XLZD

A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics

Uwe Oberlack
on behalf of the XLZD Consortium

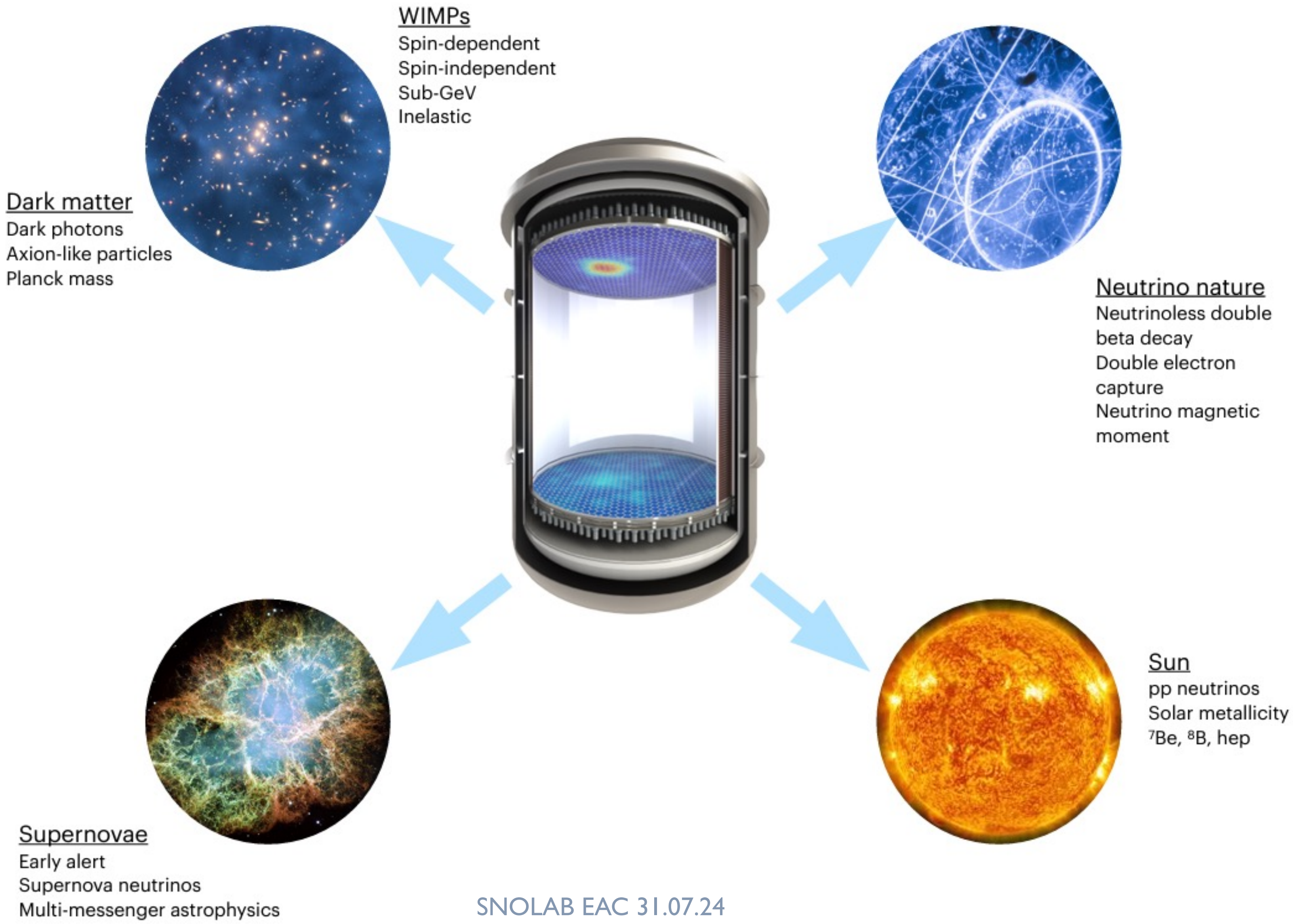
Johannes Gutenberg University Mainz

31 July, 2024

Many thanks for slide input!
Henrique Araujo, ICL
Laura Baudis, UZH

SNOLAB EXPERIMENT ADVISORY COMMITTEE MEETING

