May 21, 2026

Xe Dark Matter Experiment Status and Future

Rick Gaitskell, Brown University

Spokesperson for LZ Experiment

Funded by US DOE

IDM2026, June 3, 2026

25 min Summary

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Acknowledge my membership of LZ (LUX-ZEPLIN) Collaboration, 38 instituti

@lzdarkmatter

250 scientists, engineers, and technical staff

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
- Texas A&M University
- University of Albany, SUNY
- University of Alabama
- University of Bristol
- University College London
- University of California Berkeley
- University of California Davis
- University of California Los Angeles
- University of California Santa Barbara
- University of Liverpool
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
- University of Rochester
- University of Sheffield
- University of Sydney
- University of Texas at Austin
- University of Wisconsin, Madison
- University of Zürich

US Europe Asia Oceania

LZ Collaboration Meeting at UCLA, March 2025

https://lz.lbl.gov/

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Etymology

PARANINFO

Greek word *paránymphos*, originally meaning a "matchmaker", which evolved in universities to represent the messenger who formally announced the conferral of a degree

As will become very obvious

NO AI
WAS USED IN THE PREPARATION
OR PRETTIFICATION
OF THESE SLIDES

IDM Veteran, first attended in York in 2000

- Although I have been working in field since 1989
- We hosted IDM at Brown in 2018

LTD IV (Oxford)

I started looking for dark matter using Low Temperature Detectors

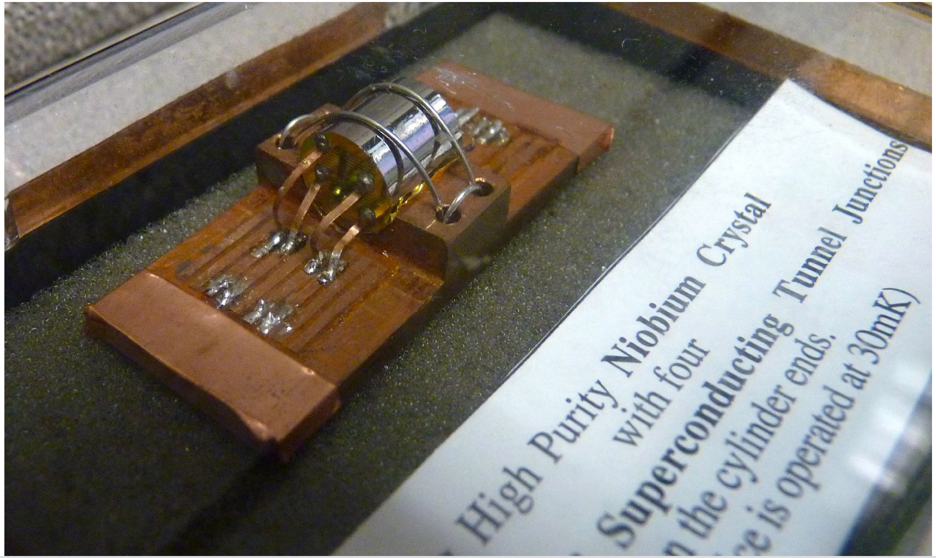
Superconducting Niobium Single Crystal 99.9999% pure ~10 g

Goal was to Trap Quasiparticles from bulk Nb using Al layer and detect trapping photons using Al STJ Arrays

Sixth sense required for dilution fridge diagnostics

Gaitskell (Graduate Work) Superconducting Nb Single Crystal Detector

- 1 cm long - 12 g - 250 eV Threshold - “State of the Art in 1991”
  - Superconducting Tunnel Junction arrays detecting phonons and quasiparticles from Nb



In Early 1990’s we studied exotic lattice photon and quasiparticle states to build sensitive dark matter detectors - today we appear to be coming full circle as see new proposals for MeV DM search experiments based on meV excitons

How does Sensitivity Improve?

You might just say Target Size

Energy Threshold compared to DM Characteristic KE (adjusted for mass)

Time

If competing with (subtracting) Backgrounds T^½

Systematics may inhibit our ability to identify clear signal

Recoil Energy?

WIMPs go at the same characteristic speed as everything else in Milky Way 230 km/s

v/c ~ 0.7 x 10^-3

½ m (v/c)^2 ~ ½ (100 GeV) (0.7 10^-3)^2 ~ 25 ~~GeV~~ ~~MeV~~ keV

If masses are matched then

If target and WIMP are not matched then r = 4 M1 M2/(M1+M2)^2

This is 1 when matched and < 1 as M1 ≠ M2

The lighter of the two objects sets the mass characteristic for KE

The Practical Matter of a Rare Event Search

- In ~33 rd year of searching - now at a sensitivity that 10^6 better than the first round - we need detectors with a

Low Sisyphean Index †

- They must want to work correctly / do so without misleading us / low complexity - mustn't roll back down the hill when we stop paying attention for a moment

- And we will need to push them (pun indented) by another 10^2 before we reach the irreducible coherent neutrino backgrounds

† Experimentalist's Perspective of the Technology itself, not the definition that the task can never be completed

Xe

My colleagues on CDMS thought I was daft when I left that world-leading experiment in 2003 to pursue a new design… bucket detectors using liquid targets

TPC’s are quantum detectors…

We count excitons … photons and electrons from the interaction site

The energy to create an excitation is ~14 eV (for low energy electron event)

This value rises for a nuclear recoils ~70 eV (for low energy nuclear event)

Scintillation is 175 nm (this is conveniently above the edge 160 nm for synthetic quartz/silica/SiO2)

Traditional Xe TPCs don’t make any use of the Heat (but … see SBC)

Quantum Detectors

We typically convert ~10% of scintillation photons into a (single) photon pulse in the photo detectors

- that is 33% of photons hit a photodetector and 33% of those are converted to a signal “QE”
- Teflon is a miracle reflector in liquid Xe for VUV (170 nm) light

In Xe the purity regularly leads to close to >90% drift survival probability for >2 m and >90% liquid-gas extraction

Electrons in gas light up like a Christmas Tree (detect ~40 photons/electron in gas) so we can count individual electrons from 100 tonne targets

Historical Point

Back in 2003 we didn't even know if low energy nuclear recoils in Xe generated any detectable ionization in LXe

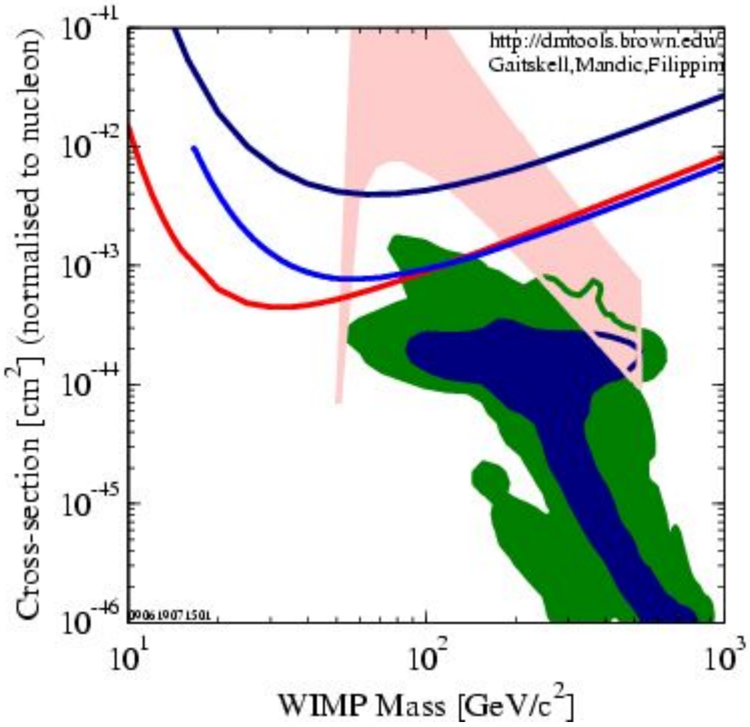
Testing Models of Particle Dark Matter in 2008

Lines show sensitivity limits of then active direct detection experiments - CDMS, XENON10, ZEPLIN III …

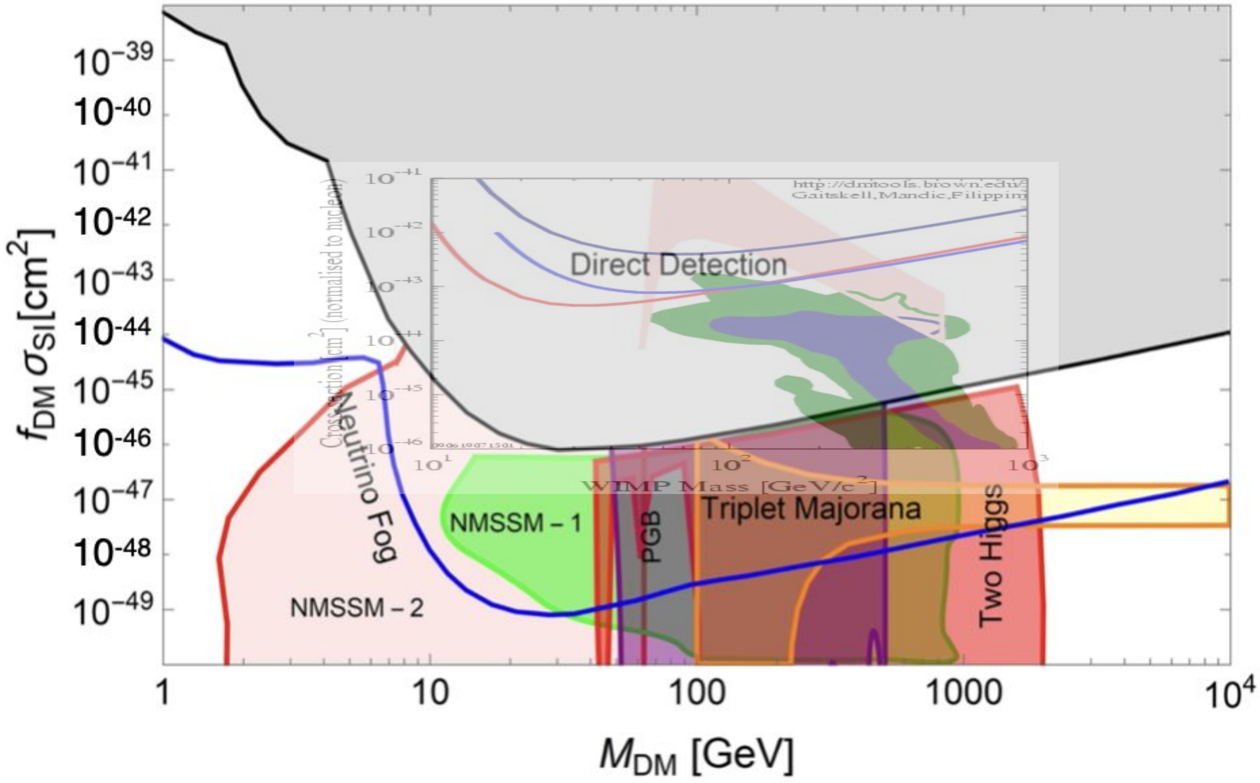
Shaded Areas are Regions from Different Theories that include Dark Matter Particles

(Red) Ellis et al MSSM

(Blue, Green) Trotta et al

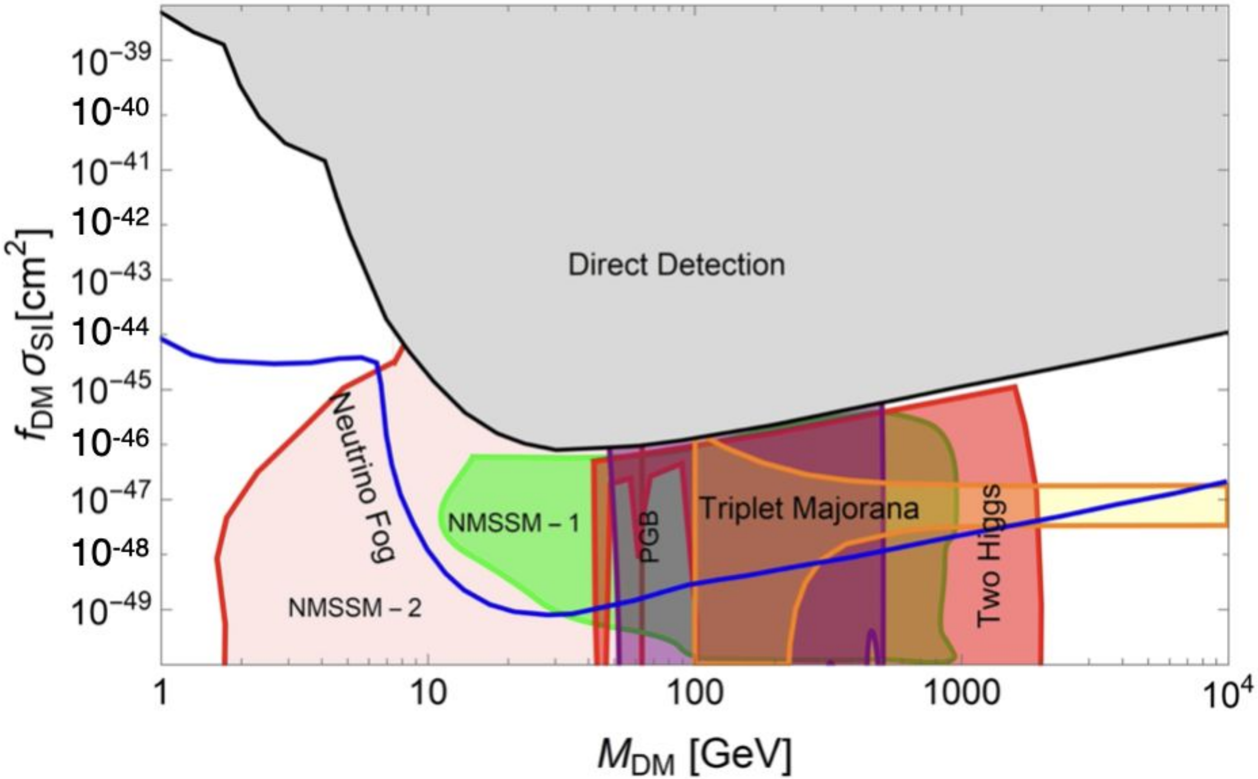


Testing Models of Particle Dark Matter (2008 -> 2016)

