

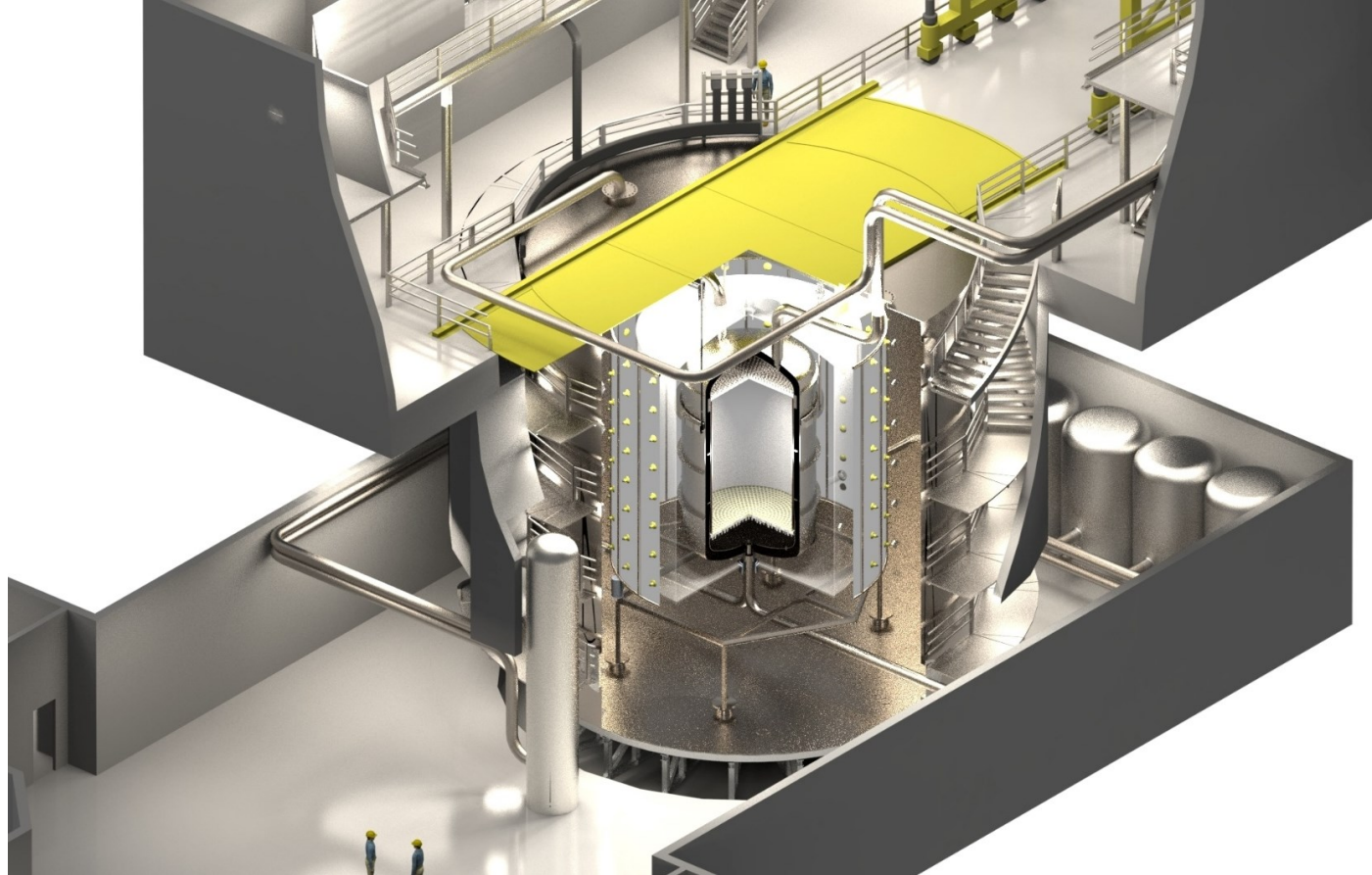


Liquid xenon rare-event observatory

ADAM SOFTLEY-BROWN



University of
Sheffield



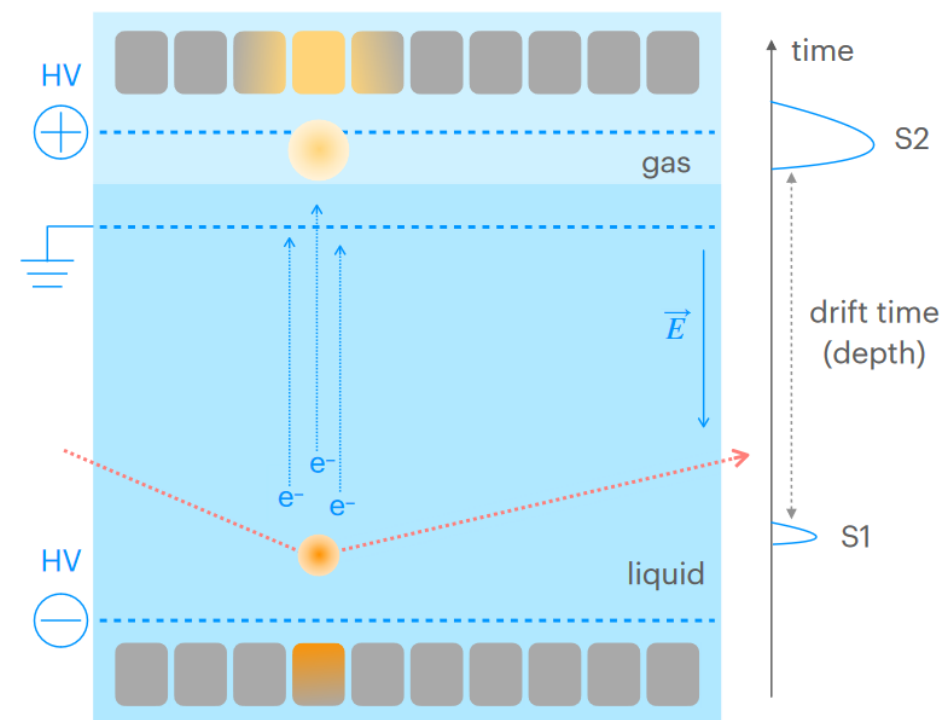
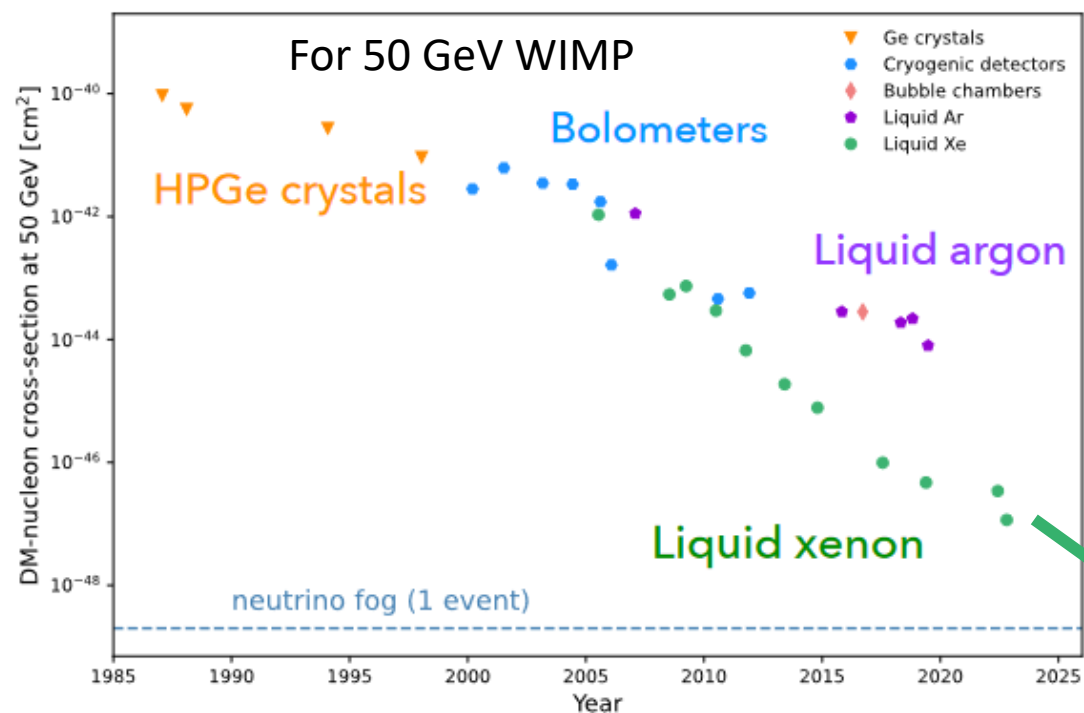
Science and
Technology
Facilities Council

Liquid xenon for dark matter

Liquid xenon leads sensitivity to GeV+ mass WIMPs

Observe light (S1) & charge (S2) from interactions

→ 5D information (x,y,z,E,t) + particle discrimination (ER / NR)





Karlsruhe 2022



UCLA 2023



RAL 2024

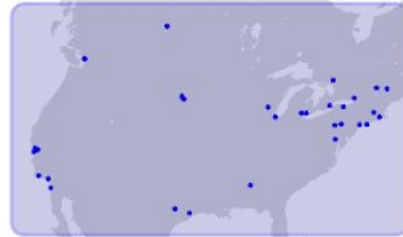


LNGS 2025

XLZD

400+ members from 80+ institutions
Drawing on experience from current-generation
liquid xenon experiments