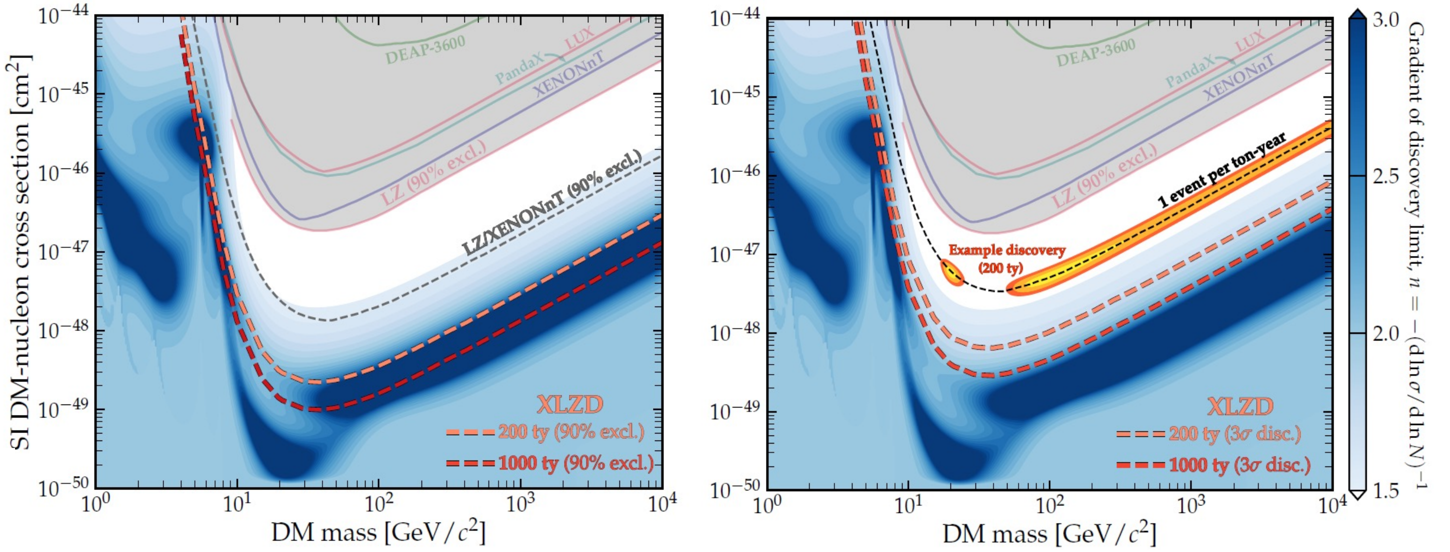
XLZD: THE DEFINITIVE LIQUID XENON RARE EVENT OBSERVATORY

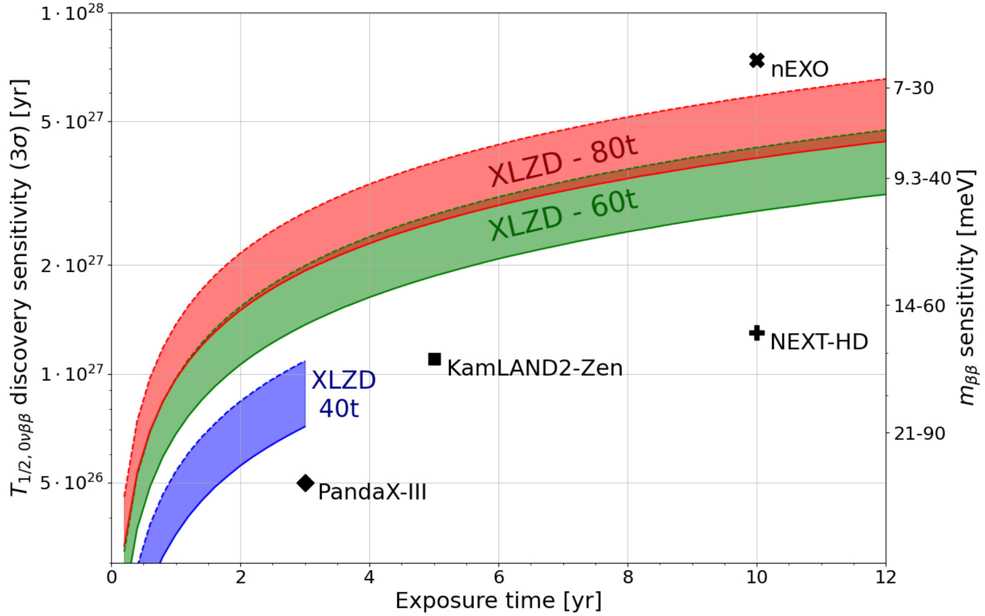


XLZD: THE DEFINITIVE LIQUID XENON RARE EVENT OBSERVATORY

A 10-fold scale-up in target mass compared to existing experiments will poise XLZD to make at least two ground-breaking discoveries