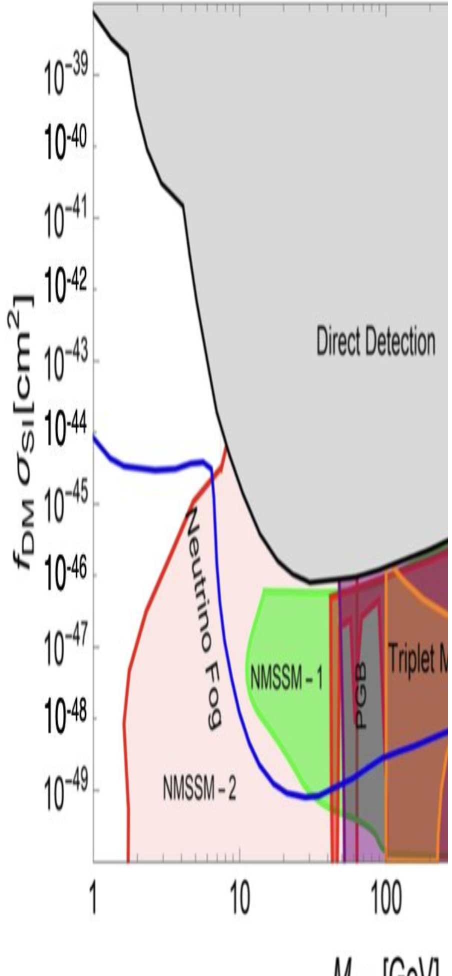


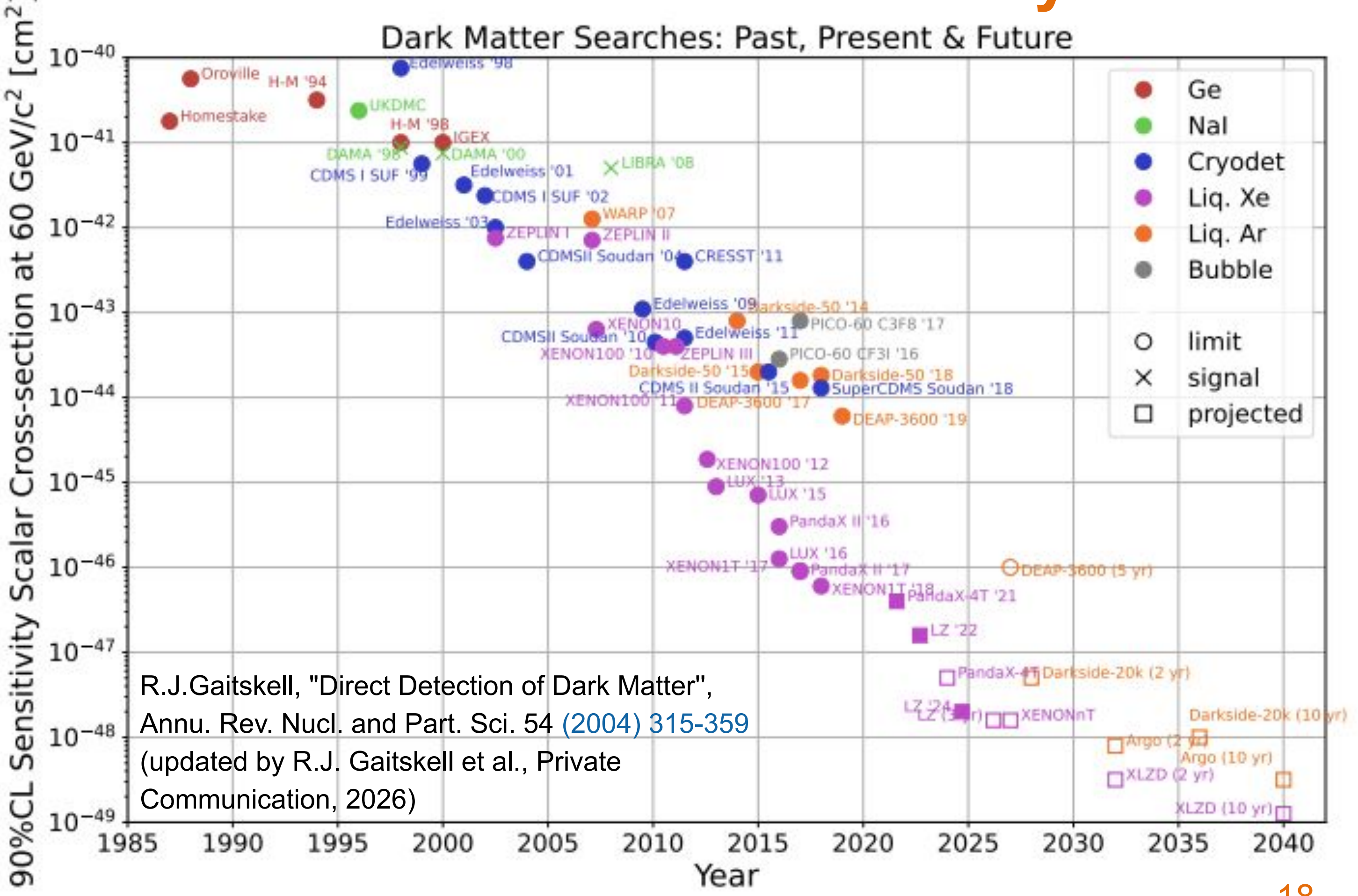
Testing Models of Particle Dark Matter in 2016

XENON100, LUX, PandaX Search Results



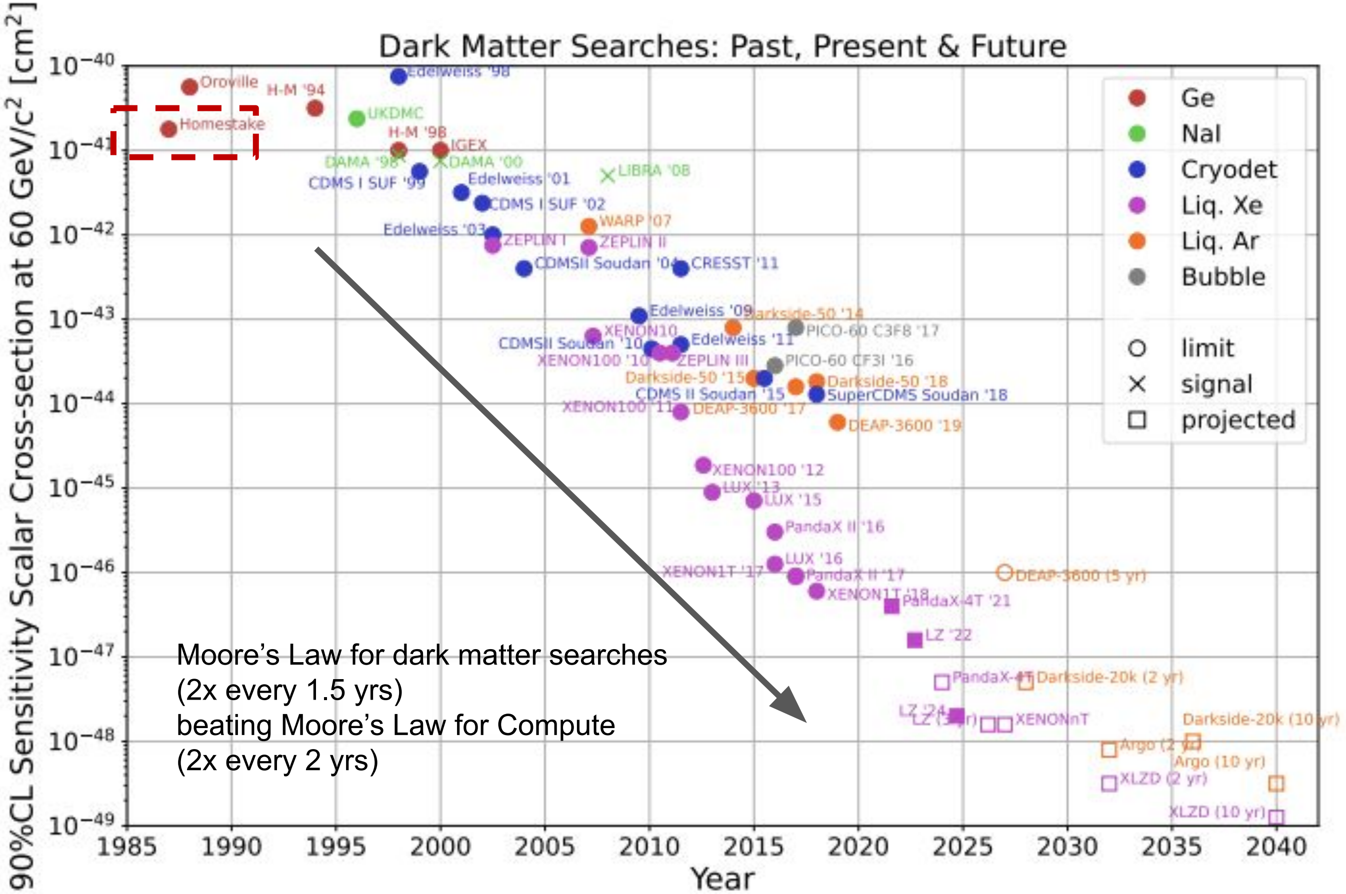
Search for WIMP Dark Matter 1986-2026 and Beyond





R.J.Gaitskell, "Direct Detection of Dark Matter", Annu. Rev. Nucl. and Part. Sci. 54 (2004) 315-359 (updated by R.J. Gaitskell et al., Private Communication, 2026)

Search for WIMP Dark Matter 1986-2026 and Beyond

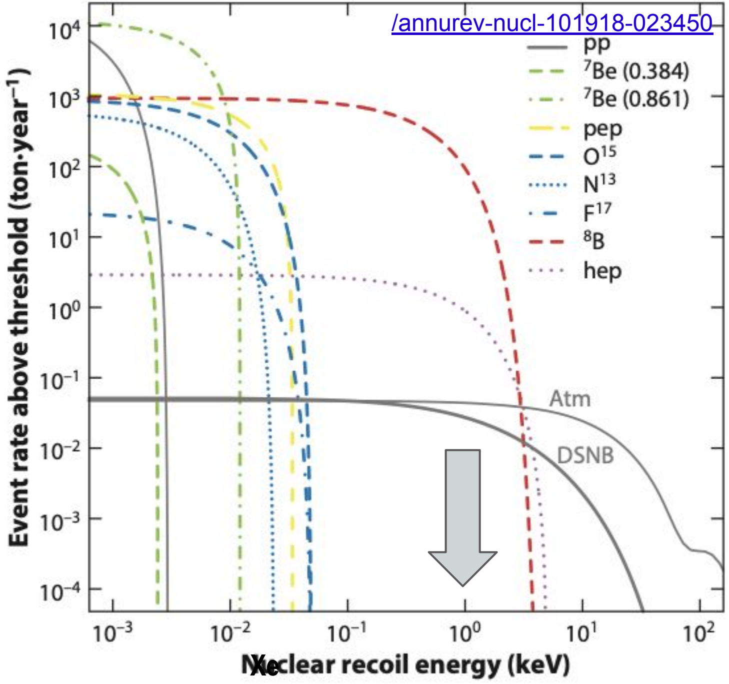


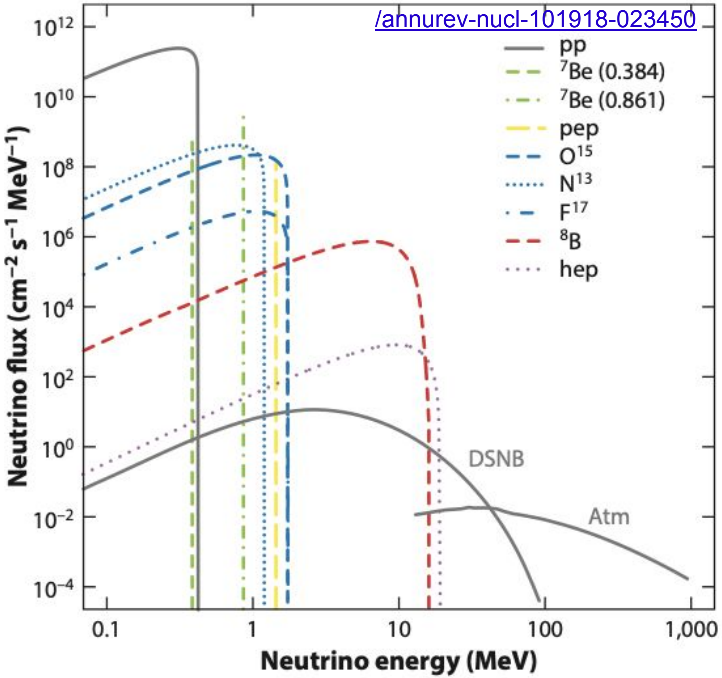
8B Detection / Subsequent Atm Neutrino Fog

CEvNS Coherent Scattering of Neutrinos on Xe LZ 5.7 tonne-year

8B measurement - LZ (4.5σ), XENONnT (2.7σ), PandaX (2.6σ)

Ultimately Neutrino Fog as exposure reach 1000 tonne-year





8B Additional Talk


Turning background into signal: solar neutrinos in xenon dark matter detectors

Beyond the primary objective of discovering dark matter, direct detection experiments are rapidly emerging as highly effective tools for the study of neutrinos, acting as competitive probes of low-energy interactions with both nuclei and el

Michela Sestu (Istituto Nazionale di Fisica Nucleare - Sezione di Cagliari)

03 June 2026 15:40

Pilar Sinués

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Cost of Xenon Targets

The reference cost is \$6/stp liter == \$1M/tonne

The commodity price can vary from 0.5x to 5x of this

The target is not destroyed, so it is possible to warehouse it (rent it rather than buy)

However, if isotopically separating 136Xe from 9% natural abundance it is the separation cost that will dominate

