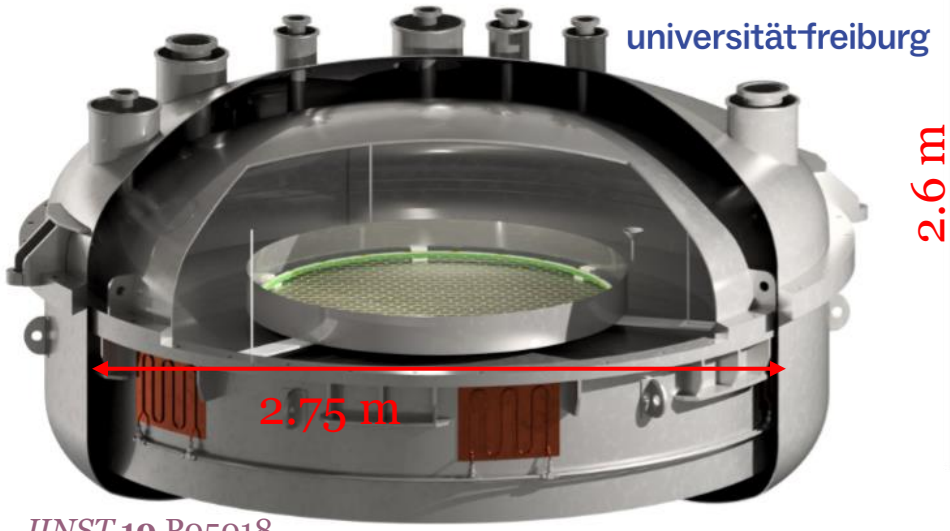
Scalability:

- High-voltage system
  - Delivery
  - Electrode design and operation
  - E-Field homogeneity
- Photosensor performance
- Background mitigation
- …

DARWIN R&D – Demonstrators

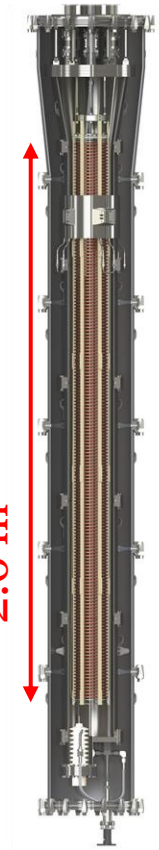
- Scalability
- Choice of photosensor
- Background mitigation

Horizontal demonstrator – Pancake



JINST **19** P05018

Vertical demonstrator – Xenoscope

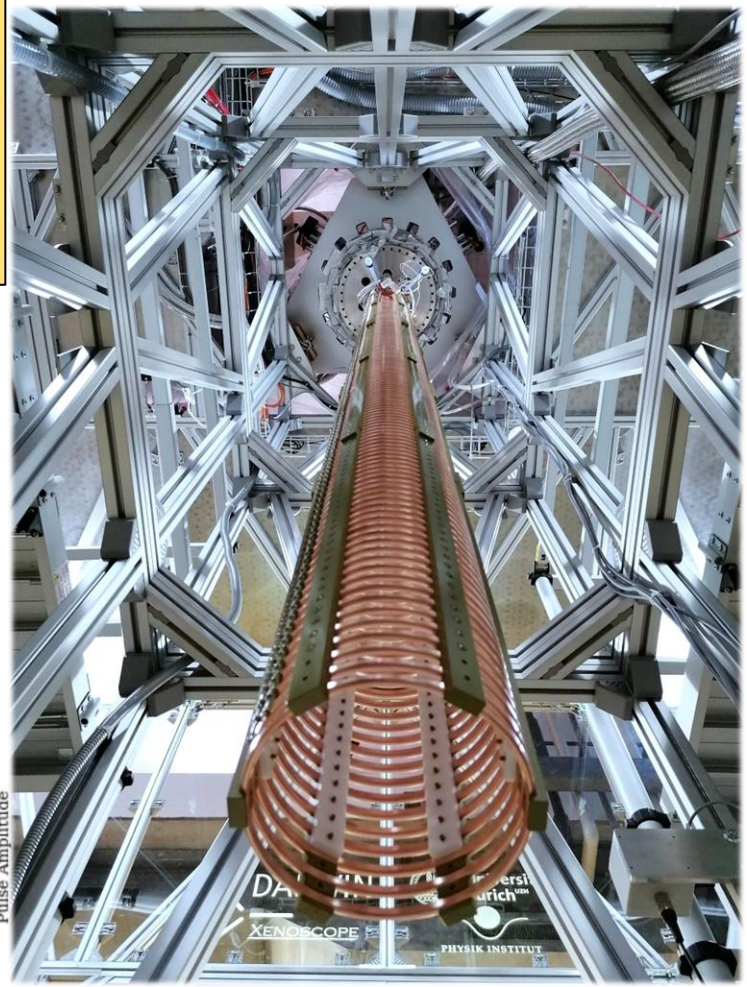


JINST **16** P08052
Eur. Phys. J. C **83**, 717 (2023)