- **WIMP dark matter**
  cover fully the available parameter space down to the "neutrino fog":
  not only to "rule out" these popular models if no signal is found, but to actually discover a faint signal hiding where the neutrino fog sets in.





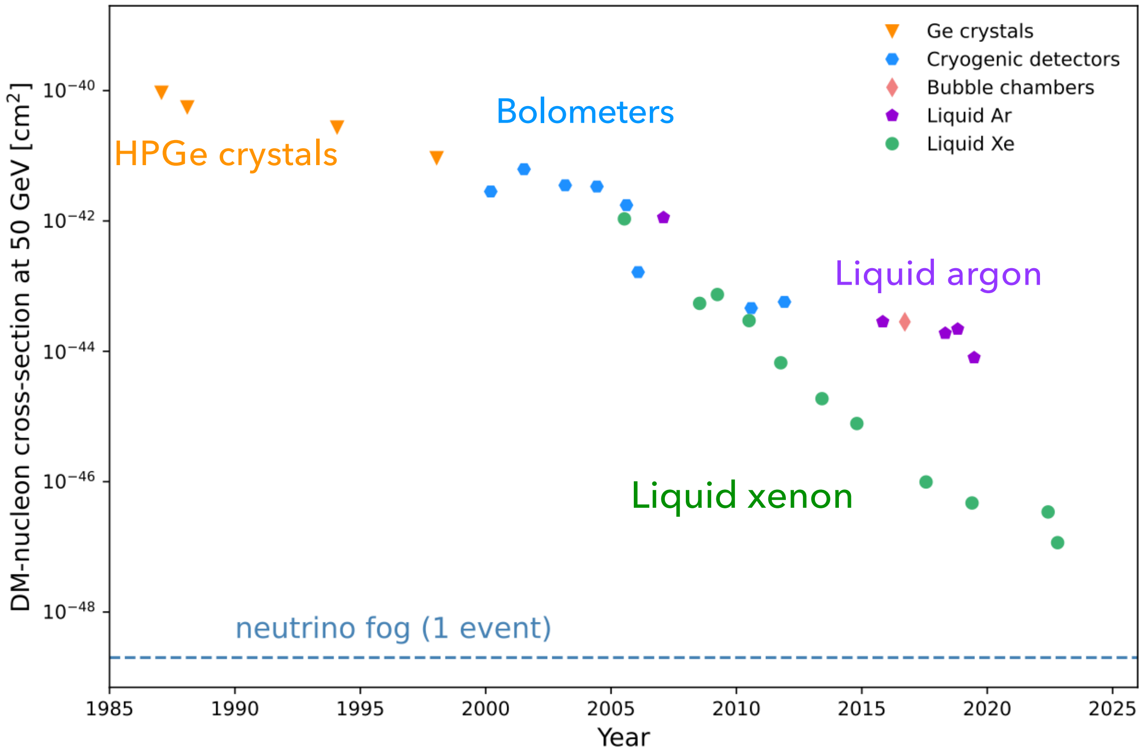
- **Neutrinoless double beta decay in Xe-136**:
  competitive search with the potential to match the best dedicated experiments; sensitivity paper out soon
- **Plus:** other physics involving **astrophysical neutrinos**, **rare nuclear decays**, **more exotic dark matter models**
  [J.Phys.G 50 (2023) 1, 013001]

An ambitious experiment enables a broad science case,
→ essential given the scale of investment!