Active collaboration with ongoing design
and R&D towards realising XLZD



Black Hills State University
 Brookhaven National Laboratory
 Brown University
 Bucknell University
 Columbia University
 Laurentian University
 Lawrence Berkeley National Laboratory
 Lawrence Livermore National Laboratory
 McGill University
 McMaster University
 Pennsylvania State University
 Queen's University
 Rice University
 SLAC National Accelerator Laboratory
 SNOLAB
 Sanford Underground Research Facility
 South Dakota School of Mines
 TRIUMF
 The University of Chicago
 University of Alabama
 University of Alberta
 University of British Columbia
 University of California, Berkeley
 University of California, Los Angeles
 University of California, San Diego
 University of California, Santa Barbara
 University of Maryland
 University of Massachusetts
 University of Michigan
 University of Rochester
 University of Texas, Austin
 University of Windsor
 University of Wisconsin
 Université de Montreal
 Université de Sherbrooke



Heidelberg University
 INAF Osservatorio Astrofisico Torino
 INFN-LNGS
 Imperial College London
 Johannes Gutenberg University Mainz
 Karlsruhe Institute of Technology
 King's College London
 LIP-Coimbra
 LPNHE
 Max-Planck-Institut für Kernphysik
 Nikhef & the University of Amsterdam
 Nikhef & the University of Groningen
 Queen Mary University of London
 Royal Holloway, University of London
 SISSA
 STFC Laboratories
 SUBATECH
 Stockholm University
 TU Darmstadt
 TU Dresden

University College London
 University and INFN Bologna
 University of Barcelona
 University of Bern
 University of Birmingham
 University of Bristol
 University of Coimbra
 University of Edinburgh
 University of Ferrara
 University of Freiburg
 University of L'Aquila
 University of Liverpool
 University of Münster
 University of Naples "Federico II"
 University of Oxford
 University of Sheffield
 University of Sussex
 University of Zurich
 Vinca Institute of Nuclear Sciences
 Weizmann Institute



Institute for Basic Science
 Kobe University
 Nagoya University
 The Chinese University of Hong Kong, Shenzhen
 The University of Tokyo
 Tsinghua University
 Westlake University



The University of Melbourne
 The University of Sydney

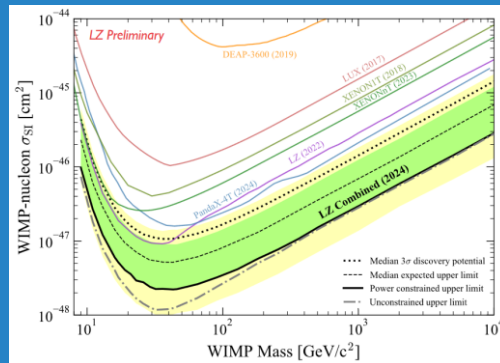
XENON and LZ: running experiments

Two cutting edge liquid xenon experiments

With 6 t (XENONnT) and 7 t (LZ)
instrumented xenon

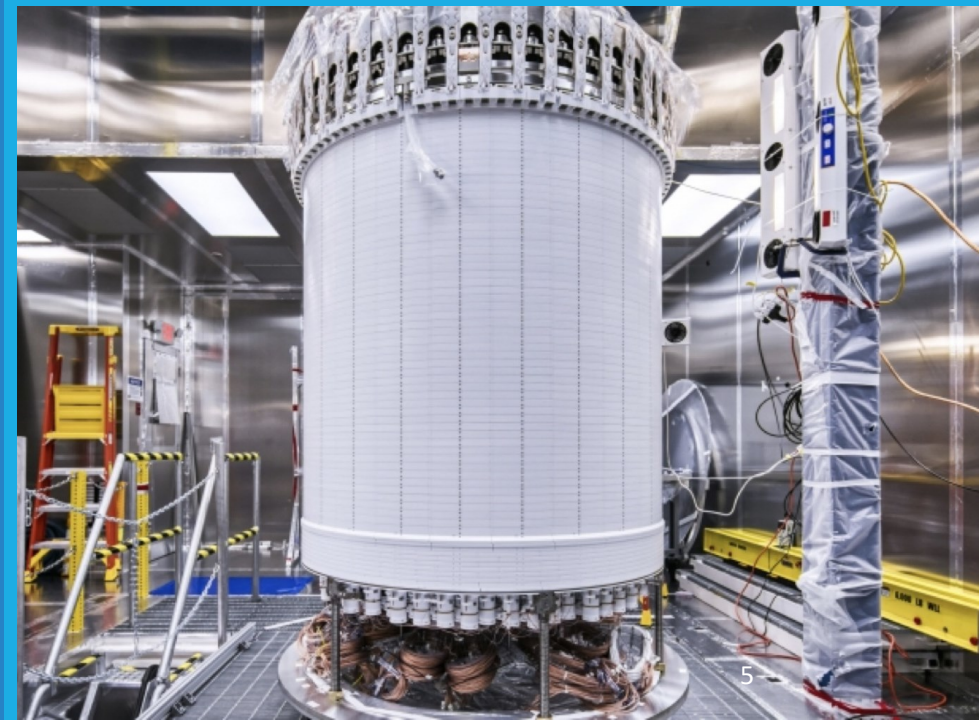
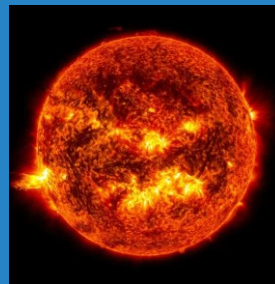
World-leading constraints on
WIMP dark matter

Increasingly sensitive to **other rare events**



Measurement of Solar ^8B Neutrinos via Coherent Elastic Neutrino-Nucleus Scattering with XENONnT

Iberv², K. Abe³, S. Ahmed Maouloud⁴, L. Althueser⁵, B. Andrieu⁴, E. Angelino^{6,7},
urtin⁸, F. Arneodo⁹, L. Bandin¹⁰, M. Bazyk¹¹, L. Bellagamba¹², R. Biondi¹³,
K. Boese¹⁴, A. Brown¹⁵, G. Bruno¹⁶, R. Budnik¹⁷, C. Cai¹⁸, C. Capelli¹⁹,
A. P. Cimental Chávez¹⁰, A. P. Colijn¹⁶, J. Conrad¹⁹, J. J. Cuenca-García¹⁰,
L. C. Daniel García⁴, M. P. Decowski¹⁸, A. Deisting²⁰, C. Di Donato^{21,7},
S. Diglio¹¹, K. Eitel²², A. Elykov²², A. D. Ferella^{21,7}, C. Ferrari², H. Fischer¹⁴,
Flierman¹⁸, W. Fulgione^{5,7}, C. Fuselli¹⁸, P. Gaemers¹⁸, R. Gaior⁴, M. Galloway¹⁰,
osh²³, R. Giacomobono²⁴, R. Gläsel-Beucke¹⁴, L. Grandi², J. Grigat¹⁴, H. Guan²⁵,
Gyergy²⁶, R. Hamann²⁷, A. Hignar²⁸, C. Hlin²⁹, L. Hostachal¹³, N. F. Hood²⁰,
Y. Ito³⁰, J. Jakob⁵, F. Joerg^{13,10}, Y. Kaminaga³, M. Kara²², P. Kavirgin¹⁵,
Kobayashi²⁷, D. Koko³, A. Kopeck²⁶, F. Kuger¹⁴, H. Landmann¹⁵, R. F. Lang²³,
I. Li¹, S. Li²⁸, S. Liang²⁵, Y.-T. Lin¹³, S. Lindemann¹⁴, M. Lindner¹³,
I. Liu^{1,16}, J. Loizeau¹¹, F. Lombardi²⁰, J. Long⁸, J. A. M. Lopes^{17,1}, T. Luce¹⁴,
C. Macolino^{21,7}, J. Mahstedt¹⁹, A. Mancuso¹², L. Manenti⁹, F. Marinetti²⁴,
oitia¹³, K. Martens³, J. Masbou¹¹, E. Masson⁴, S. Mastroianni²⁴, A. Melchiorre^{21,7},
Messina⁷, A. Michael³, K. Miuchi²⁹, A. Molinari⁹, S. Moriyama³, K. Mori¹,
x¹⁰, M. Murra¹, J. Müller¹⁴, K. Ni³⁰, U. Oberlack²⁹, B. Paetsch¹⁵, Y. Pan⁴,
R. Pires¹⁹, C. Peters²⁵, J. Pienaar^{8,15}, M. Pioner¹⁸, G. Pianta¹, J. R. Pollmann¹⁸,
L. Principe³⁰, J. Qi²⁰, D. Ramirez Garcia¹⁰, M. Rajado¹⁰, R. Singh²³, L. Sanchez²⁵,
J. M. F. dos Santos¹⁷, I. Saruwall⁹, G. Sartorelli¹², J. Schreiner¹³, P. Schulte⁵, H. Schulte Eifling⁵,
M. Schumann¹⁴, L. Scotti Lavina⁴, M. Selvi¹², F. Semeria¹², P. Shagin²⁰, S. Shi¹, J. Shi¹⁶,
M. Silva¹⁷, H. Singen¹³, A. Takada³, P.-L. Tan¹⁹, D. Thers¹¹, F. Toschi²², G. Trincherro⁶,
C. D. Tunnell²⁵, P. Tönnies¹⁴, K. Valerius²², S. Vecchi²⁰, S. Vetter²², F. I. Villazon Solar²⁰, G. Volta¹³,
C. Weinheimer⁵, M. Weiss¹⁵, D. Wenz⁵, C. Wittweg¹⁰, V. H. S. Wu²², Y. Xing¹³, D. Xu^{1,1},
Z. Xu¹, M. Yamashita³, L. Yang²⁶, J. Ye^{21,1}, L. Yuan⁸, G. Zavattini²⁰ and M. Zhong²⁶
(XENON Collaboration)*