DARWIN R&D – Xenoscope

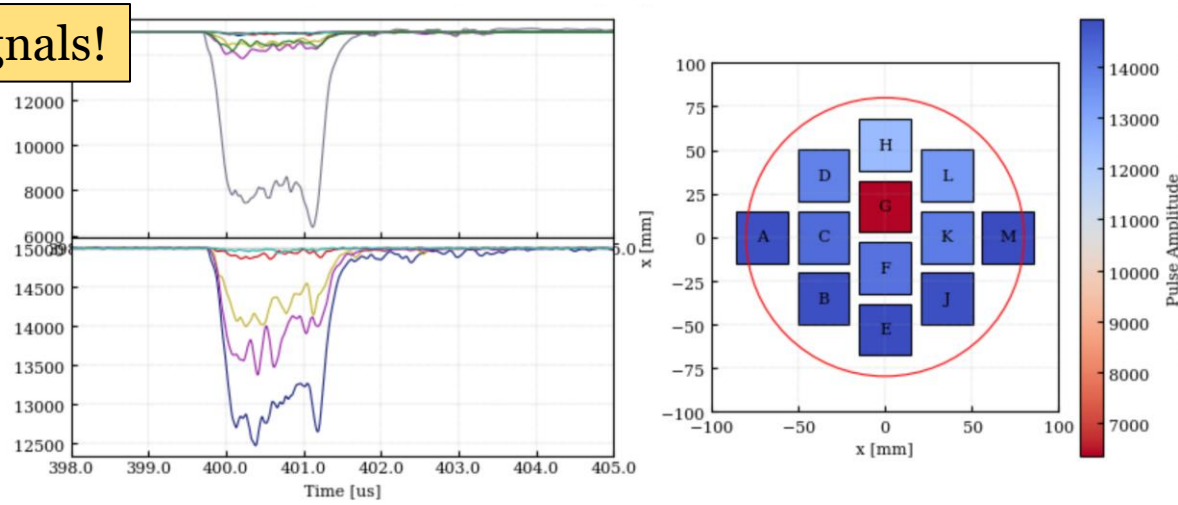
- Scalability
- Choice of photosensor
- Background mitigation

Goals:
- Drift electrons over 2.6 m
- Study e⁻-cloud diffusion
- Custom HV-delivery
- R&D platform for SiPM testing



Successful commissioning as a dual-phase TPC employing:
- ~350 kg of xenon
- 2.6 m tall field cage
- Liquid levelling system
- Top SiPM array

First S2 signals!