It is 0.1 ppm, rarest of all gases in air

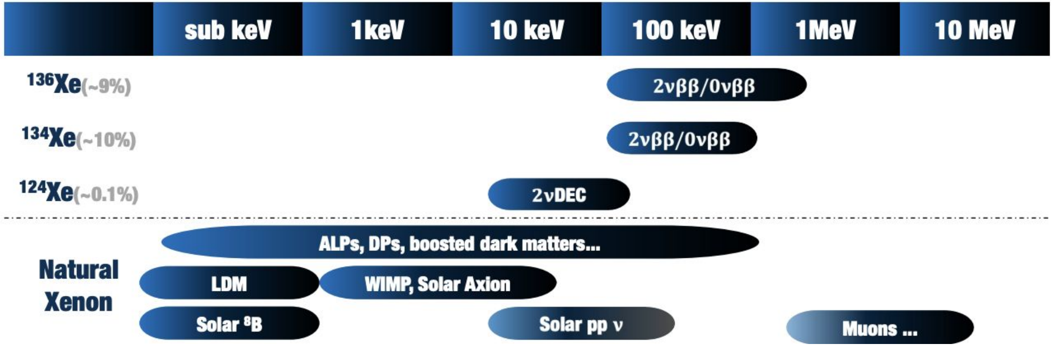
0.5 tonnes Xe in 1 km^3

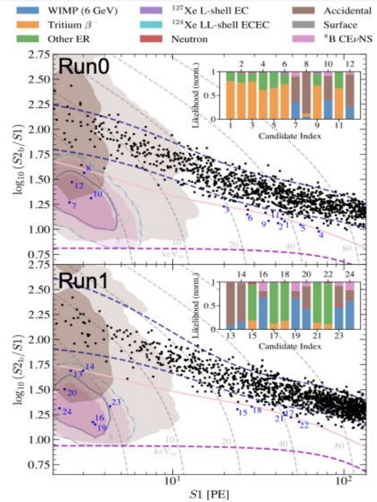
For a hurricane wind of 50 m/s down a 4x4 m corridor that would take ~1 month/tonne

Fortunately the steel industry (oxygen) / fertilizer (nitrogen) extracts

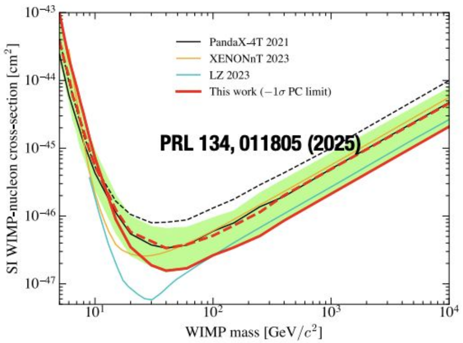
PandaX-4T @ CJPL (2020-2026)

We heard from Xiaopeng Zhou (Beihang University, Beijing) on Tuesday (link)





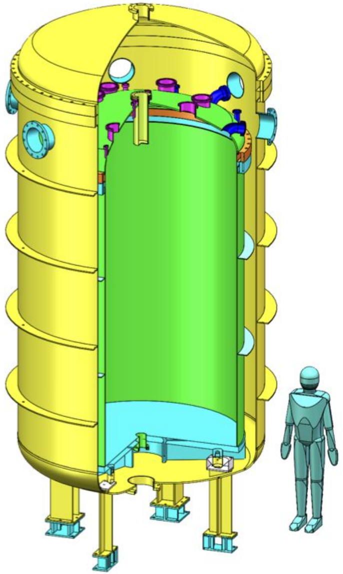
- 1 sigma upward fluctuation with <8 GeV, while downward fluctuation in high-mass region;
- Exclusion reaches 1.6e-47 cm2 @ 40GeV;



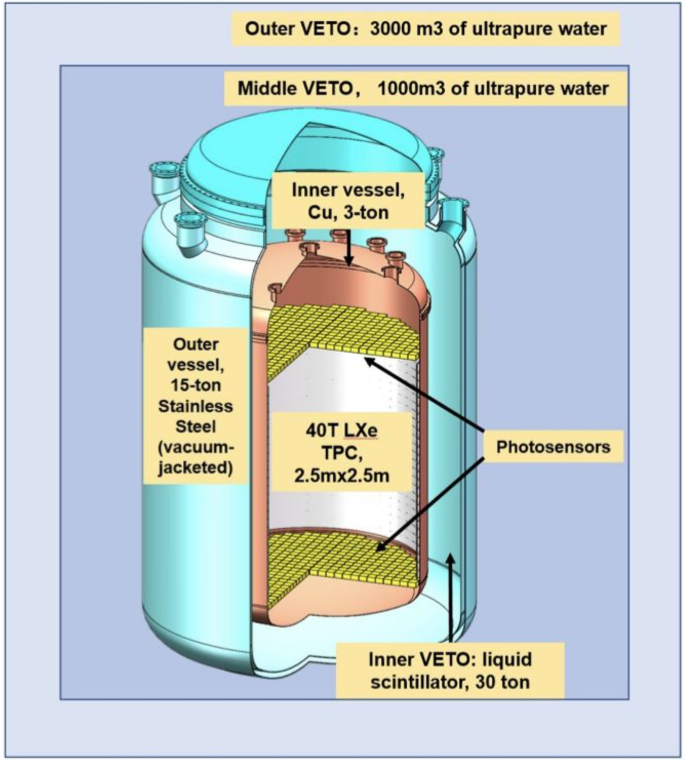
PandaX-20t (Fully funded/target purchased)

We heard from Xiang Xiao (Sun Yat-sen University) on Tuesday (link)

Goal to start science with 20t in early 2028



Xiang Xiao on behalf of PandaX



PandaX Additional Talks

Development and performance of the PandaX veto system

PandaX is a direct detection dark matter and neutrino experiment located at the China Jinping Underground Laboratory (CJPL). It utilizes liquid xenon technology to search for dark matter particles and study neutrino physics. Neutron- and ga

Yuehuan Wei (Sun Yat-sen University)

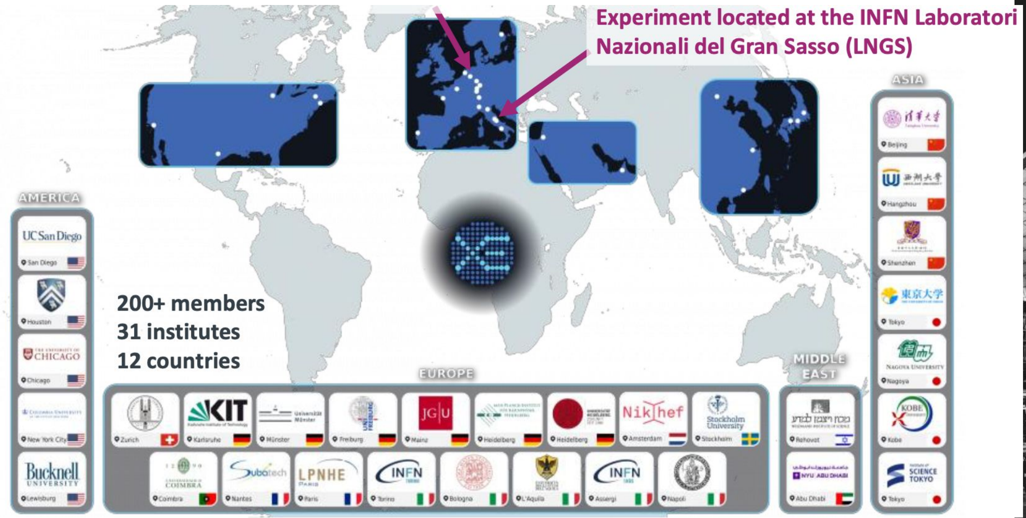
04 June 2026 16:00

Pedro Cerbuna

Identification of Dark Matter 2026

XENONnT (“n” makes it more mysterious)

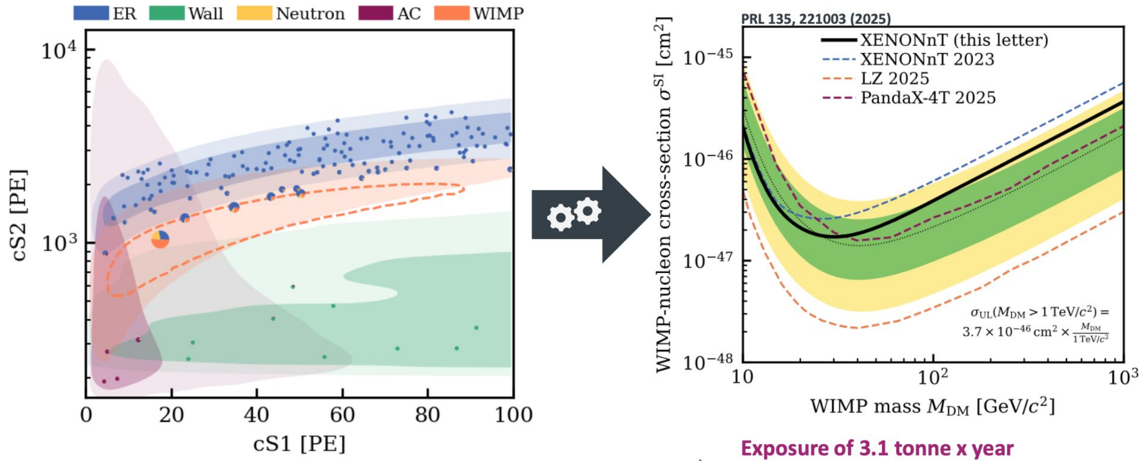
We heard from Maxime Pierre (Nikhef, Amsterdam) on Tuesday (link)



XENONnT @ LNGS

- XENON is 6 tonne LXe TPC science search since 2021

SR0 + SR1 WIMP results



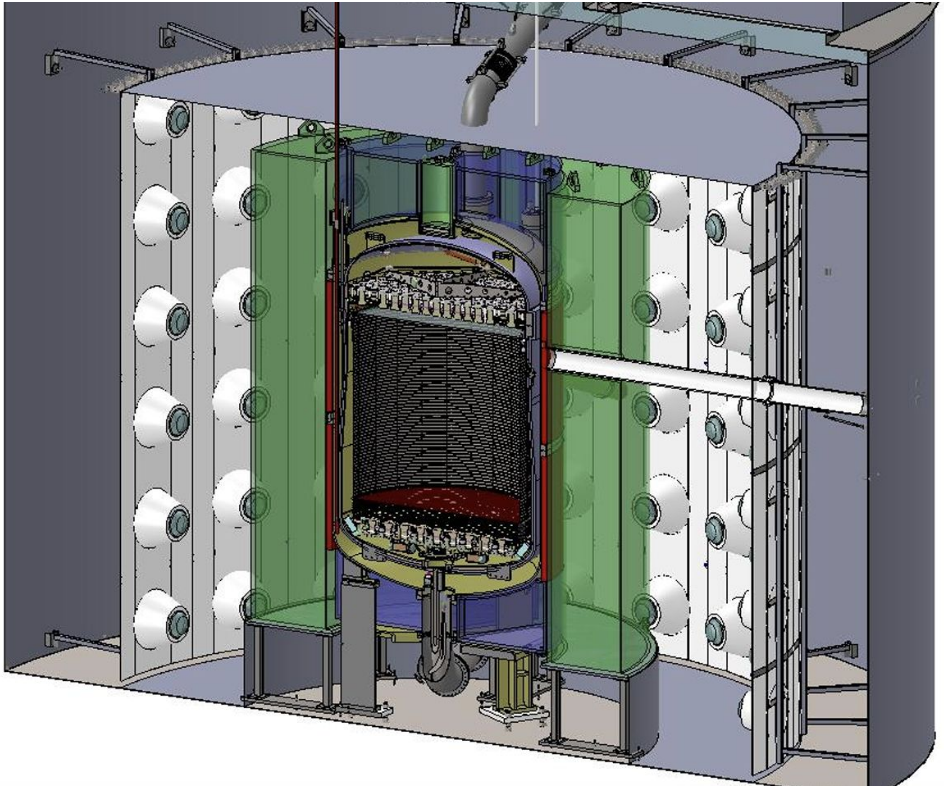
PRL 135, 221003 (2025)

Exposure of 3.1 tonne x year
Most stringent limit at 1.7×10^{-47}cm² at 30 GeV/c² WIMP mass.

- XENON was warmed up and detector opened in 2025 to repair grids
  - Low electron drift field was significantly hampering progress in DM sensitivity
- Repairs completed, detector is now cold and re-commissioning is taking place
- Plan is continue operations 2026–2029

LZ 8t @ SURF

We heard from Alberto Uson (Edinburgh) on Tuesday (link)



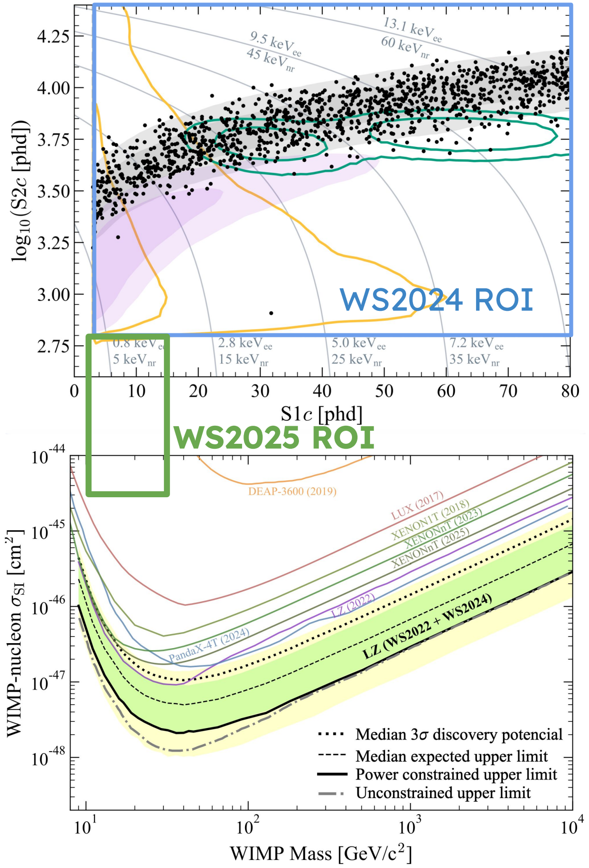
Phys. Rev. Lett. **135**, 011802

WS2024 result

- ROI targeted ≥9 GeV/c^2 DM masses
- Novel features incorporated into the analysis:
  - Rn-tag reduced 60% primary ER BGs
  - Charge yield suppression modelled and measured in EC and DEC
- Bias mitigation technique
- Final exposure included in PLR: 4.2 tonne·yr
  - WS2022: 60 days x 5.5 t = 0.9 tonne·yr exposure
  - WS2024: 220 days x 5.5 t = 3.3 tonne·yr exposure