Main XLZD goals

Be most sensitive rare event xenon observatory

Search for WIMP dark matter down to ν fog

Provide competitive constraints on $0\nu\beta\beta$

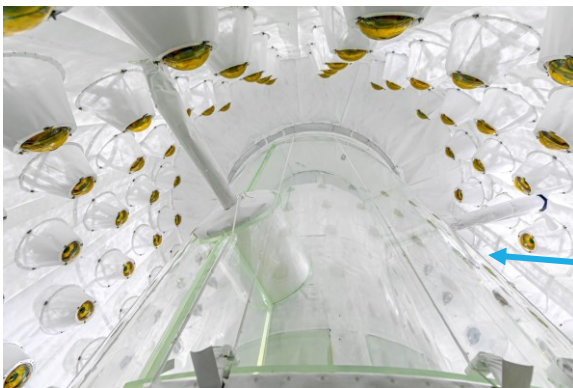
XLZD baseline design

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](https://arxiv.org/abs/2410.17137)

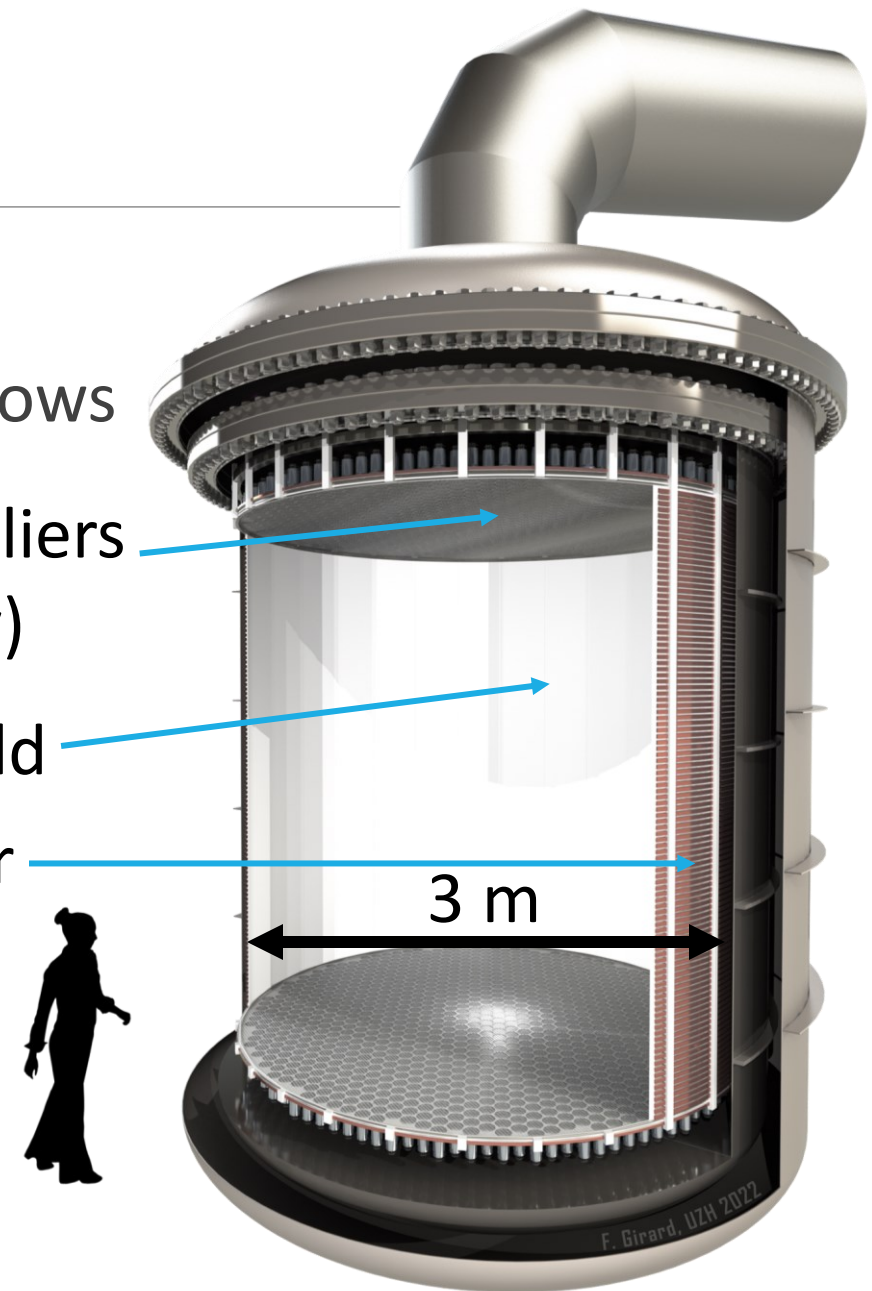


Plus outer detector
as n, μ veto

3" photomultipliers
(1182 per array)

250 V/cm drift field

LXe skin detector



Backgrounds

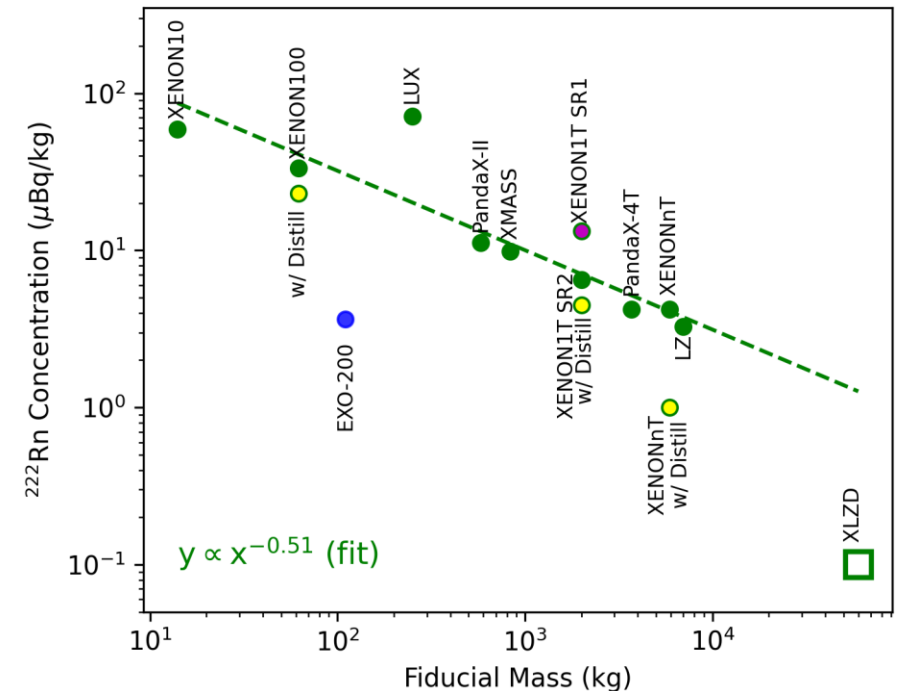
Material backgrounds factor 4—10 lower than current generation

Intrinsic backgrounds at low-E subdominant to solar neutrinos

Rn concentration $< 0.1 \mu\text{Bq/kg}$

Screening, low-activity materials,
active removal – on target

See talk #34 by Ferdos Dastgiri
Thursday at 15:00

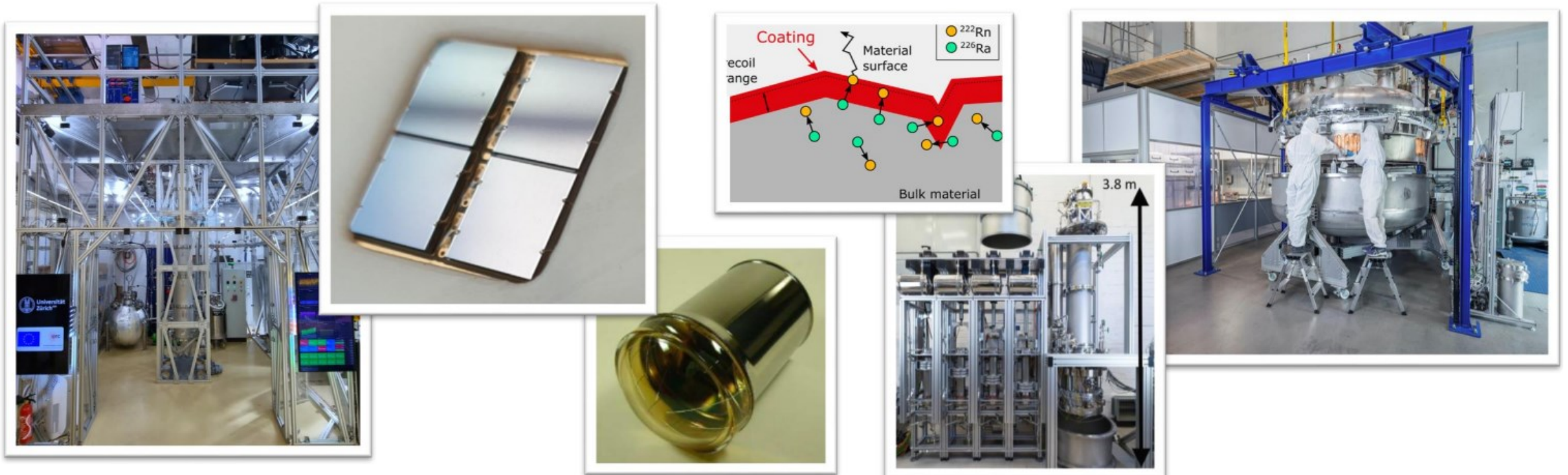


R&D

Active R&D in several areas:

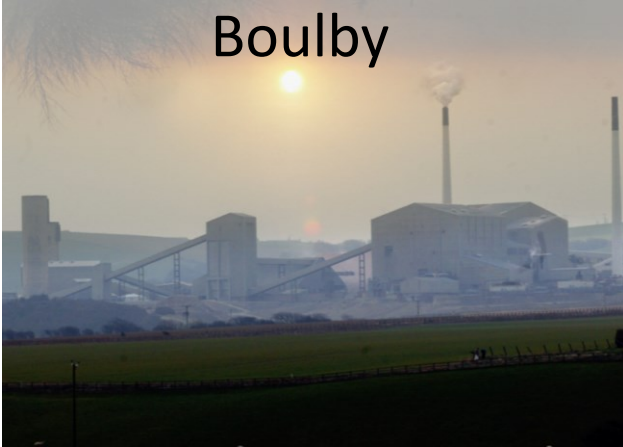
Background mitigation, PMTs, test platforms, novel technologies...

See poster #21 by Rebecca Hampp



Candidate sites

Boulby



SURF



LNGS



SNOLAB



Key requirements:

Depth for cosmogenic backgrounds

Space for construction

Possibility of transporting large items underground

Site reviews ongoing

Site	Depth		μ flux (/(m ² d))	¹³⁷ Xe rate (/(t year))	SS ROI rate (evt/(t year keV))
	(m)	(m w.e.)			
SNOLAB	2070	5890	<0.3	0.007	1.29×10^{-6}
SURF	1490	4300	4.6	0.142	2.72×10^{-5}
Boulby	1300	3330	14.6	0.404	7.73×10^{-5}
LNGS	1400	3800	29.7	0.822	1.57×10^{-4}
Kamioka	1000	2700	128	3.54	6.78×10^{-4}

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



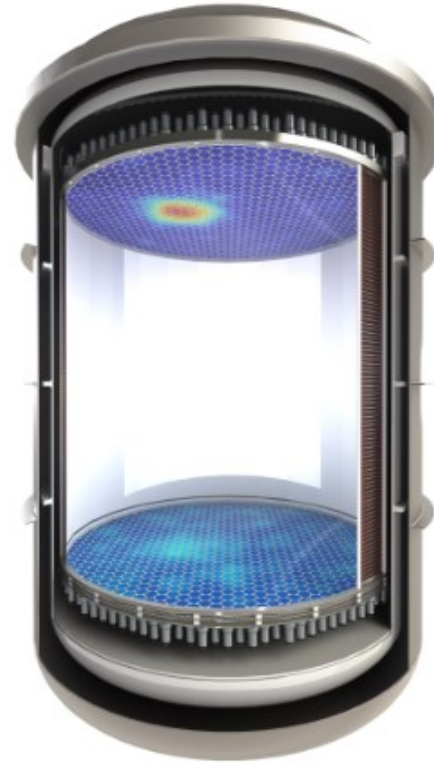
Supernovae

Early alert
Supernova neutrinos
Multi-messenger
astrophysics



Sun

pp neutrinos
Solar metallicity
 ${}^7\text{Be}$, ${}^8\text{B}$, hep



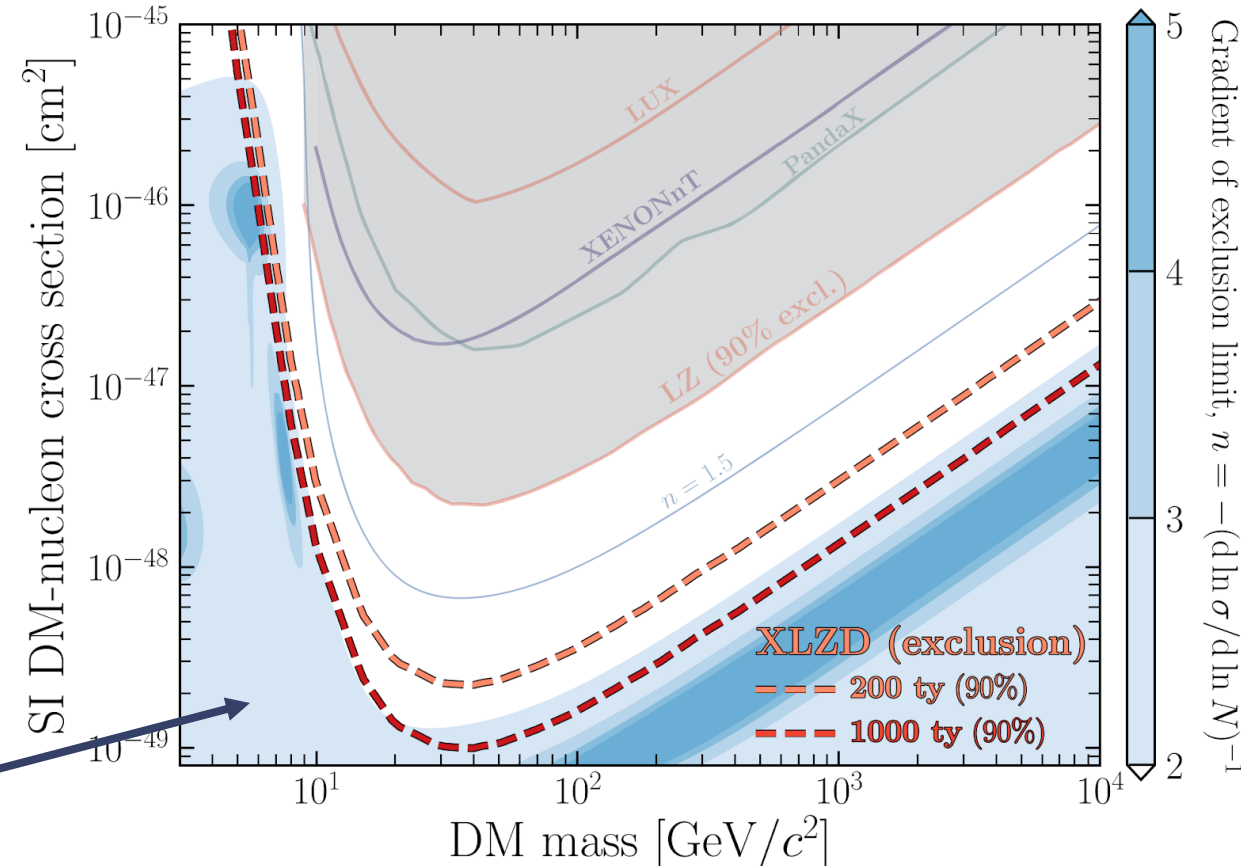
WIMP sensitivity

Definitive search for medium to high WIMP masses

Explore into the neutrino fog after ~ 1000 t yr exposure

3- σ discovery potential at SI cross section of $3 \times 10^{-49} \text{ cm}^2$ at 40 GeV