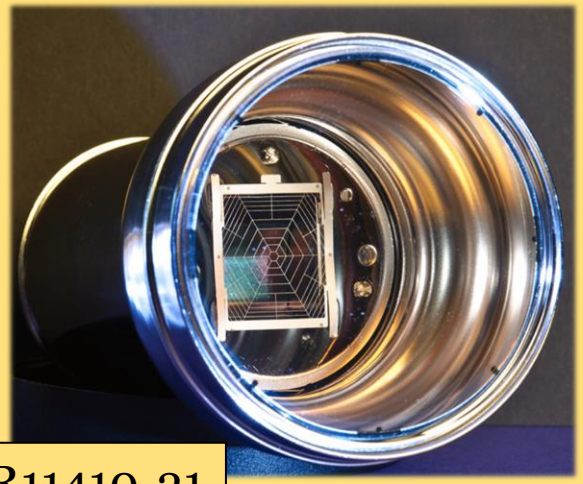


DARWIN R&D – Photosensors

- Scalability
- Choice of photosensor
- Background mitigation

And more:
- Digital SiPMs
- Hybrid sensors
- …

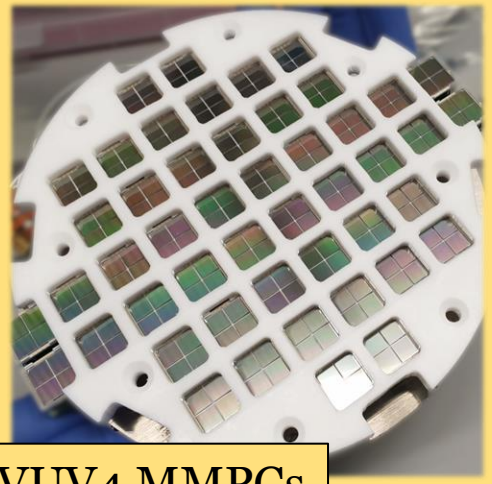
PMTs



R11410-21

+ Very low dark count rate
– Bulky

SiPMs



VUV4 MMPCs

+ Compact
+ Low cost per unit
– High dark count rate

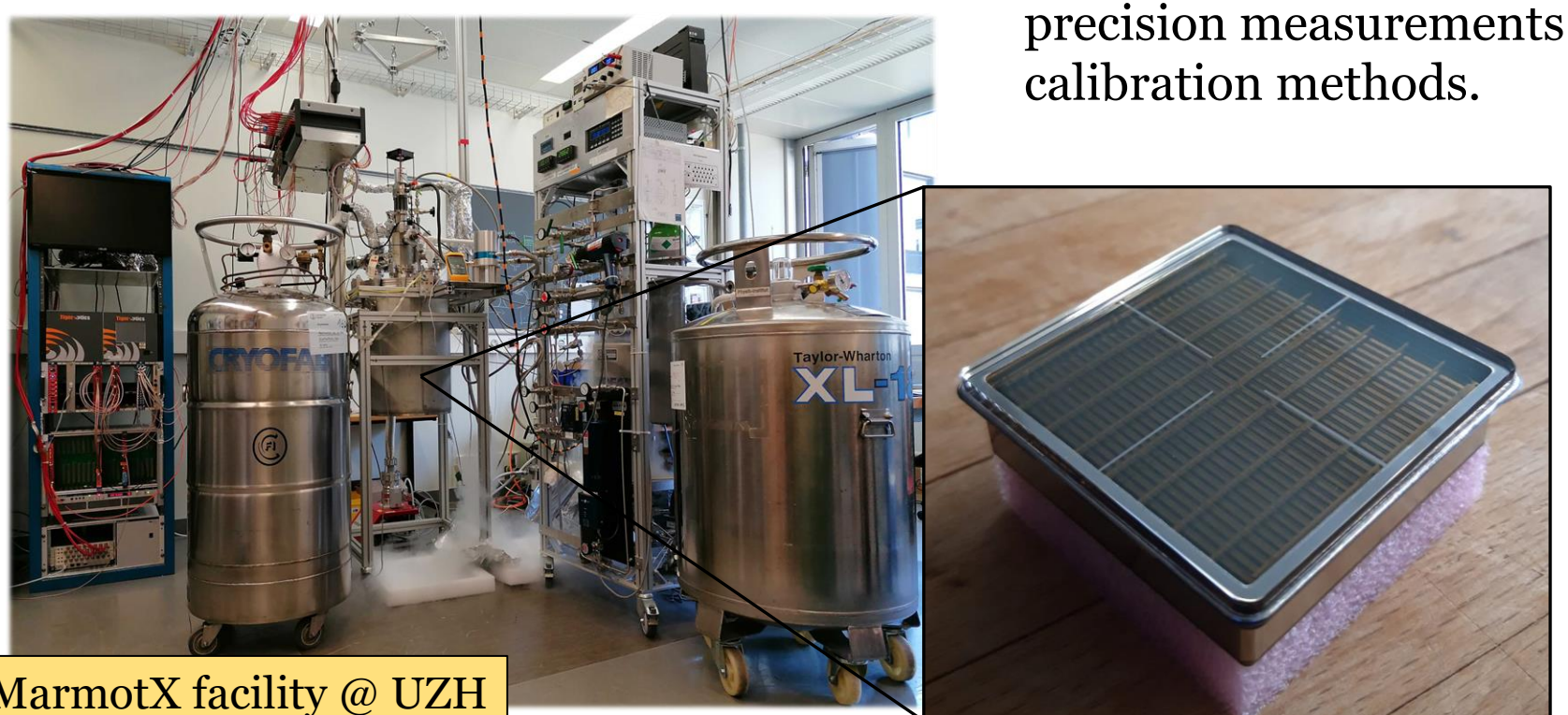
Employed in all current-generation TPCs!

DARWIN R&D – Photosensors

- Scalability
- Choice of photosensor
- Background mitigation

Hamamatsu R12699-406-M4
A square-shaped multianode PMT

- Calibration with a focus on long-term stability in a cryogenic xenon environment.
- Design and construction of a kg-scale TPC for precision measurements and testing new TPC calibration methods.