Result: world leading constraints → 2.2 × 10^{-48} cm^2 for 40 GeV/c^2 WIMP

What's next? Shift to **lighter DM masses** → WS2025
New set of challenges

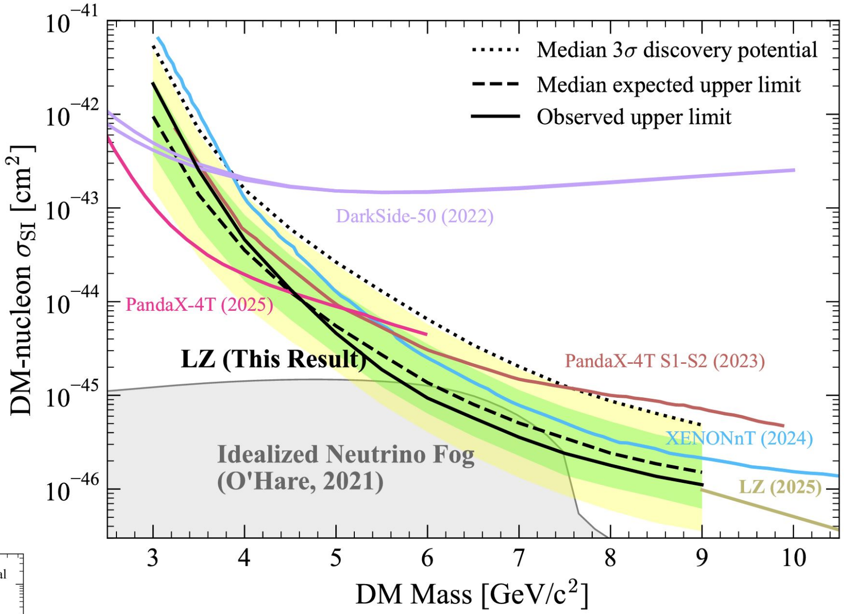


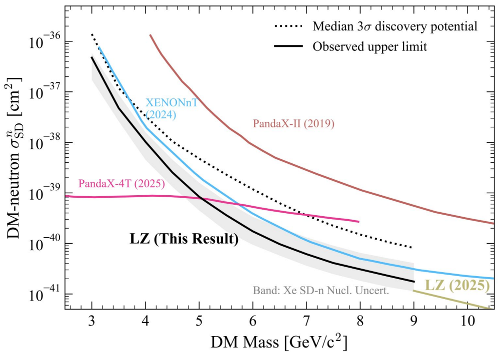
LZ WS2025 Low-mass WS search

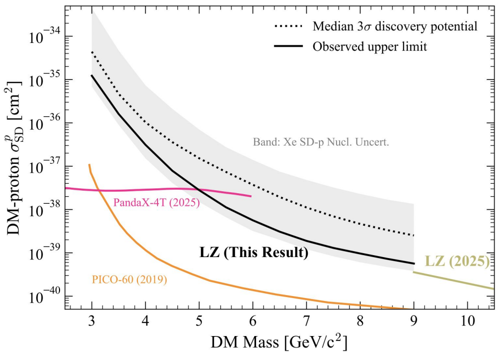
Exclusion limit with two-sided test statistic

- **Factor of two improvement in sensitivity over existing limits between 5-9 GeV/c2**
- **World-leading limits > 5 GeV/c2**

Limits on SD neutron-only and proton-only:







LZ WS2025
8B CEνNS measurement

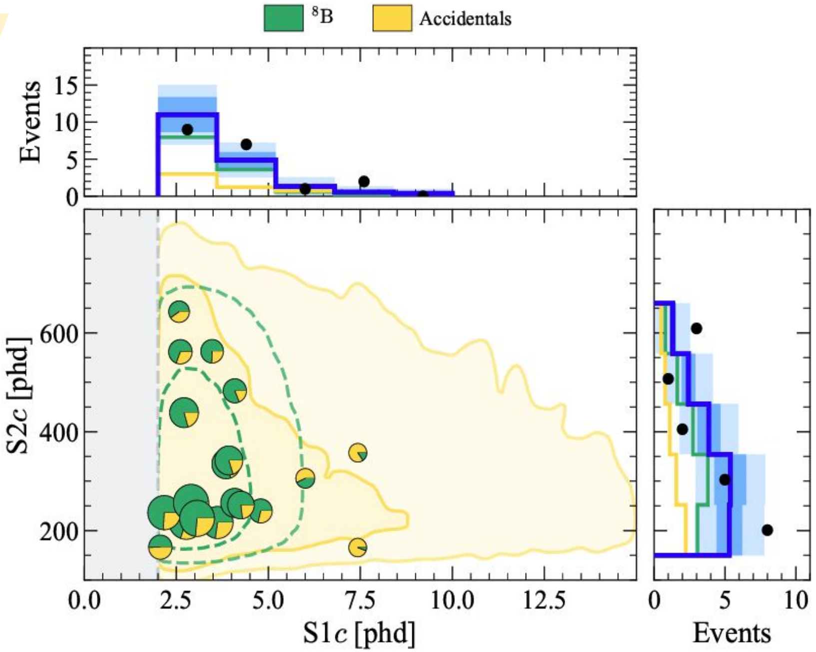
PLR test statistic to reject background-only mode

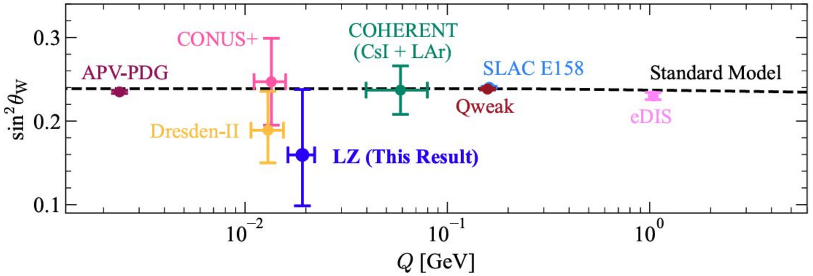
- Assumed no DM events
- Unconstrained 8B CEνNS rate

Components	Expectation	Fit Results
^{8}B CEνNS	-	$12.3^{+7.0}_{-5.4}$
Accidental coincidences	6.6 ± 0.3	6.6 ± 0.3
Detector neutrons	$0.04^{+0.25}_{-0.04}$	$0.1^{+0.2}_{-0.1}$
Total	6.6 ± 0.3	$18.9^{+7.0}_{-5.5}$

➔ Background-only model rejected with 4.5σ significance (expected 6.7σ)

Measure weak-mixing angle (sin2θW) at low momentum transfer (Q), consistent with SM





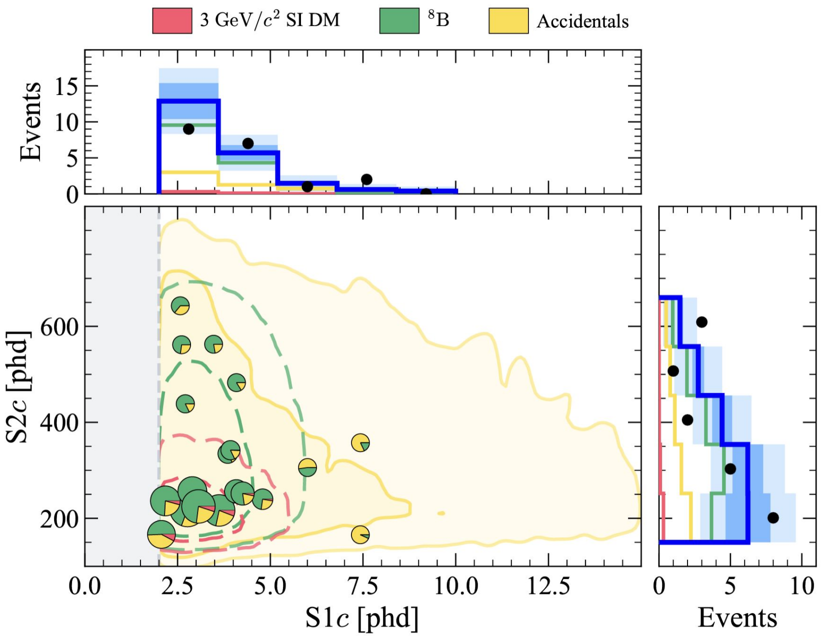
arXiv:2512.08065

LZ Low-mass WS search and 8B Signal

- Backgrounds: ^{8}B CEνNS, accidental coincidences, and detector neutrons
- ^{8}B CEνNS rate constrained based on predictions using SNO measurement*

➔ Best-fit number of DM events consistent with 0 at all DM masses tested

Components	Expectation	Background-Only Fit	3 GeV/c^2 Fit	9 GeV/c^2 Fit
SI DM	-	-	$0.4^{+5.4}_{-0.4}$	$0.0^{+4.0}_{-0.0}$
^{8}B CEνNS	$20.6^{+8.9}_{-6.8}$	$15.0^{+2.9}_{-2.5}$	$14.7^{+3.0}_{-2.8}$	$15.0^{+2.9}_{-2.5}$
Accidental coinc.	6.6 ± 0.3	6.5 ± 0.3	6.5 ± 0.3	6.5 ± 0.3
Detector neutrons	$0.04^{+0.25}_{-0.04}$	$0.1^{+0.2}_{-0.1}$	$0.1^{+0.2}_{-0.1}$	$0.1^{+0.2}_{-0.1}$
Total	$27.2^{+10.1}_{-7.3}$	$21.6^{+4.7}_{-3.8}$	$21.7^{+6.2}_{-2.8}$	$21.6^{+5.0}_{-2.5}$
$\sigma_{\rm eff}$	0 ± 1	$-0.81^{+0.59}_{-0.60}$	$-0.86^{+0.63}_{-0.71}$	$-0.81^{+0.58}_{-0.60}$



*Phys. Rev. C **88**, 025501 (2013)

Thanks to Alberto Uson, Tuesday LZ Results Talk

Other LZ DM searches and prospects

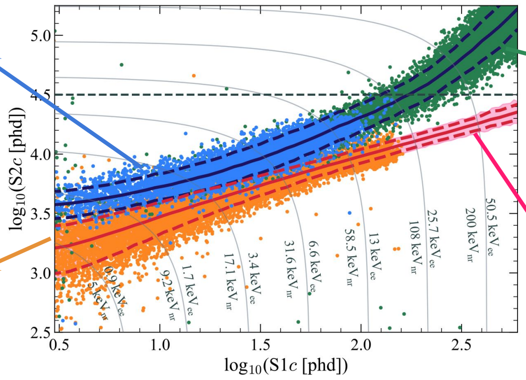
LZ can search for alternative candidates and in different energy regimes:

Low-energy ER

- LEER searches (*Phys.Rev.D **108**,072006 (2023)*)
- Atmospheric millicharge particles (*PRL **134**, 241802 (2025)*)

Low-energy NR

- Cosmic ray-boosted Dark Matter - *PRL **134**, 241801 (2025)*
- WIMP-pion - *Commun Phys **7**,292 (2024)*



High-energy ER

- e.g. Lightly Ionizing Particle searches

High-energy NR

- WIMP-nucleon EFT - *PRL **133**, 221801 (2024)*
- Ultraheavy DM - *Phys. Rev. D **109**, 112010 (2024)*

Plus other non-DM searches in the horizon → $0\nu\beta\beta$

Further into the future, much larger exposures needed to fully cover the space parameter until the neutrino fog at larger DM masses…

arXiv:2410.17137

LZ Related Talks

First observation of positron emission decay of Xe-125 in a liquid xenon detector from the LUX-ZEPLIN Experiment

We report the first observation of the positron emission process Xe-125 → e+ + ν + I-125 (Q=1.6 MeV) in a liquid xenon detector using post-calibration data from the LUX-ZEPLIN (LZ) experiment. We provide an independent measurement of the br

Miguel Hernandez (University of Zurich)
Josefa Amar y Borbón
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Constraining Environmental Backgrounds for Rare Event Searches with LZ

LUX-ZEPLIN (LZ) is the world's most sensitive direct dark matter detector. It is located deep underground at the 4850 ft level at the Sanford Underground Research Facility in Lead, South Dakota. This is a quiet environment, strongly shielde

Ellie Bishop (University of Edinburgh)
02 June 2026 15:20
Aula Magna
Identification of Dark Matter 2026

Modeling the low-energy accidental coincidence background in the LUX-ZEPLIN experiment

The LUX-ZEPLIN (LZ) experiment operates a dual-phase xenon time projection chamber with a 7-tonne active mass, which detects both scintillation photons (S1) and ionization electrons (S2) from particle interactions. LZ has recently placed wo

Ruben Coronel (Stanford University)
04 June 2026 16:30
Pedro Cerbuna
Identification of Dark Matter 2026

Electrode backgrounds in the LZ experiment

LUX-ZEPLIN (LZ) is a dark matter (DM) detection experiment that has demonstrated world-leading sensitivity to GeV-mass DM and $^(8)\mathrm(B)$ solar neutrinos. An ionization-only (S2-only) analysis can enhance LZ's sensitivity to lower-mass

Yubo Zhou (Imperial College London)
Josefa Amar y Borbón
Identification of Dark Matter 2026

Setting limits on blazar-boosted dark matter with xenon-based detectors

Not scheduled
20m
Josefa Amar y Borbón

Poster | DDLDM | Poster session / Wine ...

Speaker

Erin Barillier (University of Zurich)

SBC - Scintillating Bubble Chamber Experiment

We heard from Ben Broerman (Queen's U, Kingston, Ontario) on Monday (link)

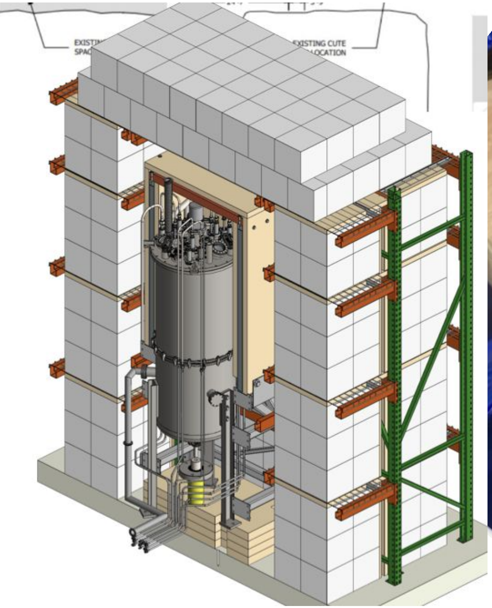
Target fluid flexibility (Xe, Ar, N2, etc.)