At contour n , improving limit by $10\times$ requires $10^n\times$ the exposure



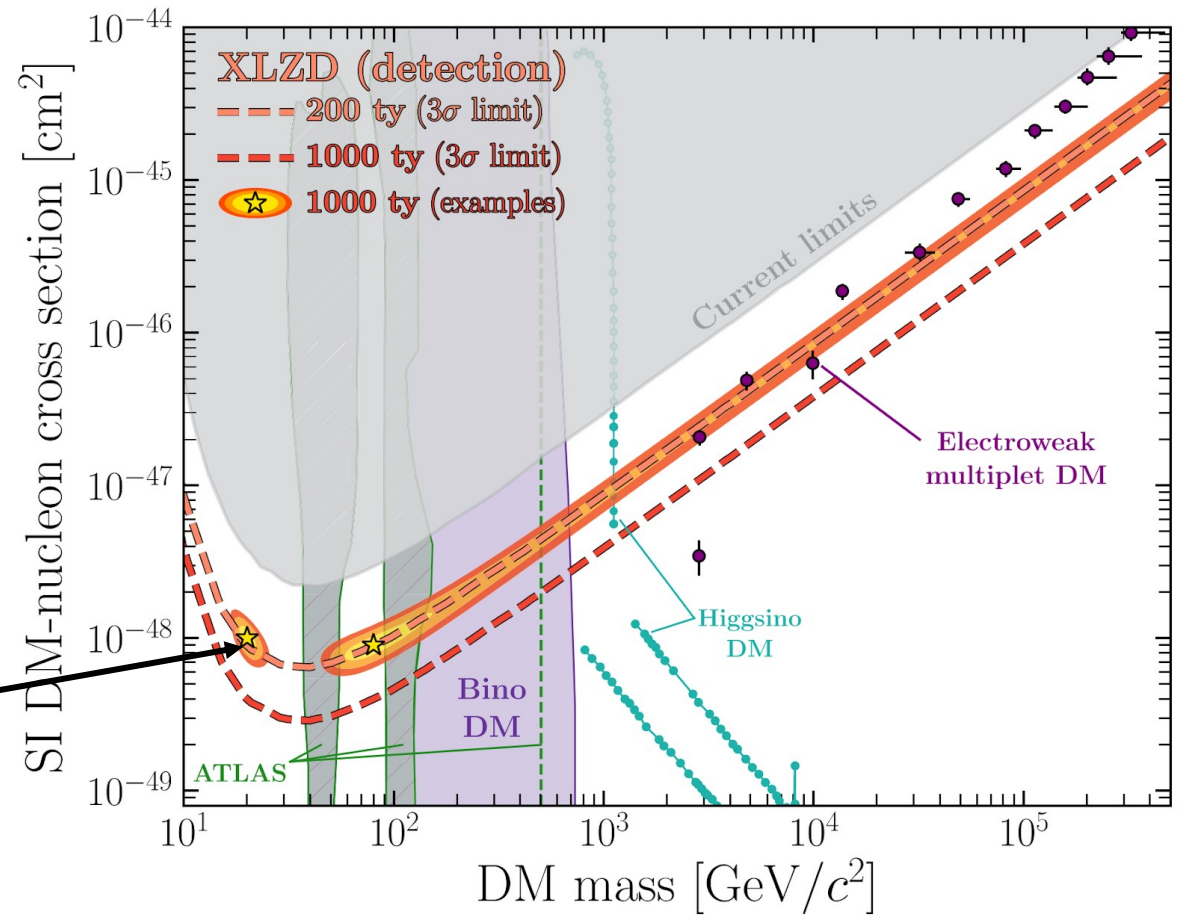
WIMP sensitivity

Definitive search for medium to high WIMP masses

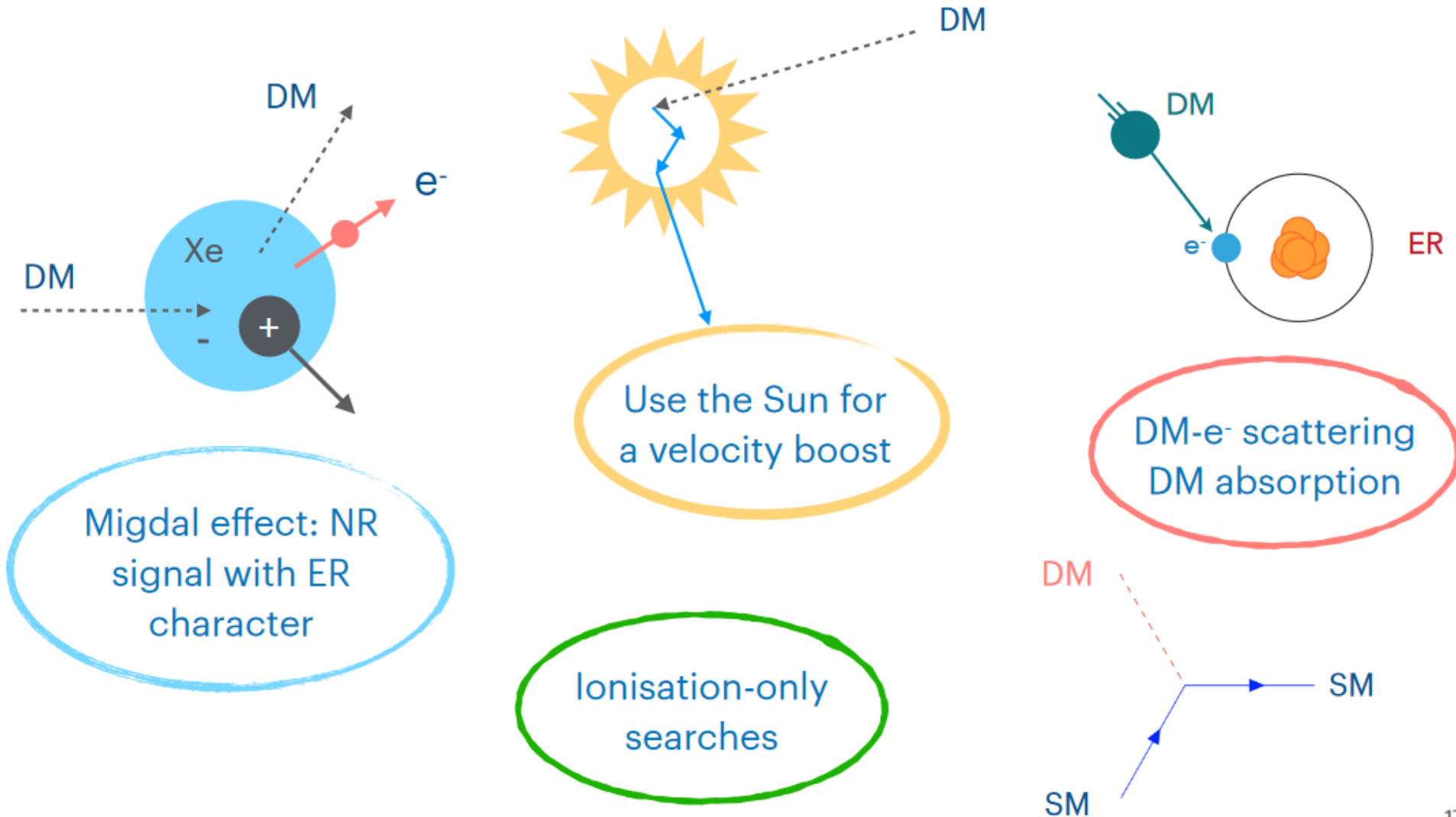
Reach into the neutrino fog after ~ 1000 t yr exposure

3- σ discovery potential at SI cross section of $3 \times 10^{-49} \text{ cm}^2$ at 40 GeV

Example confidence intervals for 1000 t yr exposure

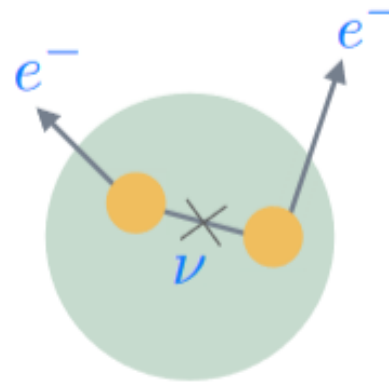
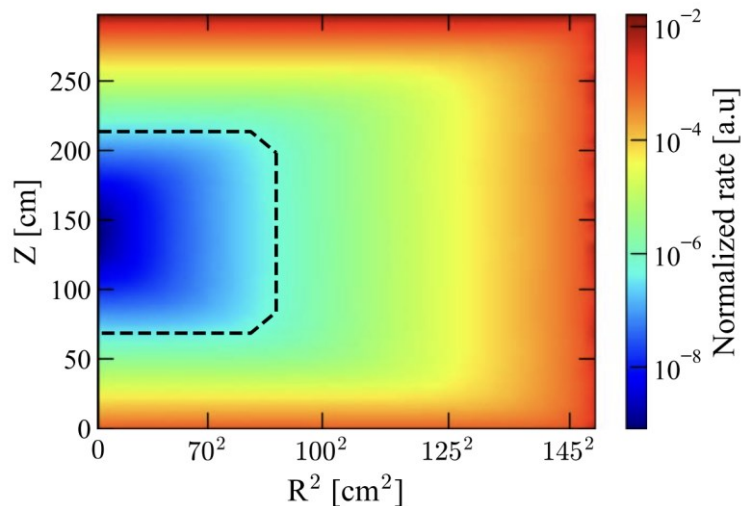
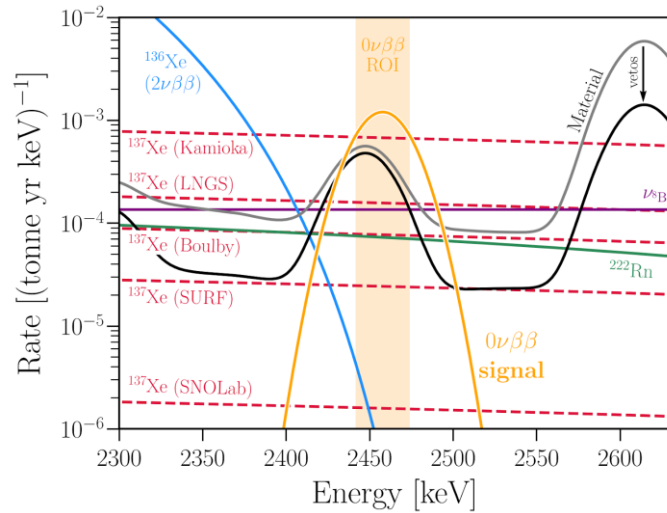


Lighter dark matter



17

Neutrinoless double beta decay



^{136}Xe (8.9%) double beta decay ($2\nu\beta\beta$)
with half-life 2×10^{21} yr

Search for $0\nu\beta\beta$ peak at $Q=2.458$ MeV

Energy resolution of large TPCs $< 0.8\%$ (σ/E)