MarmotX facility @ UZH

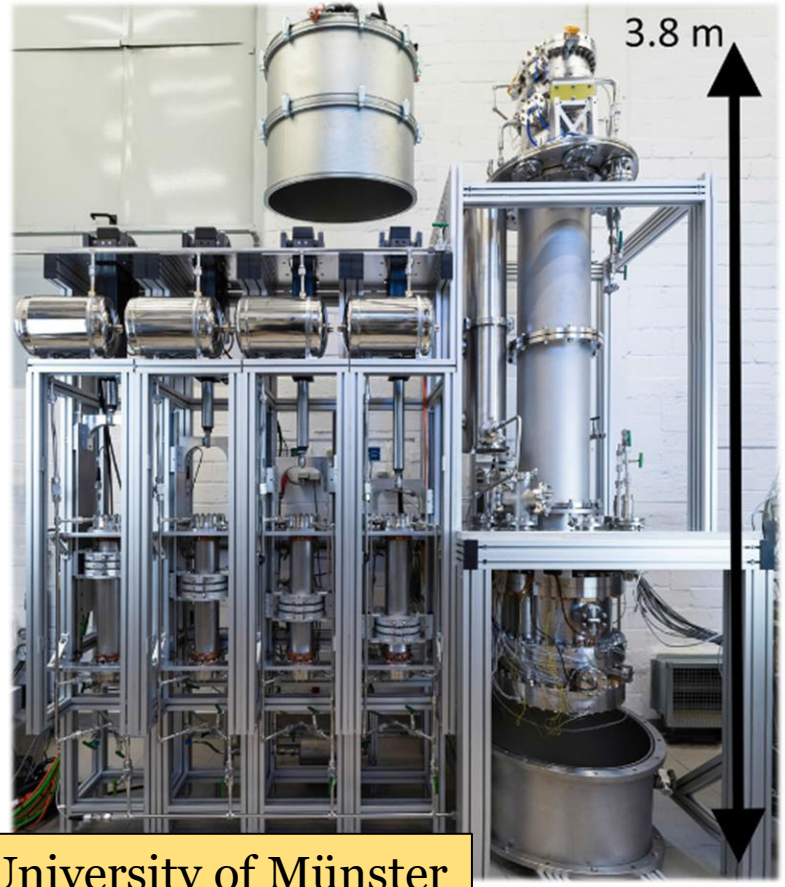
DARWIN R&D – Background Reduction

- Scalability
- Choice of photosensor
- Background mitigation

Xenon purification in high-flow distillation column:

- Achieved in XENONnT
  - ^{222}Rn < 1 µBq/kg
  - ^{85}Kr < 26 ppq

Goal: ^{222}Rn < 0.1 µBq/kg
^{85}Kr < 200 ppq

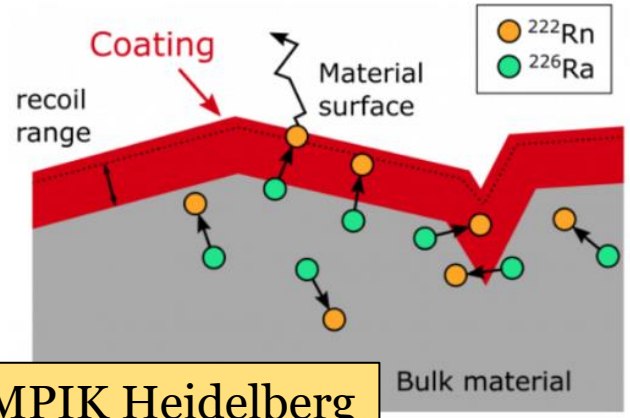


University of Münster

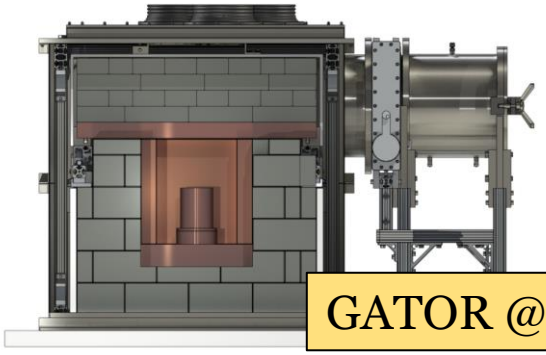
Eur. Phys. J. C (2022) **82**: 1104

Mitigating radon-emanation:

- Coating techniques
- Rigorous screening and selection of radio-pure materials



MPIK Heidelberg



GATOR @ LNGS

Summary

- The XENON-LUX-ZEPLIN-DARWIN collaboration aims to build a next generation LXe detector for WIMP searches down to the neutrino fog in a joint effort.

- Extensive R&D efforts are ongoing to address the challenges arising from the unprecedented scale.

  - Scalability → Large scale demonstrators Pancake & Xenoscope.
  - Photosensors → Numerous photosensors are being studied.
  - Background mitigation → Purification, mitigation and selection.

Back Up

PMT v. SiPM

	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

Table provided by R. Peres

Two-Phase Time Projection Chambers

Search for: Particle scattering off of Xe-nucleus

- Signal generation in xenon target
  - Prompt scintillation signal S1
  - Delayed charge signal S2

→ Electronic recoil discrimination via charge-to-light ratio, S2/S1

- Event reconstruction:
  - x-y position from S2 *hit-pattern*
  - z position from Δt
  - $E \propto (n_\gamma + n_e)$