Fermilab 6 months of stable operation with Ar

nucleation thresholds

from 0.46 – 3 keV

Simultaneous measurement of scintillation and bubble nucleation observed



XLZD 60-80t Future Detector

We heard from Adam Softley-Brown (U Sheffield) on Tuesday (link)
(XENONnT, LZ, Darwin) A Generation 3 DM Experiment

XLZD baseline design

Nominal plan: 60 t in 1:1 ratio (3 m x 3 m)

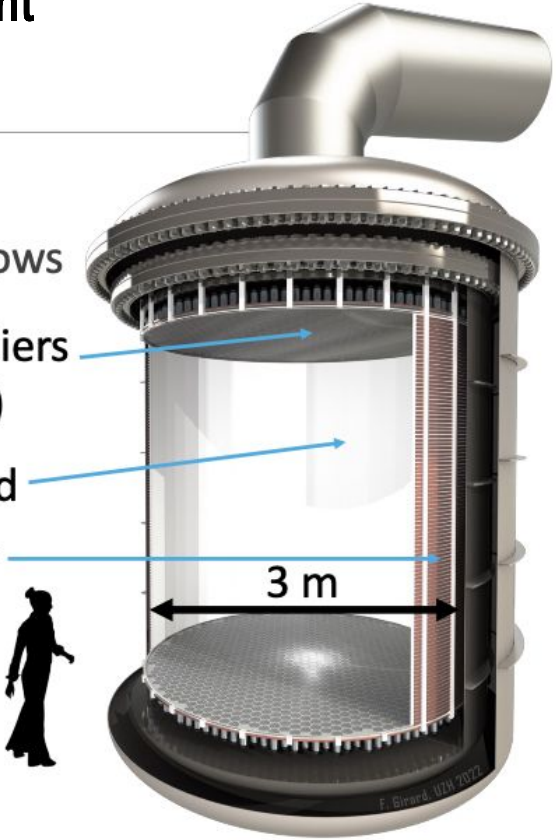
Possibility of longer 80 t detector if funding allows

Design book
arXiv 2410.17137

3” photomultipliers
(1182 per array)

250 V/cm drift field

LXe skin detector

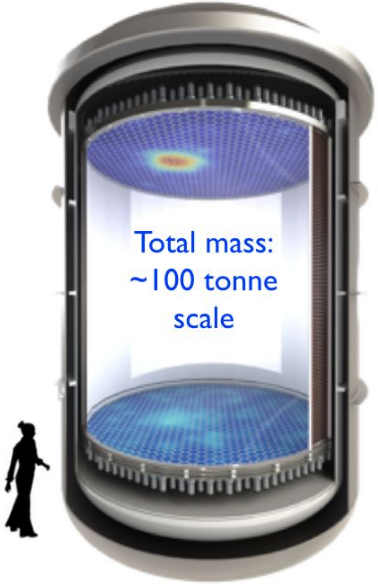


Plus outer detector
as n, μ veto

XLZD history, status and related events

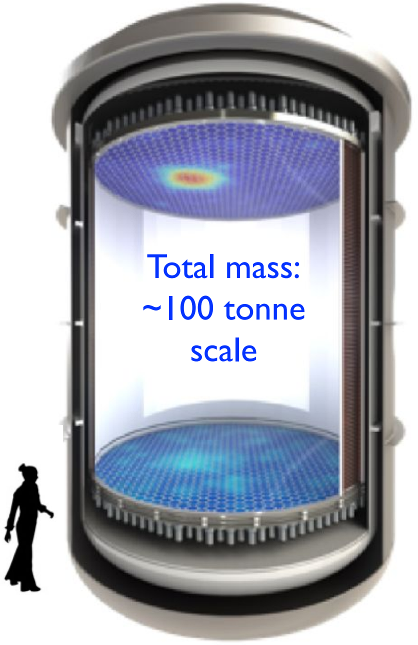
- July 2021: Consortium MOU signed by XENONnT, LUX-ZEPLIN, DARWIN
- Oct 2023: NSAC LRP recommends pursuit of 0vbb in multiple isotopes at the ton-scale
- Dec 2023: P5 recommends Generation 3 DM (G3DM) search to neutrino fog limit
- Sept 2024: XLZD Collaboration agreement signed
- Dec 2024: DOE NP announces indefinite pause of nEXO project due to funding constraints
- Dec 2025: DOE HEP announces deferring of G3DM until early 2030's due to funding constraints
- Key activities in 2026:
  - International partners continue to vigorously pursue XLZD; working towards CDR for early 2027, with ongoing US engagement
  - Significant engagement from DM and 0vbb community in Canada: 11 institutions join XLZD, bid for SNOLAB hosting
  - Technical evaluation of 4 sites to complete in the coming months: Boulby, LNGS, SURF, SNOLAB
  - US participation is a critical part of the technology base and needed to realize the full scientific reach of 80-t active target on a competitive timeline

Natural xenon in a 2-phase TPC

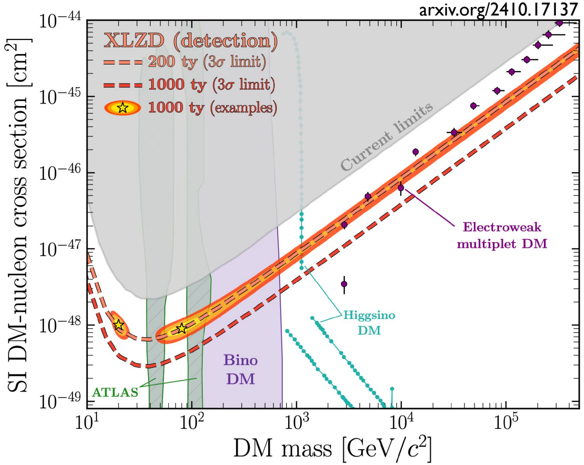


XLZD: liquid xenon observatory at the 100-tonne scale

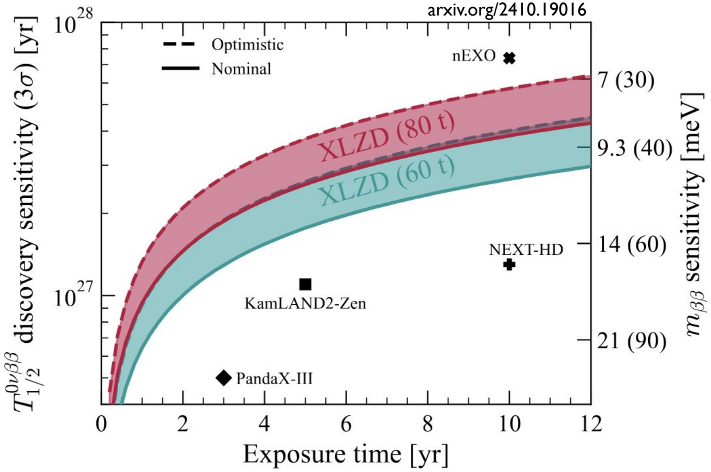
Natural xenon in a 2-phase TPC



Probe WIMP Dark Matter to neutrino fog systematic limit



DM detector w/natural xenon: Competitive sensitivity for $0\nu\beta\beta$



- Definitive WIMP search: systematics limited by ν fog at ~1000 tonne-years of exposure sets scale for ~100-tonne detector
- Xe-136 is 9% of the natural abundance, allowing a search for $0\nu\beta\beta$ with the potential to approach the nEXO design sensitivity
  - Optimization to push sensitivity to $T^{1/2} \sim 10^{28}$ years is under study

XLZD Related Talks

Boulby Underground Laboratory: Projects and plans at the UK's deep underground science facility

Boulby Underground Laboratory is the UK's deep underground science lab, located in the North East of England. Initially created to host dark matter direct detection experiments, the lab has since expanded into a multidisciplinary facility h

Alice Hamer (Boulby Underground Laboratory)
02 June 2026 18:10
Pedro Cerbuna
Identification of Dark Matter 2026

XLZD – the next generation of dark matter search

Liquid-xenon based dark matter experiments have rapidly increased in size and sensitivity in recent years. They are at the forefront of the search for dark matter interactions with nuclei for dark matter masses above a few GeV/c². XLZD is t

Adam Softley-Brown (University of Sheffield)
02 June 2026 15:40
Aula Magna
Identification of Dark Matter 2026

Xenoscope - A Large Scale LXe Demonstrator

The XLZD (XENON-LUX-ZEPLIN-DARWIN) collaboration is developing the next-generation dual-phase xenon time projection chamber (TPC) for dark matter and rare-event searches. To significantly enhance the sensitivity beyond current experiments,

Rebecca Hampp
Josefa Amar y Borbón
Identification of Dark Matter 2026

Bedretto: A New Underground Laboratory for Fundamental Physics

Deep underground low-background laboratories are critical infrastructure for dark matter experiments and rare event physics searches. With real-estate in short supply, we are establishing a new underground laboratory in Tichinio, Switzerlan

Alexander Kavner (University of Zurich)
02 June 2026 17:25
Pedro Cerbuna
Identification of Dark Matter 2026

Radiopurity and Cleanliness Control in next generation dark matter direct detection experiment, XLZD

In this talk I will outline the unique challenges of scaling up, and efforts we are exploring to push down background of the next-generation xenon dark matter direct-detection experiment, XLZD. The detector is envisioned as a 60-80 tonne ac

Ferdos Dastgiri (University College London)
04 June 2026 15:00
Pedro Cerbuna
Identification of Dark Matter 2026

Backgrounds/Radon Levels inside Xe TPC

Backgrounds

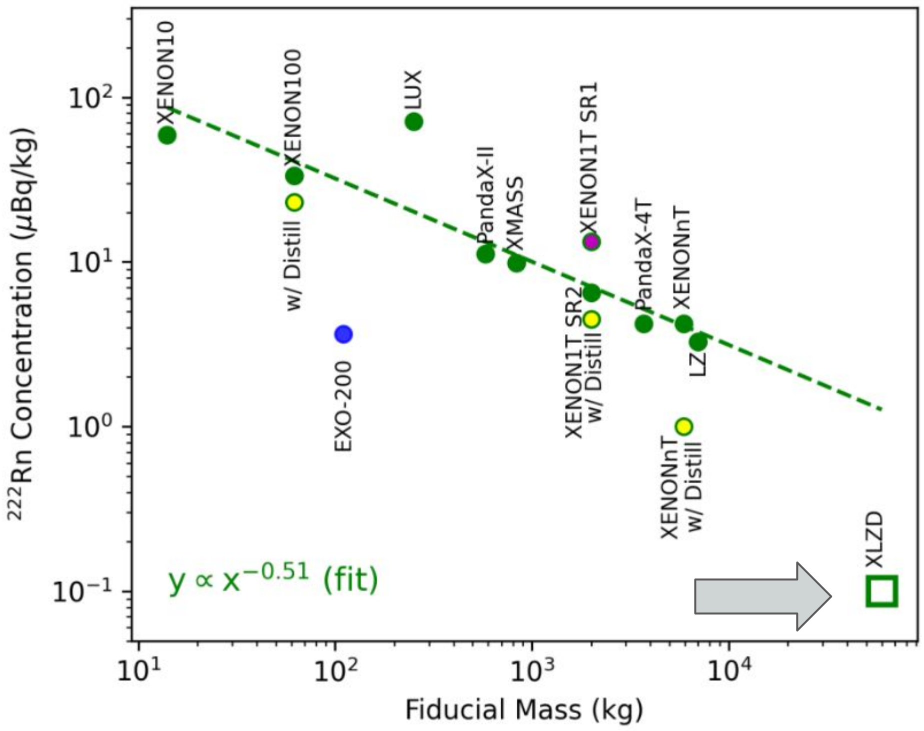
Material backgrounds factor 4-10 lower tl

Intrinsic backgrounds at low-E subdomir

Rn concentration < 0.1 µBq/kg

Screening, low-activity materials,

active removal – on target



Adam Softley Brown, Tuesday

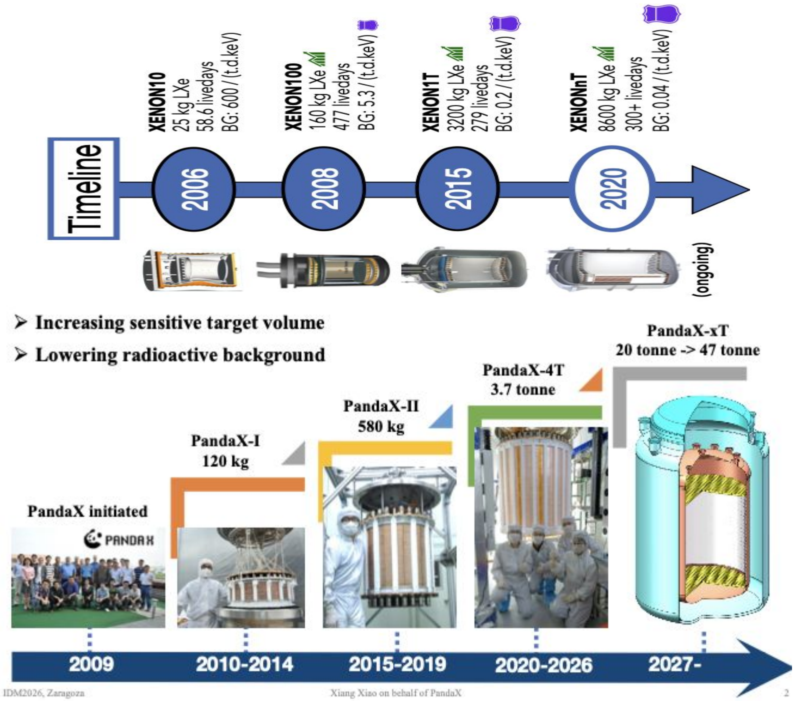
Ferdos Dastgiri, Thursday at 15:00

Xe Major Running >10 live-years Science

LUX >400 live days
Science 2013-2016

LZ >800 live days
Science 2020-

XENON10 (2005)



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Strong Guidance from DOE HEP FY27-FY31

Dec 2025: Gina Rameika, Associate Director (Head) of Science for High Energy Physics & Associate Director of Science for Nuclear Physics

DOE - No New Starts for coming 5 years

HEP includes the High Energy and Cosmic Frontiers

What does this mean?

Existing programs can continue on operations. Extensions of existing searches are being considered.

We cannot submit new construction/project proposals.