Detector materials dominate background –
targeting 4–10 $\times$ reduction in activity

Skin, RFR, OD help veto ^{208}Tl backgrounds

Optimal FV around 10 t

Cosmogenic (^{137}Xe +) subdominant at all four sites

Neutrinoless double beta decay

XLZD competitive with dedicated experiments

Published sensitivity based on scaling LZ BGs:

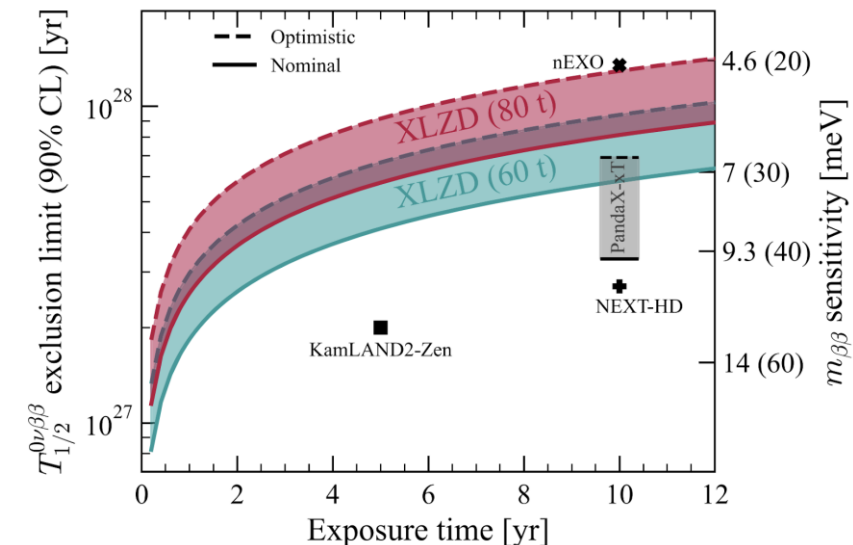
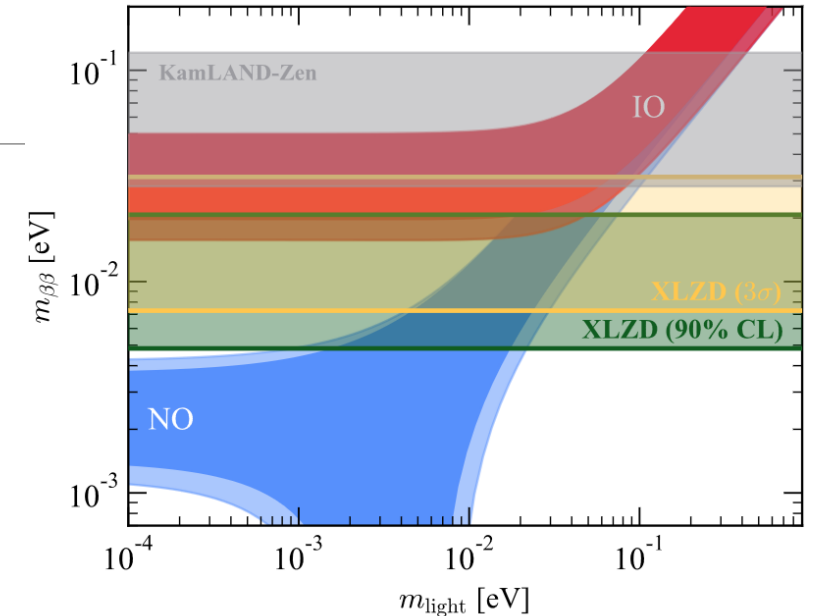
5.7×10^{27} yr discovery after 10 yr

1.3×10^{28} yr exclusion at 90%

Can cover IO for a wide range of NMEs

Work ongoing to refine with detailed Geant4 simulations and PLR inference

See [J. Phys. G 52 045102](#) / [2410.19016](#) for more details

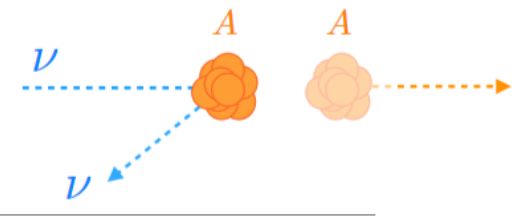


Astrophysical neutrinos

Neutrino-nucleus scattering (^8B)

Observed by LZ (4.5σ), XENONnT (2.7σ), PandaX (2.6σ)

High precision measurement possible with 1000 t yr exposure



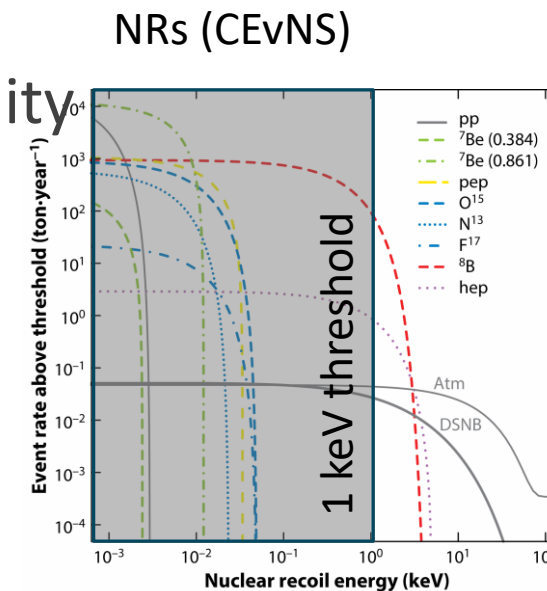
Solar pp neutrinos

~5% precision on low-E survival probability

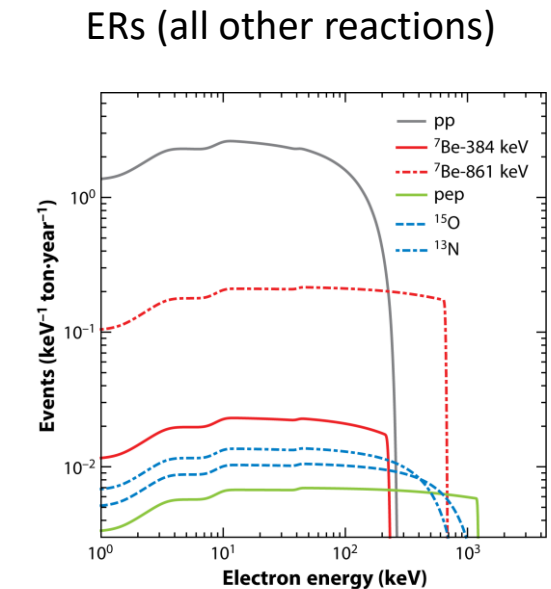
Test of solar and neutrino physics

Supernova neutrinos

Sensitivity to type-II SN beyond SMC



Dutta B, Strigari L.E. 2019.
Annu. Rev. Nucl. Part. Sci. 69:137–61



Dutta B, Strigari L.E. 2019.
Annu. Rev. Nucl. Part. Sci. 69:137–61

Conclusions

Definitive WIMP search with liquid xenon

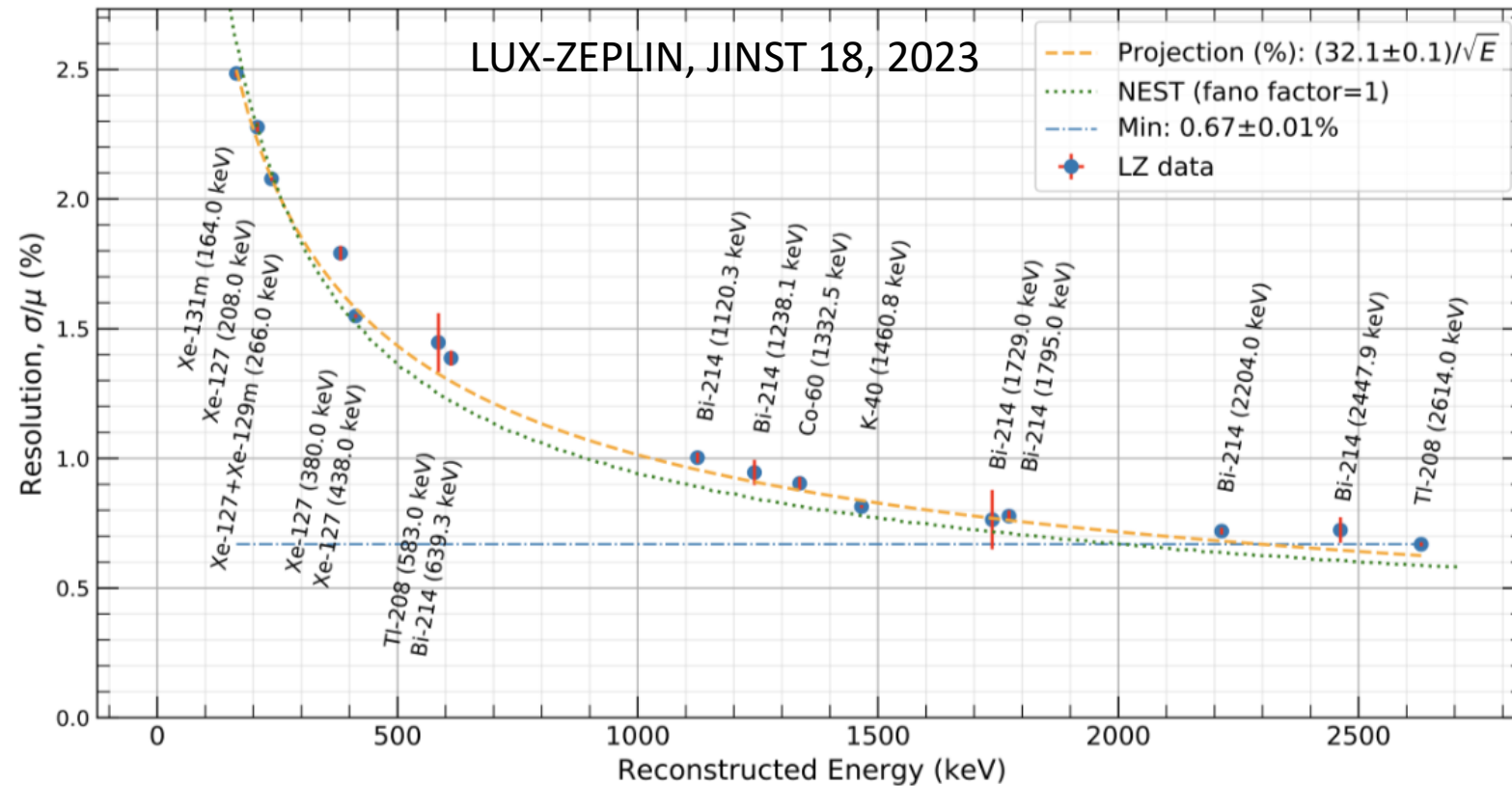
Globally competitive $0\nu\beta\beta$ sensitivity