Liquid xenon detectors

- Leading sensitivity at intermediate / high DM masses since ~2007
- Advantages
  - scalable ⇒ large target masses
  - readily purified ⇒ ultra-low backgrounds
  - high density ⇒ self-shielding
- SI and SD (^{129}Xe, ^{131}Xe) interactions
- Many other science opportunities (second order weak decays of ^{124}Xe, ^{126}Xe, ^{134}Xe, ^{136}Xe; solar and supernova neutrinos)

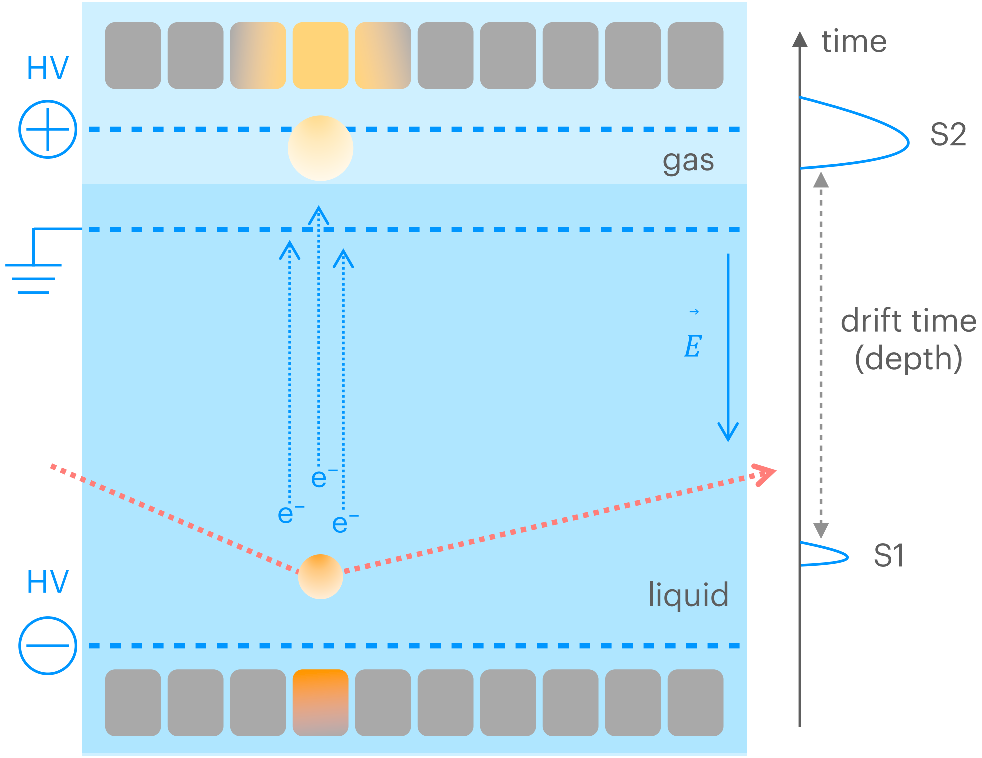
Upper limits for a 50 GeV WIMP



Time

Two-phase xenon TPCs

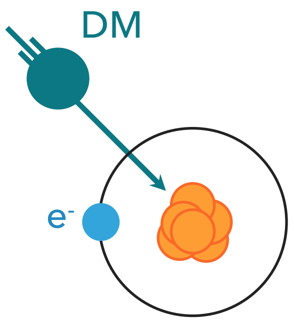
5D detectors: (x,y,z,E,t)