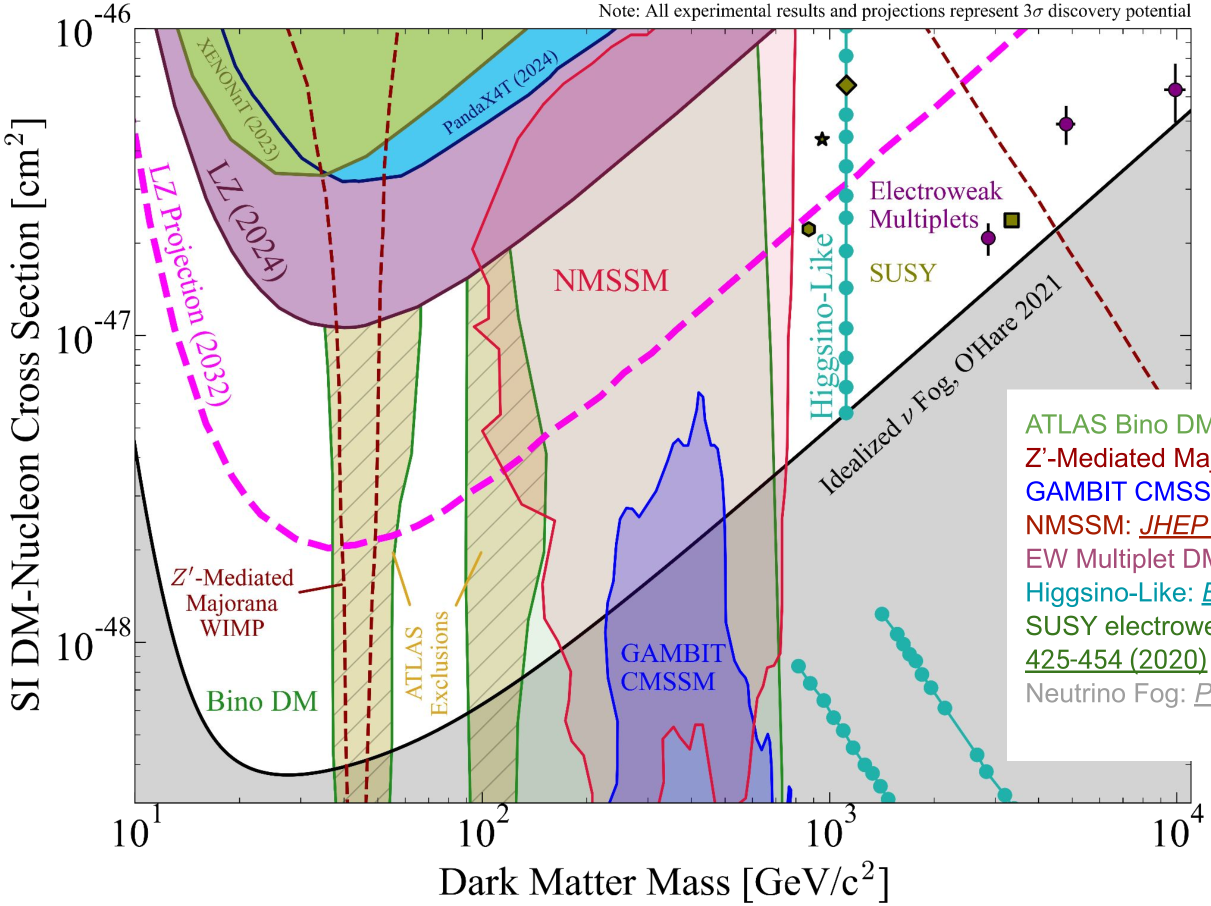
In the language of DOE we are unable to start a CD-0 - Critical Decision 0 which is referred to as Mission Need for a Next Generation Dark Matter Experiment

(Offices of High Energy Physics and Nuclear Physics are merging)

Proposal for LZ+ for 2028–2032

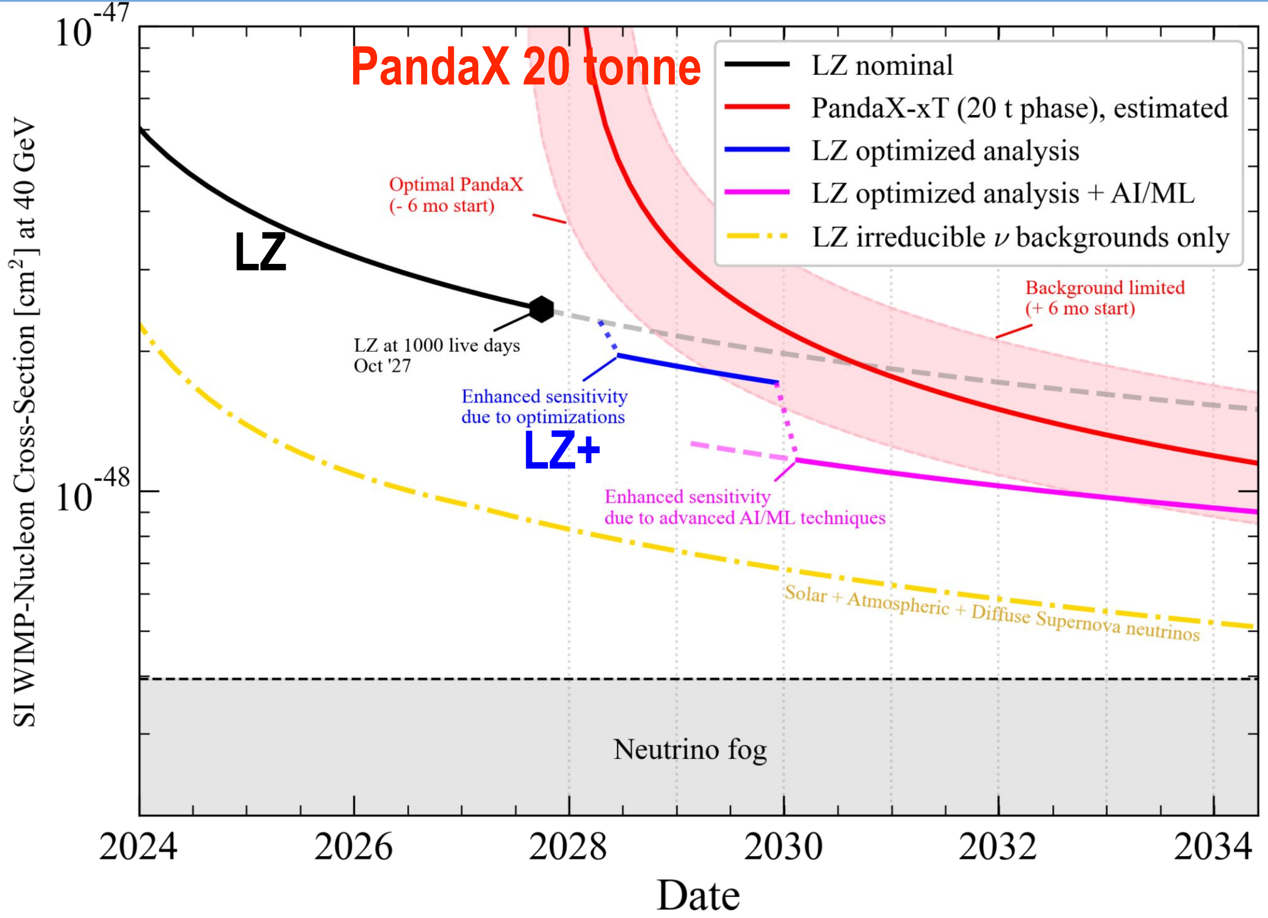
LZ+ Step 1: Continued LZ running for Pillar 1 science

3σ Discovery



ATLAS Bino DM: *JHEP* 05 106 (2024)
Z'-Mediated Majorana WIMP: *JCAP11* 024 (2019)
GAMBIT CMSSM: *Eur. Phys. J. C.* 77, 824 (2017)
NMSSM: *JHEP* 2024, 212 (2024)
EW Multiplet DM: *Eur.Phys.J.C* 82 1, 31 (2022)
Higgsino-Like: *Eur. Phys. J. C.* 83, 246 (2023)
SUSY electroweakinos: *Ann.Rev.Nucl.Part.Sci.* 70 425-454 (2020)
Neutrino Fog: *Phys.Rev.Lett.* 127, 251802 (2021)

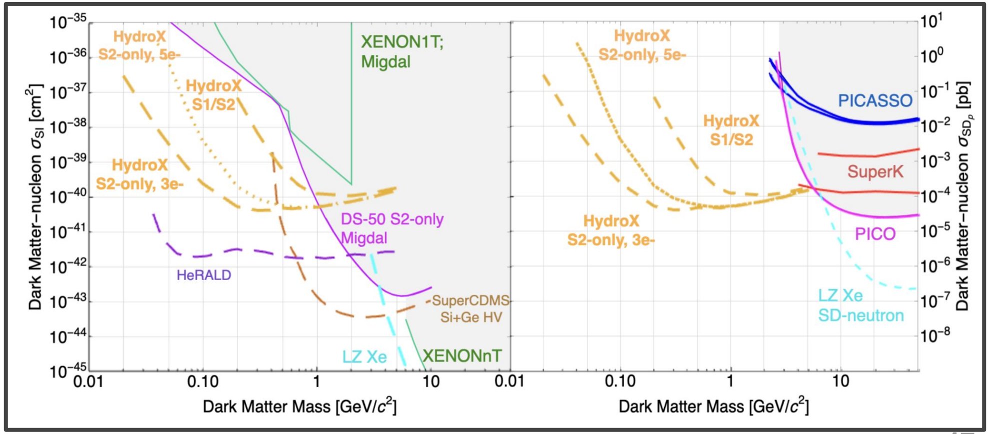
LZ+ Step 1: Continued LZ running for Pillar 1 science



LZ+ Step 2: Continued dark matter science with HydroX

- Get the benefit of simple LZ extension through ~2031, maintain Pillar 1 focus until LZ is no longer world-leading, <u>then</u>:
- Shift focus leveraging sensitivity to lower masses DM using low-Z dopant >kg
  - HydroX: sensitivity to low-mass dark matter (10 MeV to 1 GeV mass range).
  - Basic technical feasibility of low-Z doping of xenon: solubility, signal size
    - Under investigation now with dedicated setups
    - Technical solution for adding and removing a dopant in LZ while maintaining purification
  - <u>Unique</u> and <u>complementary</u> science goals to other DOE programs.
  - Simultaneous sensitivity to Spin-Independent and Spin-Dependent interactions; unique and complementary to other DOE programs.
  - Repurpose the LZ instrument for a different goal, still world-leading dark matter science

- HydroX is compelling:
  - LZ would be sensitive to both spin-independent and spin-dependent interactions <u>at the same time.</u>
  - Complementary to other experiments:
    - If a signal is seen in another low-mass DM experiment (e.g. TESSERACT), the signal in LZ/HydroX could reveal the nature of the dark matter.



LZ+ Summary

A. LZ should do “Pillar 1 Science”; searches for dark matter with mass > 1 GeV.
   a. Our Step 1 will maintain LZ as the world’s leading experiment in this regime. We propose to keep running LZ, while improving our software and analysis capabilities, with a strong focus on AI/ML in line with the GENESIS mission.
   b. Only after world-leading Pillar 1 science is no longer viable with the LZ instrument, our Step 2 unlocks a unique dark matter space that only LZ can explore, complementary to other experiments in the DOE program.

A. The plan has support from senior leaders within the collaboration and maintains US expertise in the Xe technology
   b. Step 2 scope has emerged internally as the most appropriate extension to LZ which both brings new science reach and maintains technological progress in the community. It builds on existing efforts from the last several years and has buy-in from most major LZ institutions - HydroX workshop.

US Dark Matter (Higher Mass) Xe/Ar Summary

- **US Has Maintained Leadership in DOE Pillar 1 High Mass Dark Matter Search Sensitivity**
  - LZ World leading limits for WIMP dark matter >5 GeV, LZ science running since start of 2022
  - Current LZ Schedule - Science Running to end CY2027
- **Under DOE HEP No New Starts Scenario**
  - **LZ+ Proposal**
    - DOE DM Pillar 1: Extend Sensitivity FY28, FY29, FY30…
      - Improved BG through technical upgrade/analysis
      - AI/ML Analysis Impact / via GENESIS and Direct Support
    - Additional Option if Technology Demonstrated: Could transition to HydroX FY31-FY33
      - Dope Xe with low-Z material, Leverages low mass DM sensitivity
  - **Current Experiments with Existing US Component**
    - XENONnT @LNGS (Xe 6 tonne)
      - Started science 2021, now being recommissioned 2026 for operation to 2028
    - Darkside DS20k @LNGS (Ar 20 tonne)
      - Under construction for commissioning start before end 2028
- **XLZD**
  - Site TBC, Xe 60-100 tonne / Originally formed as a combination of Xe Groups from XENON, LZ and Darwin
  - US Participation in G3 Experiment directly impacted by <u>DOE no new starts</u>
  - UK has development funds to plan the hosting of XLZD in a major new underground facility at Boulby
  - Europe Awaiting the APPEC Roadmap which is released later this year

Summary Xe Detectors for DM Future

Prospects for new discoveries with existing LXe TPC are very strong - searching new parameter space, systematics well under control

Major accumulation of science running over last 20 years

Design Scales for 20-80 tonne operation sensitive to ~100% single electrons and 10% photons from interaction in bulk - excellent discovery potential

- LZ running with goal of 1000 live days by 2021-2027
- LZ+ proposal for running 2028-2032 include doping with low mass target
- XENONnT has been repaired and has started running again 2026-2028
- XLZD heavily impacted by DOE no new starts
- PandaX-4t ended 2026, will be replaced by PandaX-20t start science in 2028
- SBC 10kg (Ar) assembling at SNOLab (could run with Xe)