Rich array of neutrino physics



Neutrinoless double-beta decay

Energy resolutions < 1% achieved by current detectors

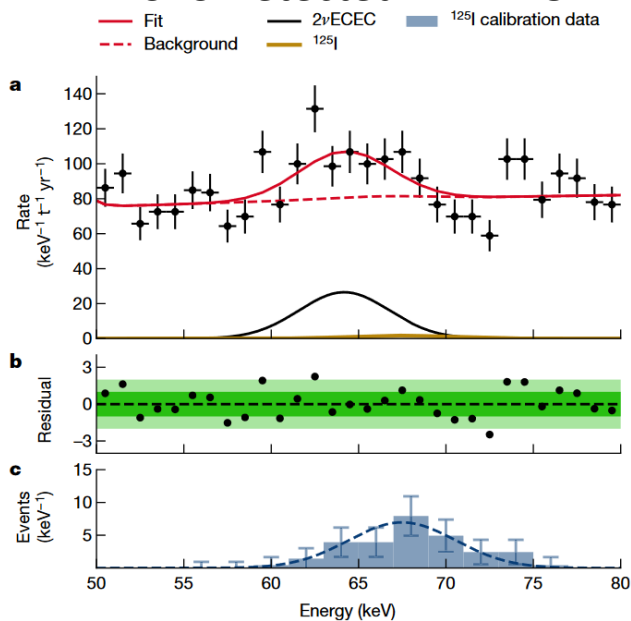


Other second order decays

Three other isotopes with (predicted) 2nd order weak decays

^{124}Xe (0.1%), ^{126}Xe (0.09%), ^{134}Xe (10%)

2νECEC Detected in XENON1T

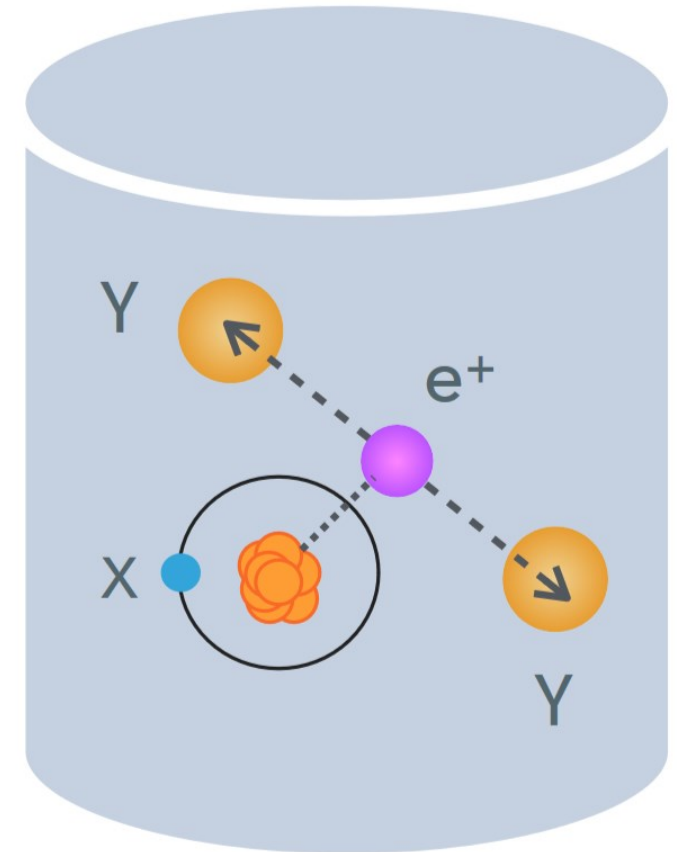


XENON, Nature 568, 2019

Predicted but not observed

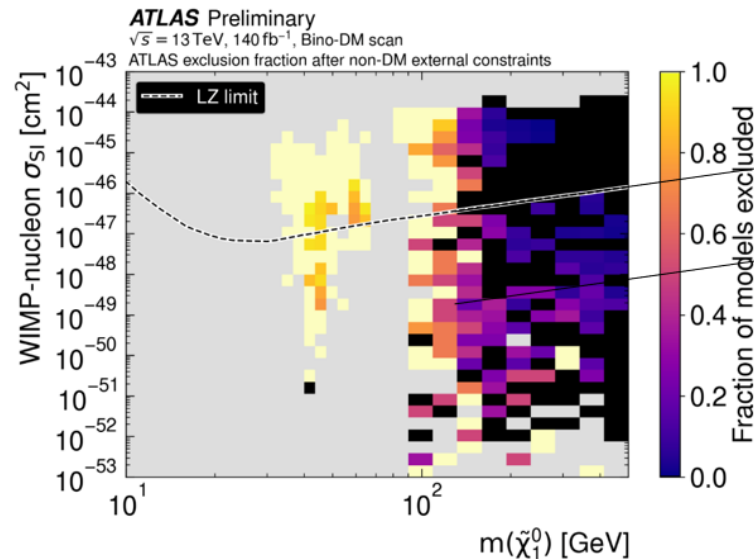
More interesting topologies
 $0\nu/2\nu\text{EC}\beta^+$, $0\nu/2\nu\beta^+\beta^+$

Tests of SM & nuclear physics



WIMP sensitivity

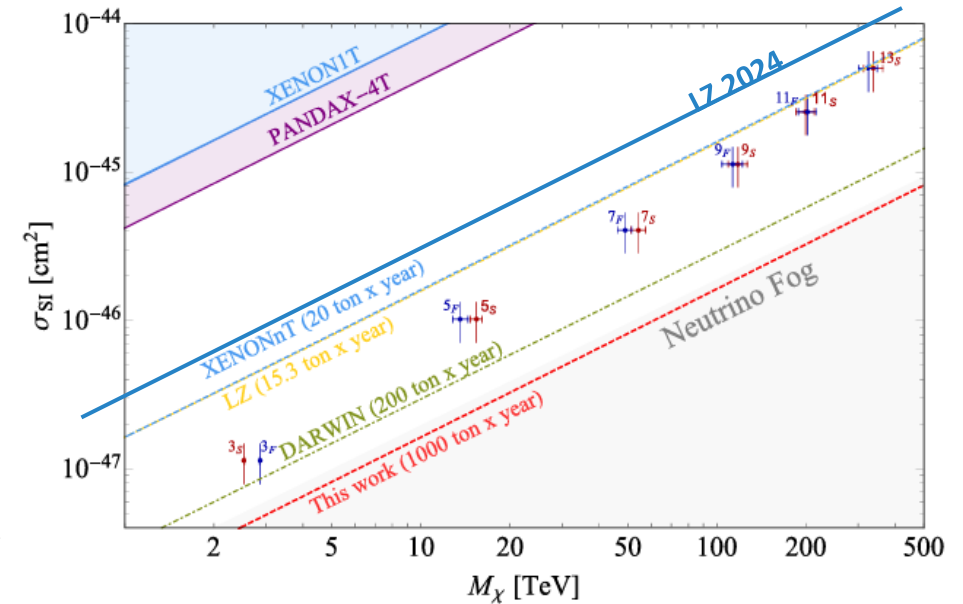
Probe “minimal dark matter” model
this canonical WIMP is a member of an EW multiplet
mediated by SM gauge bosons and the Higgs