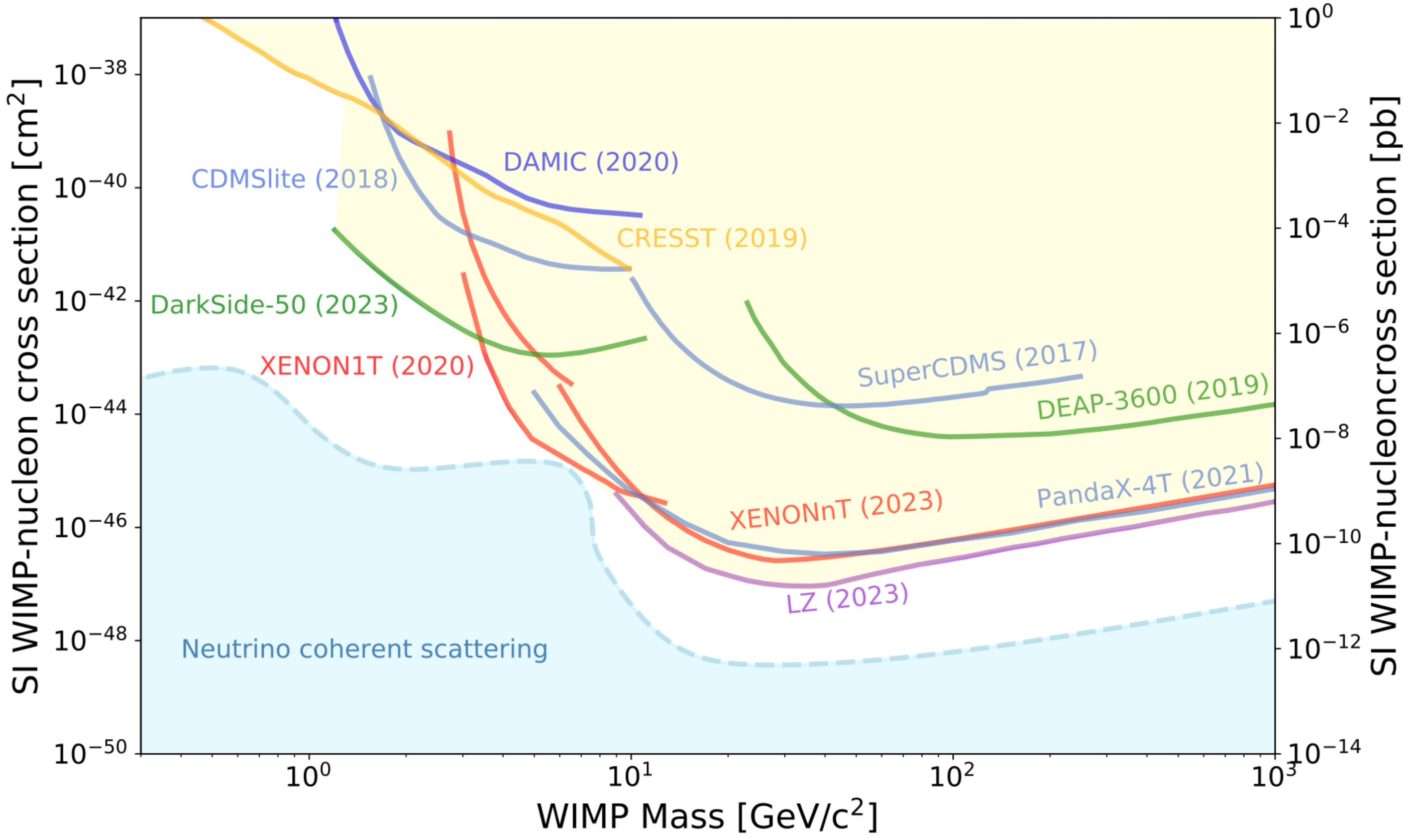


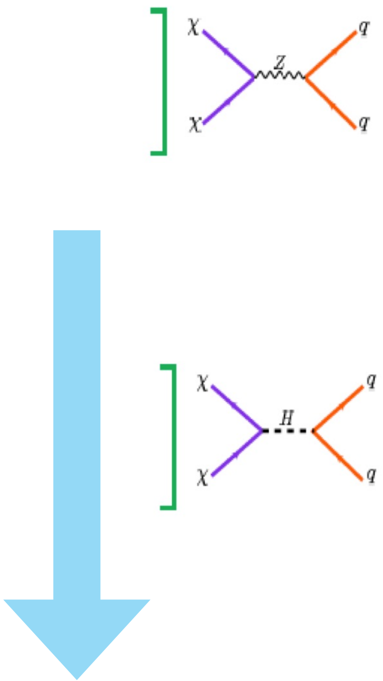
$\lambda_{LXe} = 175\ \text{nm}$

- Observe light (S1, primary scintillation) and charge signals (S2, secondary scintillation) when a particle interacts in the dense liquid
- 3D position reconstruction
- Energy reconstruction
- Particle discrimination: ratio of charge/light (ER vs. NR)