--- END ---

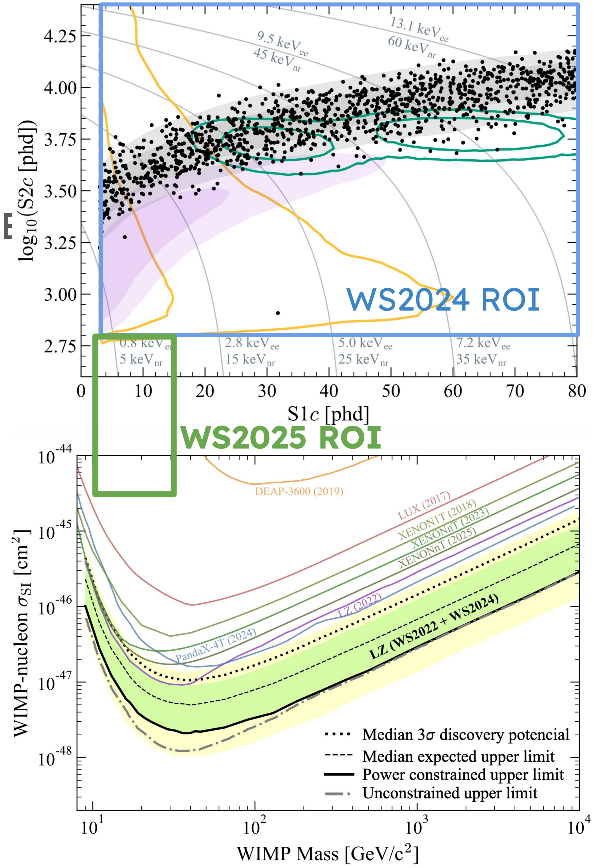
ADDITIONAL SLIDES

LZ

Phys. Rev. Lett. **135**, 011802

WS2024 result

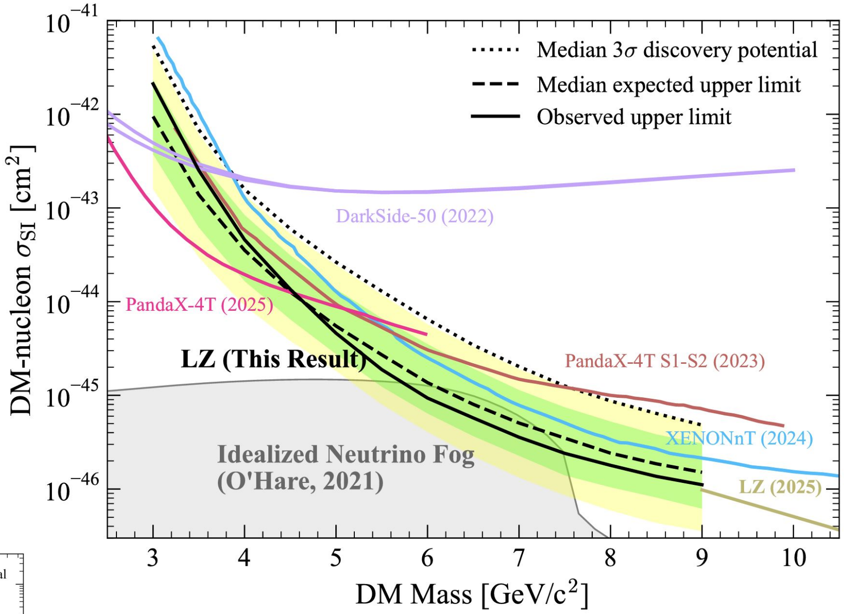
- ROI targeted ≥9 GeV/c^2 DM masses
- Novel features incorporated into the analysis:
  - Rn-tag reduced 60% primary ER BGs
  - Charge yield suppression modelled and measured in E
- Bias mitigation technique
- Final exposure included in PLR: 4.2 tonne·yr
  - WS2022: 60 days x 5.5 t = 0.9 tonne·yr exposure
  - WS2024: 220 days x 5.5 t = 3.3 tonne·yr exposure



Result: world leading constraints → 2.2 × 10^{-48} cm^2 for 40 GeV/c^2 WIMP

What's next? Shift to **lighter DM masses** → WS2025
New set of challenges

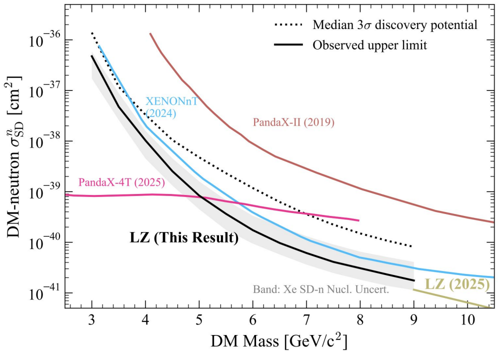
Low-mass WS search

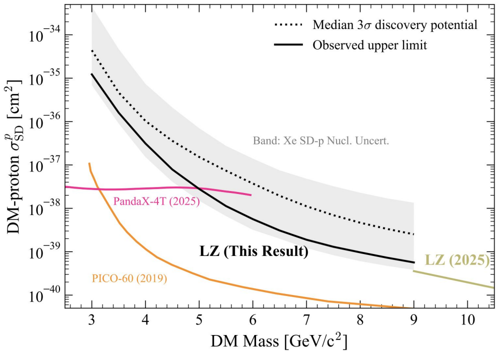


Exclusion limit with two-sided test statistic

- Factor of two improvement in sensitivity ove GeV/c2
- World-leading limits > 5 GeV/c2

Limits on SD neutron-only and proton-only:





8B CEνNS measurement

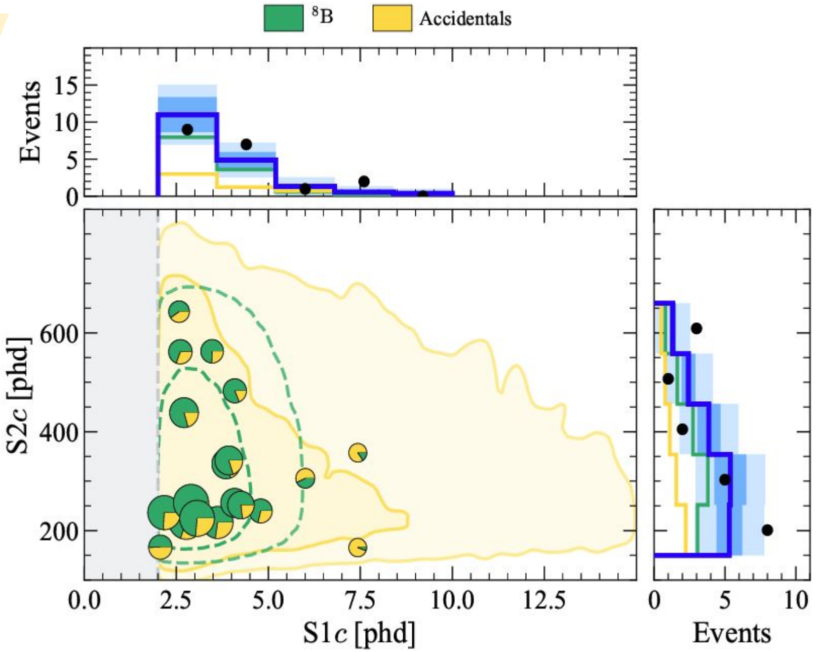
PLR test statistic to reject background-only mode

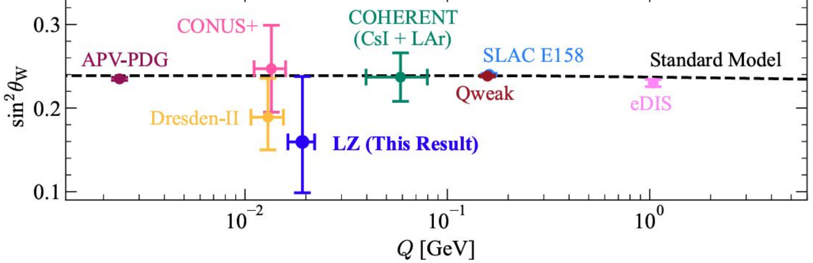
- Assumed no DM events
- Unconstrained 8B CEνNS rate

Components	Expectation	Fit Results
^{8}B CEνNS	-	$12.3^{+7.0}_{-5.4}$
Accidental coincidences	6.6 ± 0.3	6.6 ± 0.3
Detector neutrons	$0.04^{+0.25}_{-0.04}$	$0.1^{+0.2}_{-0.1}$
Total	6.6 ± 0.3	$18.9^{+7.0}_{-5.5}$

➔ Background-only model rejected with 4.5σ significance (expected 6.7σ)

Measure weak-mixing angle (sin2θW) at low momentum transfer (Q), consistent with SM





Other LZ DM searches and prospects

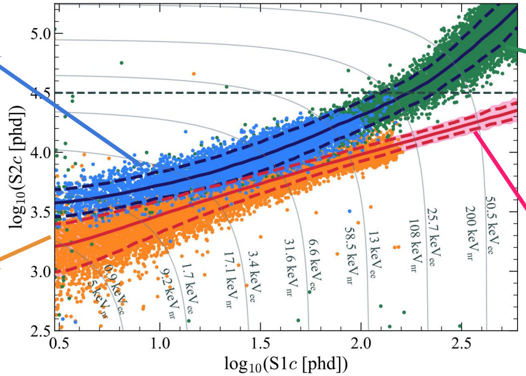
LZ can search for alternative candidates and in different energy regimes:

Low-energy ER

- LEER searches (*Phys.Rev.D* ***108***, *072006 (2023)*)
- Atmospheric millicharge particles (*PRL* ***134***, *241802 (2025)*)

Low-energy NR

- Cosmic ray-boosted Dark Matter - *PRL* ***134***, *241801 (2025)*
- WIMP-pion - *Commun Phys* ***7***, *292 (2024)*



High-energy ER

- e.g. Lightly Ionizing Particle searches

High-energy NR

- WIMP-nucleon EFT - *PRL* ***133***, *221801 (2024)*
- Ultraheavy DM - *Phys. Rev. D* ***109***, *112010 (2024)*

Plus other non-DM searches in the horizon → $0\nu\beta\beta$

Further into the future, much larger exposures needed to fully cover the space parameter until the neutrino fog at larger DM masses…

arXiv:2410.17137

Step 2: Continued dark matter science with HydroX

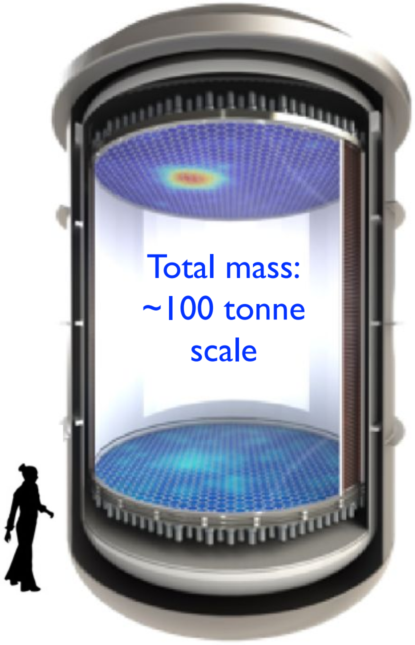
- **Motivation:**
  - Only after LZ is no longer the world-leading experiment for pillar 1; what other dark matter science can we do?
  - HydroX: sensitivity to low-mass dark matter (10 MeV to 1 GeV mass range).
  - Simultaneous sensitivity to Spin-Independent and Spin-Dependent interactions; unique and complementary to other DOE programs.
- **R&D needs:**
  - Basic technical feasibility of low-Z doping of xenon: solubility, signal size
    - Under investigation now with dedicated setups
  - Technical solution for adding and removing a dopant in LZ while maintaining purification
- **LZ Modification needs:**
  - Requires modification to circulation system
  - Unproven technology update (loading of sufficient low Z mass). Mitigation: includes a go/no-go milestone

XLZD: A next generation observatory for rare events

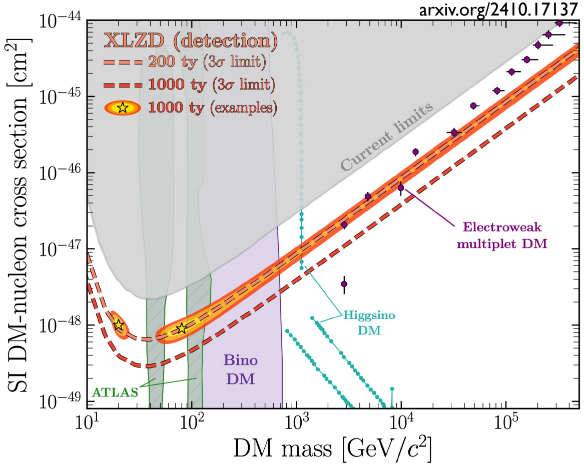
Prepared for Rick Gaitskell on behalf of XLZD

XLZD: liquid xenon observatory at the 100-tonne scale

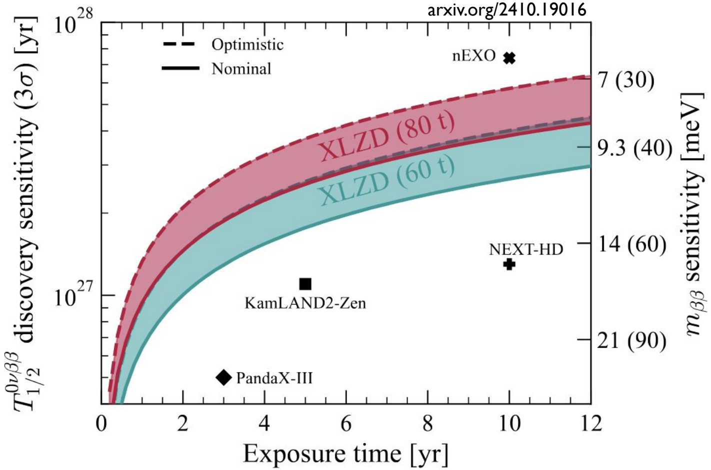
Natural xenon in a 2-phase TPC



Probe WIMP Dark Matter to neutrino fog systematic limit



DM detector w/natural xenon: Competitive sensitivity for $0\nu\beta\beta$



- Definitive WIMP search: systematics limited by ν fog at ~1000 tonne-years of exposure sets scale for ~100-tonne detector
- Xe-136 is 9% of the natural abundance, allowing a search for $0\nu\beta\beta$ with the potential to approach the nEXO design sensitivity
  - Optimization to push sensitivity to $T^{1/2}$ ~ 10^{28} years is under study