To 100 TeV, and then on to M_{Pl}

XLZD, 90% CL sensitivity

Probe higher-energy
SUSY models inaccessible to the LHC

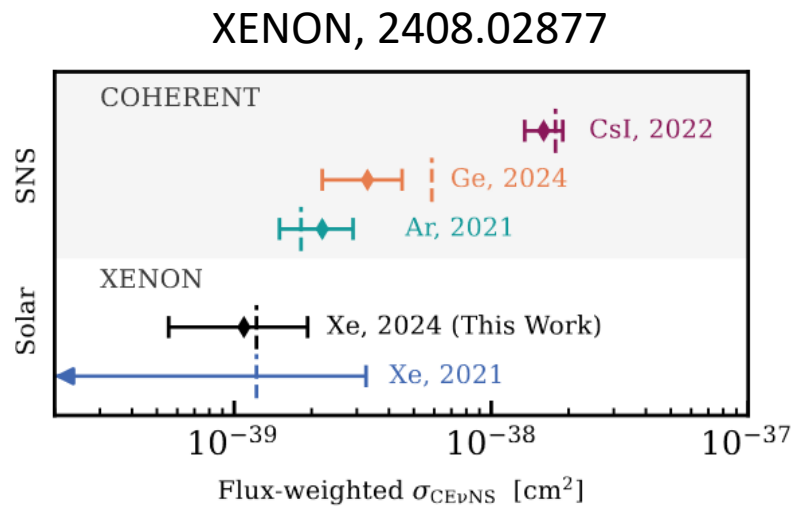
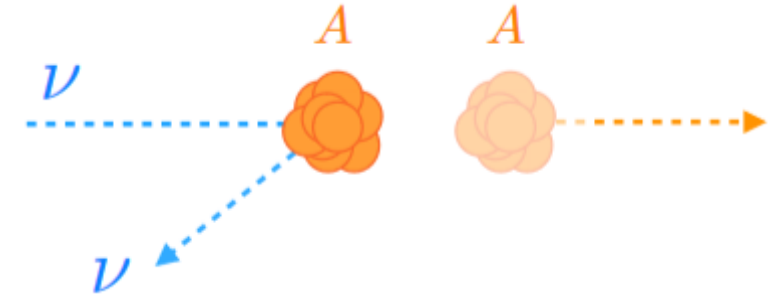


23

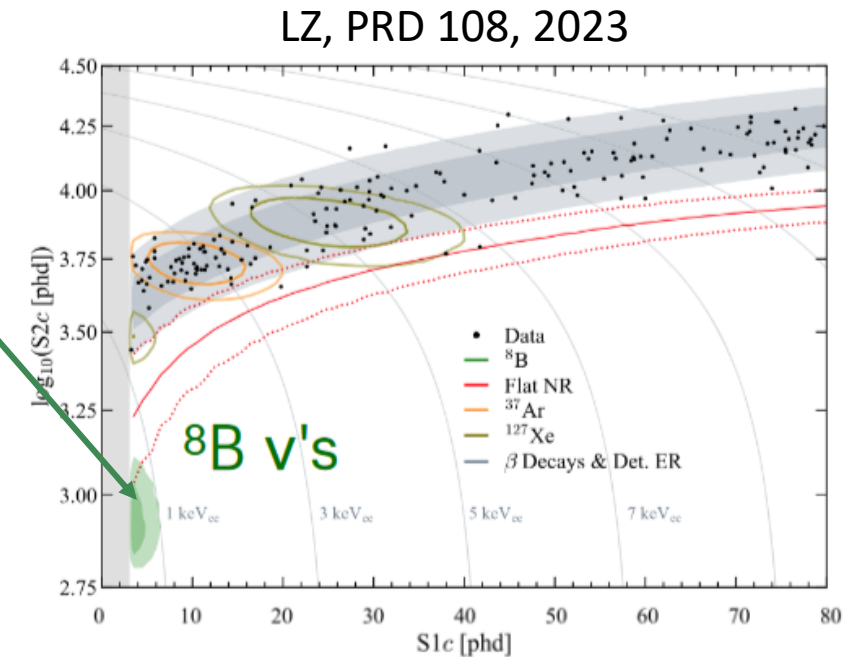
^8B neutrinos

Already observed by LZ (4.5σ),
XENONnT (2.7σ), PandaX (2.6σ)

Significance and precision will be far higher in XLZD



Signal very close
to threshold

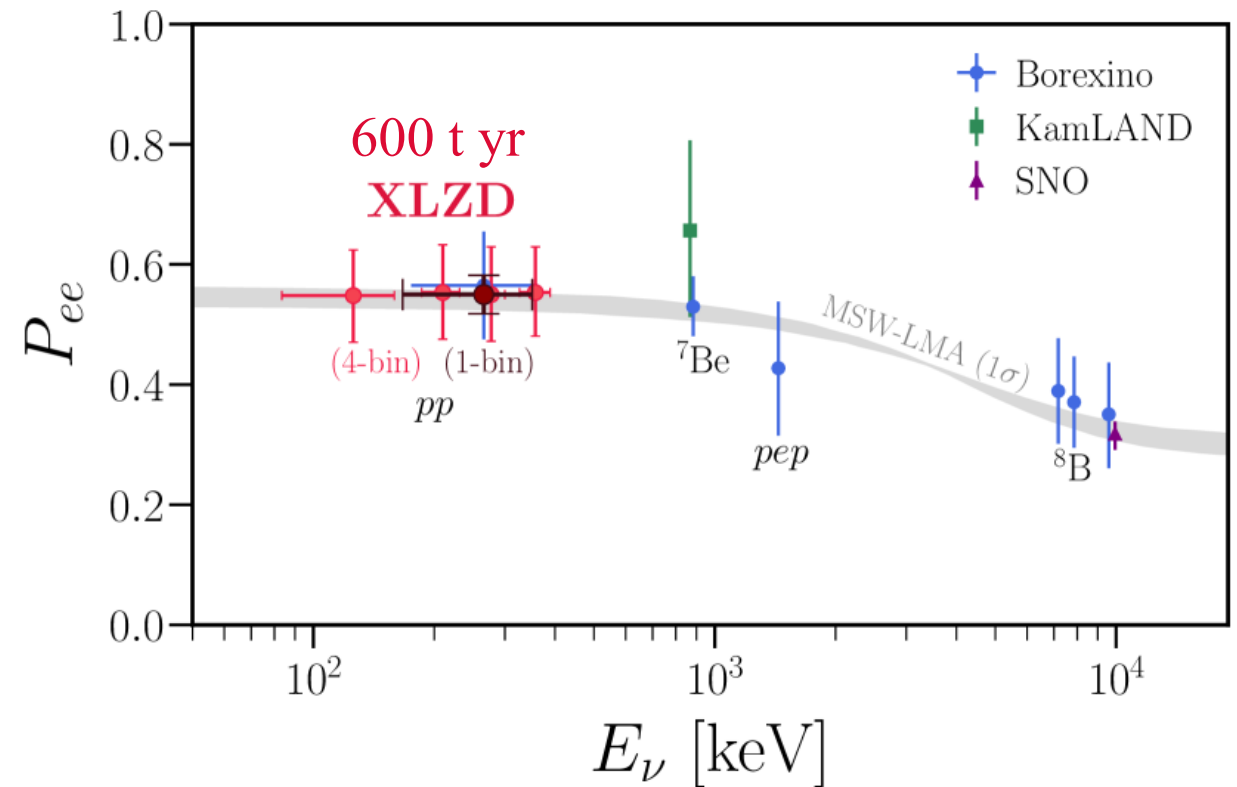
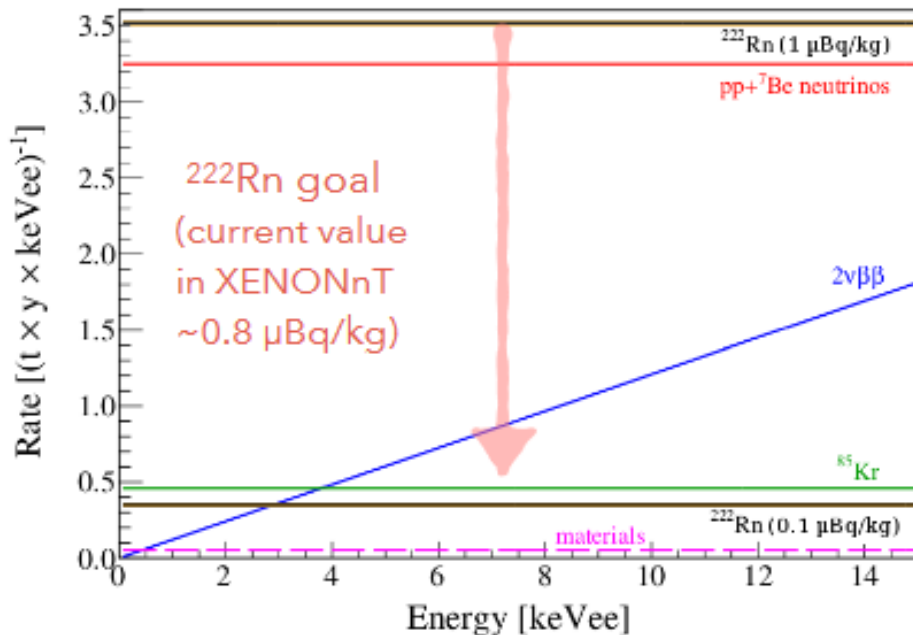


Astrophysical neutrinos – pp neutrinos

Intrinsic and material backgrounds subdominant to solar pp neutrinos

~5% measurement of low-E survival probability

Test solar and neutrino physics



Supernova neutrinos

Sensitivity to all flavours: few events/ton from SN at ~ 10 kpc

- Main challenge: low energies, understand few-e- backgrounds
- XLZD: sensitivity beyond SMC; part of SNEWS2.0