Towards the neutrino fog







Laura Baudis and Stefano Profumo, PDG 2024

Ongoing LXe experiments

LUX-ZEPLIN

SURF, 7 t

XENONnT

LNGS, 5.9 t

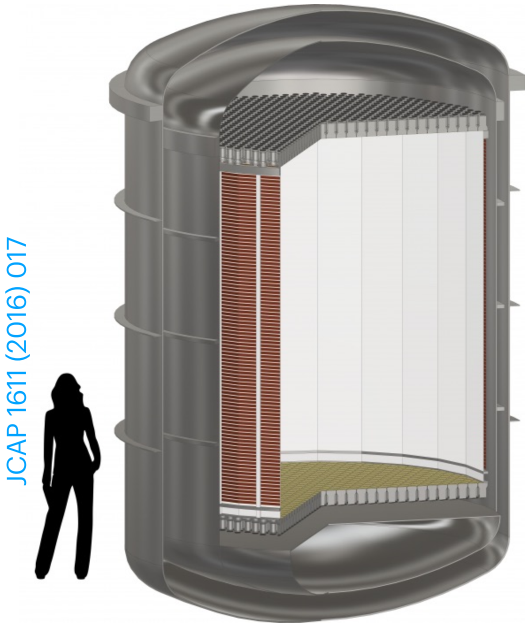
PandaX-4T

JinPing, 3.7 t

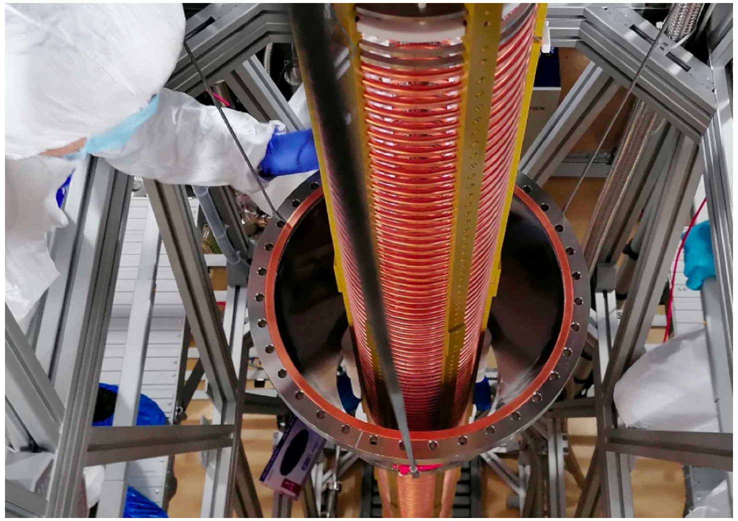
- TPCs with 2 arrays of 3-inch ø PMTs
- Kr & Rn removal techniques (to mitigate ^{85}Kr and ^{222}Rn backgrounds)
- Neutron & muon vetos, ultra-pure water shields, liquid scintillator

DARWIN R&D

- R&D for next-generation liquid xenon detector
- Several large-scale demonstrators in operation (3 ERCs)
- Photosensors, TPC design, large-scale purification, Rn removal, Gd-loaded water, etc.