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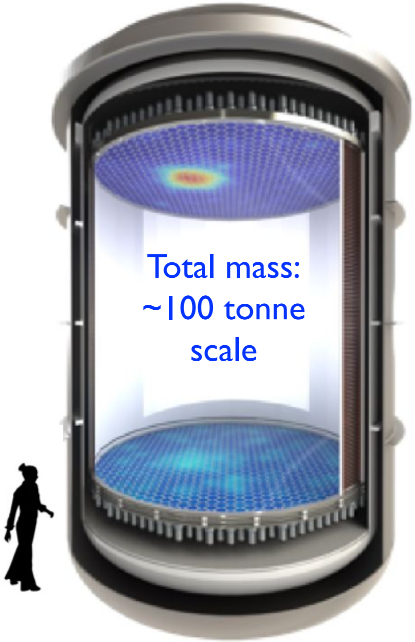
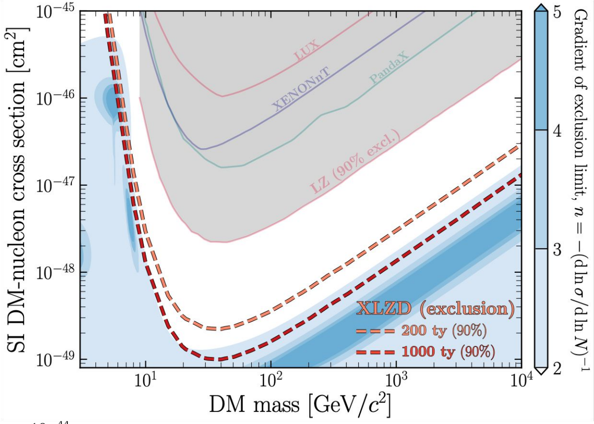
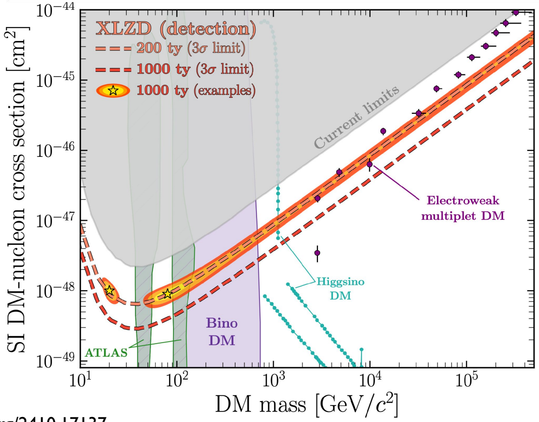


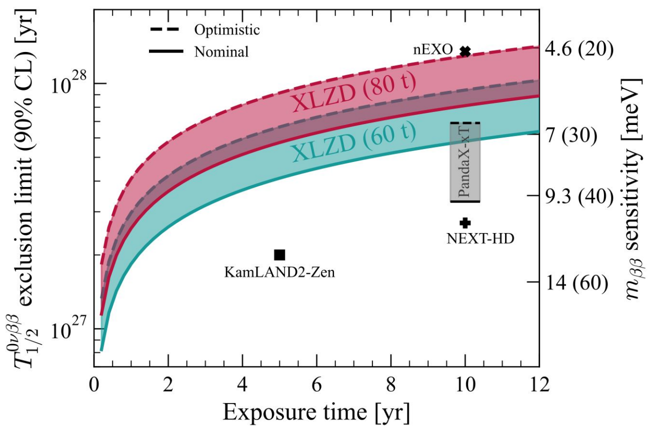
Probe WIMP Dark Matter to neutrino fog systematic limit

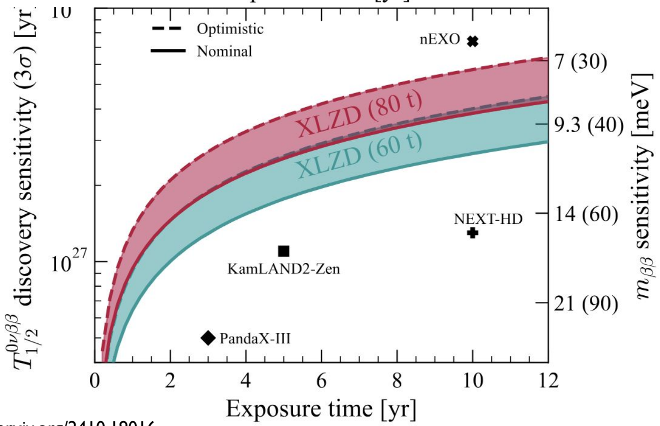




arxiv.org/2410.17137

DM detector w/natural xenon: Competitive sensitivity for $0\nu\beta\beta$

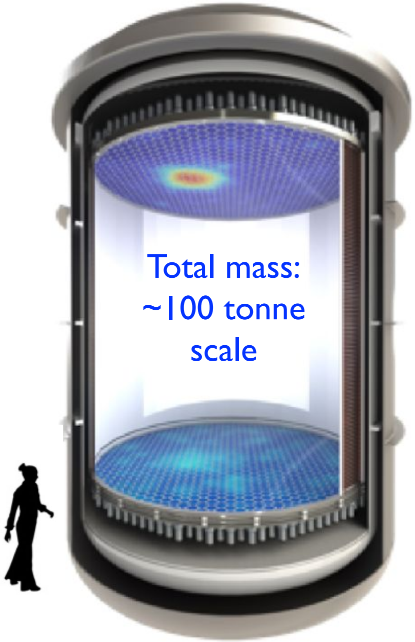




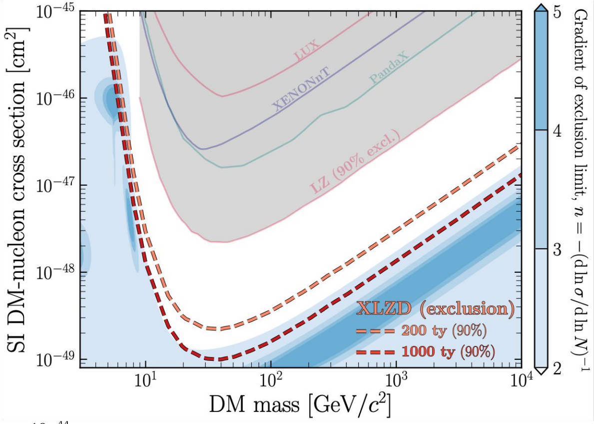
arxiv.org/2410.19016

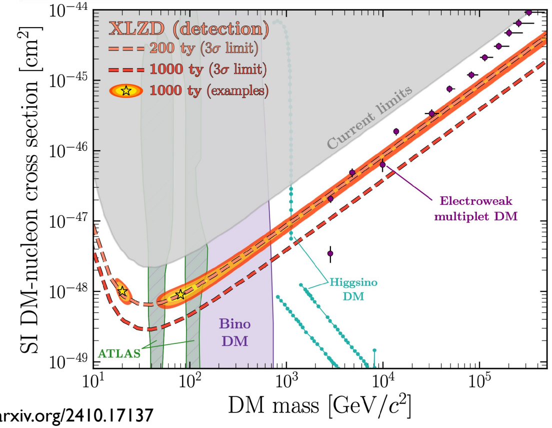
XLZD: liquid xenon observatory at the 100-tonne scale

Natural xenon in a 2-phase TPC



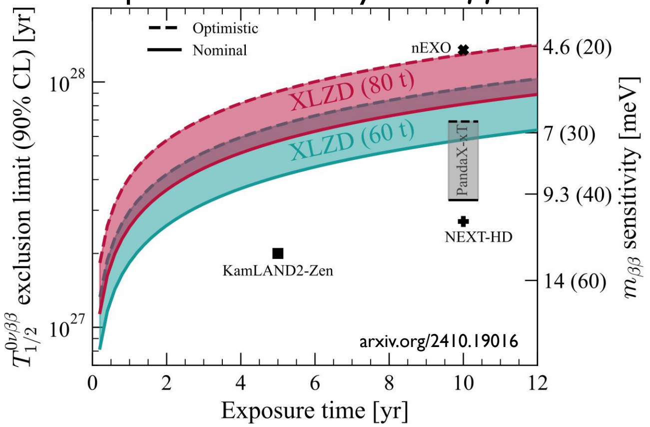
Probe WIMP Dark Matter to neutrino fog systematic limit

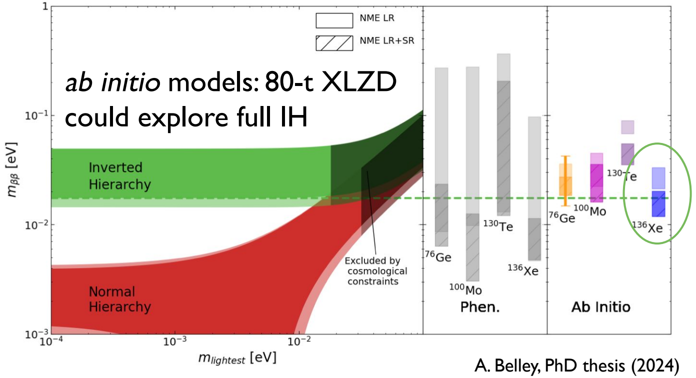




arxiv.org/2410.17137

DM detector w/natural xenon: Competitive sensitivity for $0\nu\beta\beta$





A. Belley, PhD thesis (2024)

XLZD 0ν-DBD Sensitivity (Double Beta Decay)

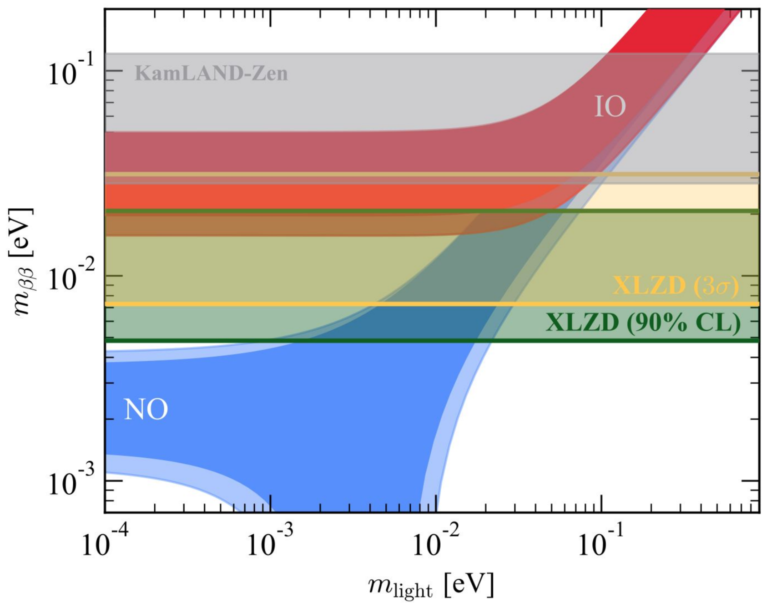
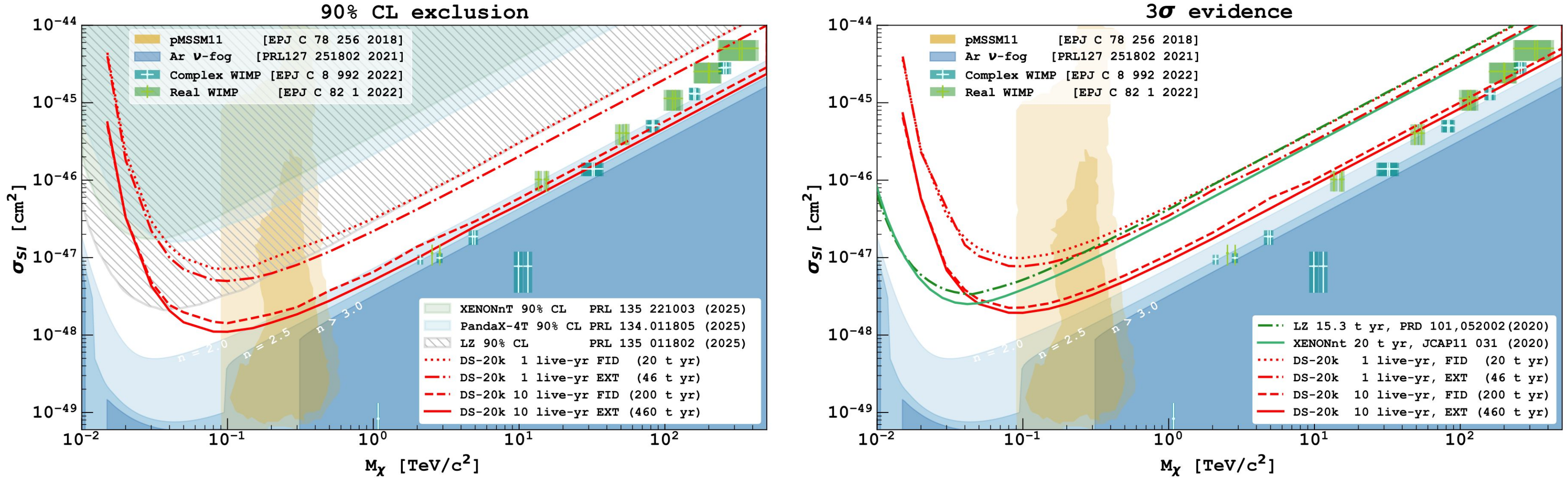


Figure 5. Sensitivity of XLZD to the effective Majorana neutrino mass as a function of the lightest neutrino mass for the 80 t configuration in the optimistic scenario with 10 years of data. The two metrics considered in this work are shown: 3σ discovery potential (yellow band) and 90% CL exclusion (green band). The width of the bands is caused by the uncertainty in the nuclear matrix element models (see main text, also for the expected sensitivity using the most recent nuclear matrix elements). The current best experimental limits from KamLAND-Zen, also from $0\nu\beta\beta$ decay in ^{136}Xe and assuming the same range of NMEs, are shown in grey [5]. The allowed regions ($\pm 3\sigma$) for the effective Majorana neutrino mass in the inverted (IO) and normal (NO) neutrino mass ordering scenarios are also shown [64, 65].

DS20k Reference

DS20k Science Reach - High Mass Searches



DS-20k sensitivity (left: 90 % C.L. exclusion; right: 3 σ significance evidence for a signal) to spin-independent WIMPs for different live-times, 1 and 10 yr, and for different target volumes, fiducial and extended volume. The DS-20k projected 90 % C.L. exclusion is compared with the world-leading dark matter results published by LZ, XENONnT, and PandaX-4T. The DS-20k 3 σ detection sensitivity is instead compared against the published values of the ultimate projected sensitivities of the two U.S. experiments: for LZ, 2.7 yr run, 15.3 t yr exposure; for XENONnT, 5 yr run, 20.2 t yr exposure. Also represented are the neutrino "fog" for an argon detector, shown by the blue-shaded regions of different density, and the 1-, 2-, and 3-σ favored regions from the pMSSM11 model constrained by astrophysical measurements and the ~36/fbarn LHC dataset at 13 TeV, shown by the ochre-filled contours. Green and blue rectangles identify regions where complex and real WIMPs can be thermally produced at the relic abundance, subject to current constraints from indirect and collider searches.