DARWIN collaboration
JCAP 1611 (2016) 017

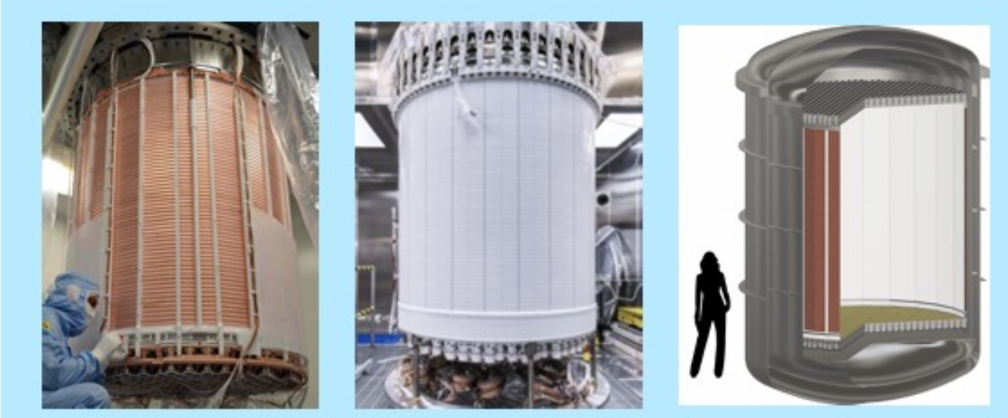


Xenoscope at UZH
L. Baudis et al., JINST 16, 2021, EPJ-C 83, 2023

Pancake in Freiburg
A. Brown at al., JINST 19, 2024

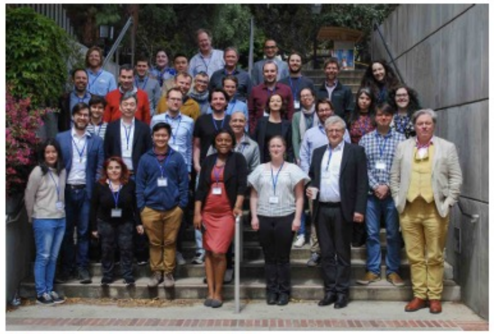
XENON-LUX-ZEPLIN-DARWIN

- XLZD Consortium MoU signed by 104 senior researchers from 16 countries in July 2021
- Steering Committee and Working Groups in place, regular meetings; "Design Book" in preparation
- The new collaboration to build & operate the next-generation experiment is forming right now
- Our team(s) are operating the largest, world-leading LXe-TPCs: LZ and XENONnT



DARWIN

KIT, summer 2022



UCLA, spring 2023

RAL, spring 2024

CANDIDATE LABORATORIES

Facilities and locations being considered, “leading to the down-selection of those sites that meet key physical and infrastructure requirements, i.e. those laboratories where such an experiment can deliver its science mission fully.”

Location		**Depth**		**Muon flux**
Kamioka (JP)	/Lab-C	1,000 m	2,700 m w.e.	128 $/m^2/d$
LNGS (IT)	/Hall C	1,400 m	3,800 m w.e.	29.7 $/m^2/d$
Boulby (UK)	/New	1,300 m	3,330 m w.e.	14.6 $/m^2/d$
SURF (USA)	/New	1,490 m	4,300 m w.e.	4.6 $/m^2/d$
SNOLAB (CA)	/Cube Hall	2,070 m	5,890 m w.e.	<0.3 $/m^2/d$

SELECTING A FACILITY TO HOST XLZD

- Over the past 1-2 years we have developed requirements motivated by
  - i) the science we want to do (driven by dark matter and $0\nu\beta\beta$ decay searches)
  - ii) the infrastructure needed to support that science
- The "baseline" XZLD experiment considered was essentially that in a "Design Book" which is about to be published (60-80 tonnes of active xenon mass)
- The XLZD Siting Working Group included several sub-teams
  - Underground science experts; backgrounds experts; infrastructure experts
  - Each candidate laboratory had a formal liaison to XLZD
- **We have concluded the first part of this work with a preliminary shortlist**

In view of the foregoing considerations, the XLZD Siting Working Group has formally short-listed Boulby, LNGS and SURF to proceed to a final decision on host site in consultation with key stakeholders, which is due in mid/late 2025. Kamioka remains a backup option should funding or technical impediments arise for all other facilities. SNOLAB could also be suitable for hosting a smaller experiment but in this case there is no funding path to expand the facility.

NOTE: THIS IS AN INTERNAL XLZD DOCUMENT, BUT ALL LABS HAVE SEEN IT.

REPORT SCOPE

INTERIM REPORT

XLZD-TN-2024-XXX

SHORTLISTING OF UNDERGROUND LABORATORIES
TO HOST A NEXT-GENERATION LIQUID XENON OBSERVATORY
FOR RARE EVENT SEARCHES

DRAFT

For the XLZD Consortium:

D.S. Akerib[†1], H.M. Araújo[†*2], A.-P. Colijn[3], J. Cuenca[4], P. Decowski[3], P. Di Gangi[5], Y. Itow[†6], V.A. Kudryavtsev[7], A. Lindote[8], M. Schumann[9], A. Schwenck[10], M. Selvi[†*5], T.J. Sumner[2], D. Taylor[11], K. Valerius[10], B. von Krosigk[†10], and R. Wang[12]

[1]SLAC National Accelerator Laboratory, [2]Imperial College London, [3]Nikhef & the University of Amsterdam [4]University of Zurich, [5]University of Bologna & INFN-Bologna, [6]Nagoya University, [7]University of Sheffield, [8]LIP-Coimbra & University of Coimbra, [9]University of Freiburg, [10]Sanford Underground Research Facility, [11]Karlsruhe Institute of Technology, [12]University of Alabama

[†]Underground laboratory liaison roles
[*]Lead contacts: h.araujo@imperial.ac.uk; selvi@bo.infn.it

April 12, 2024

Issue 1.4

DOCUMENT CLASSIFICATION TBC

Contents

1 Introduction **5**

2 Candidate Sites **7**
2.1 Boulby Underground Laboratory (UK) 8
2.2 Kamioka Observatory (JP) 9
2.3 Laboratori Nazionali del Gran Sasso (IT) 10
2.4 SNOLAB (CA) 11
2.5 Sanford Underground Research Facility (USA) 12
2.6 Test Facility 13

3 Physics Backgrounds Requirements **14**
3.1 Cosmogenic backgrounds 14
3.2 Shielding the main detector 17
3.3 Airborne radon 19
3.4 Additional local shielding 20

4 Infrastructure Requirements **22**
4.1 Underground facility 22
4.2 Surface facility 26

5 Additional Considerations **29**

6 Compliance Matrix **32**
6.1 Explanatory notes 33

7 Summary and Shortlist **34**

XLZD@SNOLAB?

- We need to know more about how SNOLAB would meet some of our requirements related to availability of space underground and other constraints
- Without this additional information it is fairly clear to us that SNOLAB could only host a smaller experiment

The space available presently at SNOLAB is insufficient to support the nominal XLZD plans. This conclusion derives from the footprint required for installation of XLZD subsystems and is reinforced by the need for significant spaces for underground manufacture, which are not presently available to the extent required. SNOLAB has conceptual-phase plans to expand, but there is currently no path to funding for these developments.

SNOLAB It may be possible to meet INS-UG-0010 with a smaller water tank, but additional confirmation is needed; for this reason both this requirement and INS-UG-0030 are orange. Additional space (INS-UG-0020) is insufficient to accommodate all XLZD subsystems, and a multi-level service building cannot be located in the Utility Drift since this lacks sufficient height. A more extensive facility for OD process plants under INS-UG-0030 cannot be provided. The liquid nitrogen supply (FAC-UG-0020) does not meet requirement of 3,000 L/day, although the existing capacity indicated could in the table could be doubled. The conveyance constraints are severe (FAC-UG-0105) – cf. Section 2.4 – such that extensive underground manufacture would be required. However, the available spaces for clean manufacture are also limited (e.g. FAC-UG-110) (TBC).

Specific requirements not met or not met in full (this remains TBC)

XLZD@SNOLAB?

Requirement ID	Note	SNOLAB
SR-XLZD-SCI-BG-0010	Muon (DM)	
SR-XLZD-SCI-BG-0020	Muons ($0\nu\beta\beta$)	
SR-XLZD-INS-UG-0010	Space 1	280 m^2
SR-XLZD-INS-UG-0020	Space 2	208 m^2
SR-XLZD-INS-UG-0025	Space 3 (OD)	
SR-XLZD-INS-UG-0027	LS	
SR-XLZD-INS-UG-0030	Tank	
SR-XLZD-INS-UG-0035	Crane(19.5)	~18.5 m
SR-XLZD-INS-UG-0037	Crane(15)	
SR-XLZD-FAC-UG-0010	Radioassay	
SR-XLZD-FAC-UG-0020	LN2 supply	300 L/day
SR-XLZD-FAC-UG-0030	Ventilation	
SR-XLZD-FAC-UG-0040	Radon	TBC
SR-XLZD-FAC-UG-0050	Comms	
SR-XLZD-FAC-UG-0060	Power	
SR-XLZD-FAC-UG-0070	Workshop	
SR-XLZD-FAC-UG-0080	Messroom	
SR-XLZD-FAC-UG-0090	Goods-in	
SR-XLZD-FAC-UG-0100	Storeroom	
SR-XLZD-FAC-UG-0105	Max size	TBC
SR-XLZD-FAC-UG-0110	Manufacture	TBC
SR-XLZD-FAC-UG-0120	Cleaning	TBC
SR-XLZD-FAC-UG-0130	Assembly	TBC
SR-XLZD-FAC-SF-0010	Surface	

Specific requirements not met or not met in full (this remains TBC)

NEXT STEPS

Presentations by the laboratories to XLZD over the summer

- XLZD must scrutinise the information presented; the shortlist may change if new information emerges
    - Describe the proposed facility and location, and how XLZD could be accommodated (e.g. CAD layout)
    - State how orange and red requirements could be met or circumvented
    - What else is on offer to attract XLZD to that location

- **SNOLAB will be invited to present too**
    - We are happy to continue to liaise with SNOLAB to explain our requirements and understand the "fit"
    - In any case, SNOLAB could host a smaller XLZD experiment and our contact should continue!

Thank you!