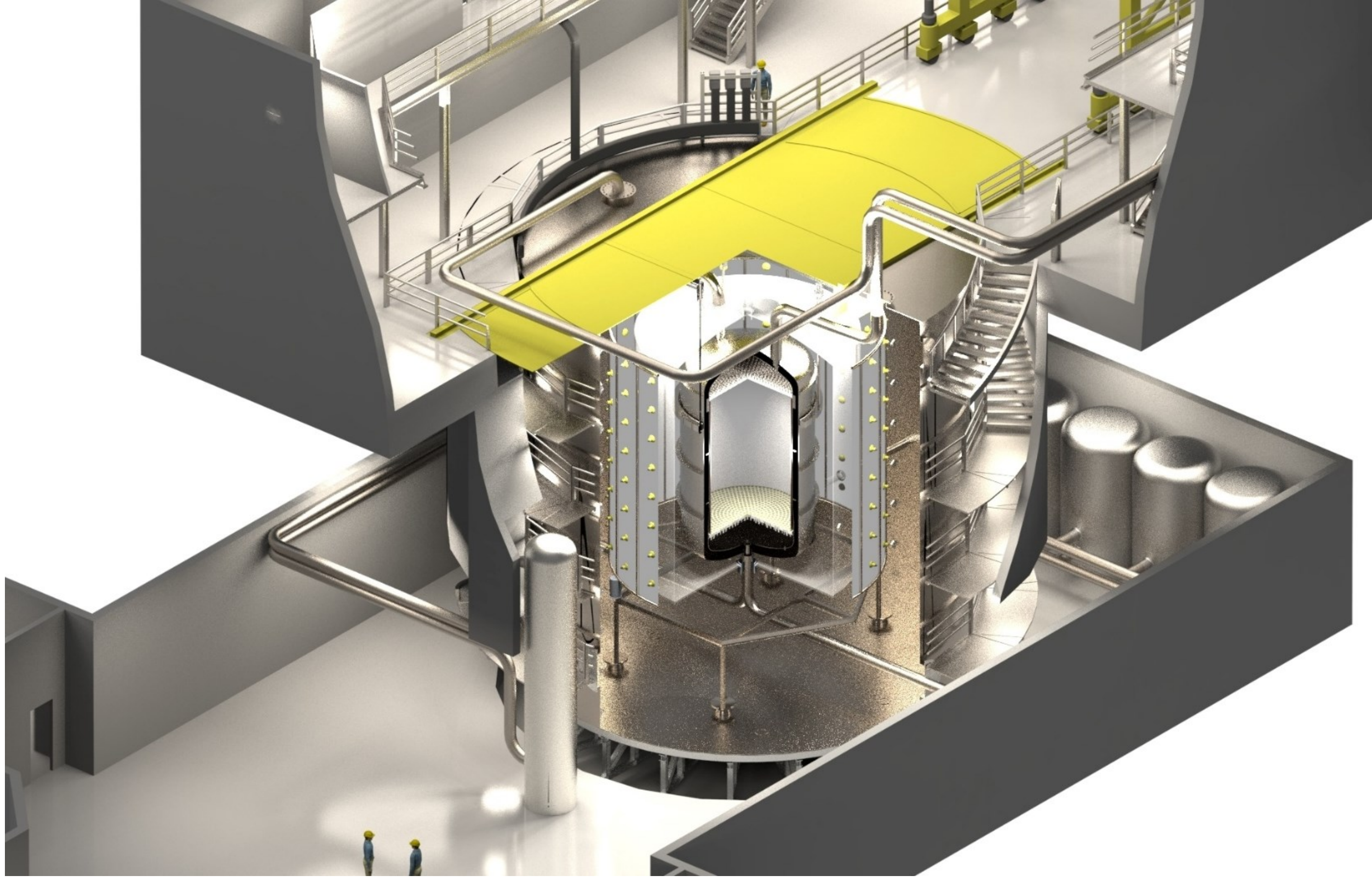
Liquid xenon rare-event observatory



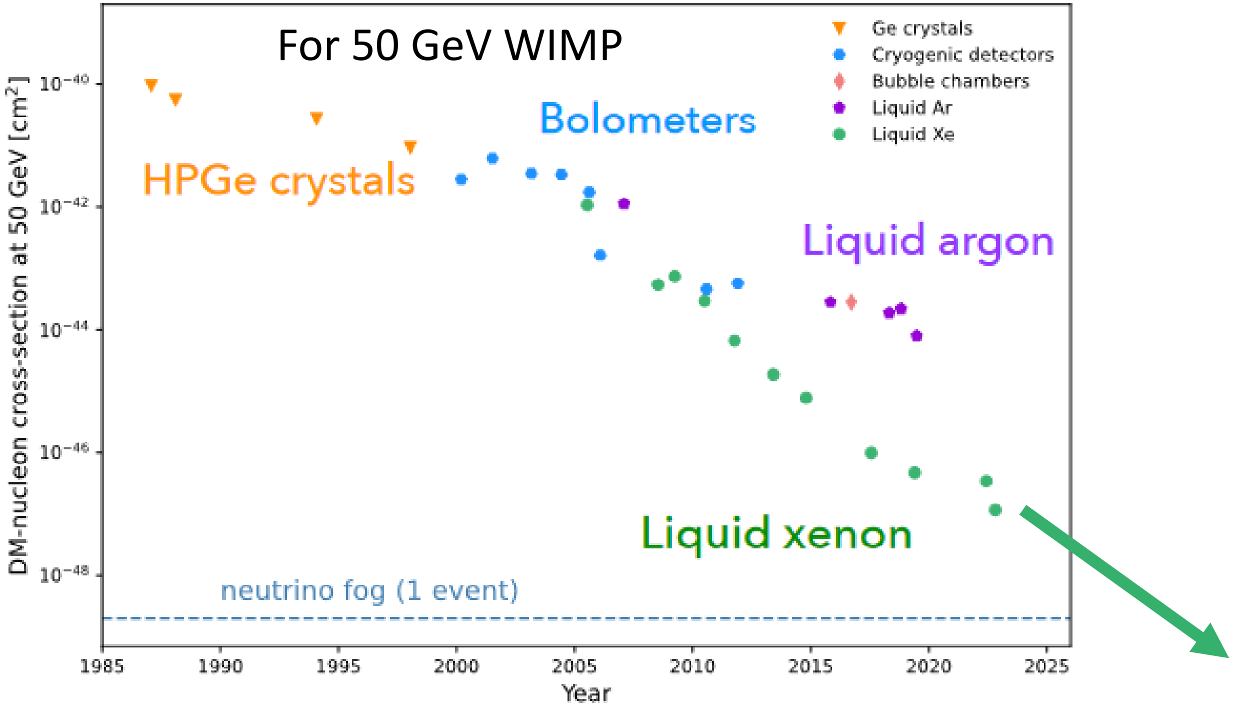
ADAM SOFTLEY-BROWN

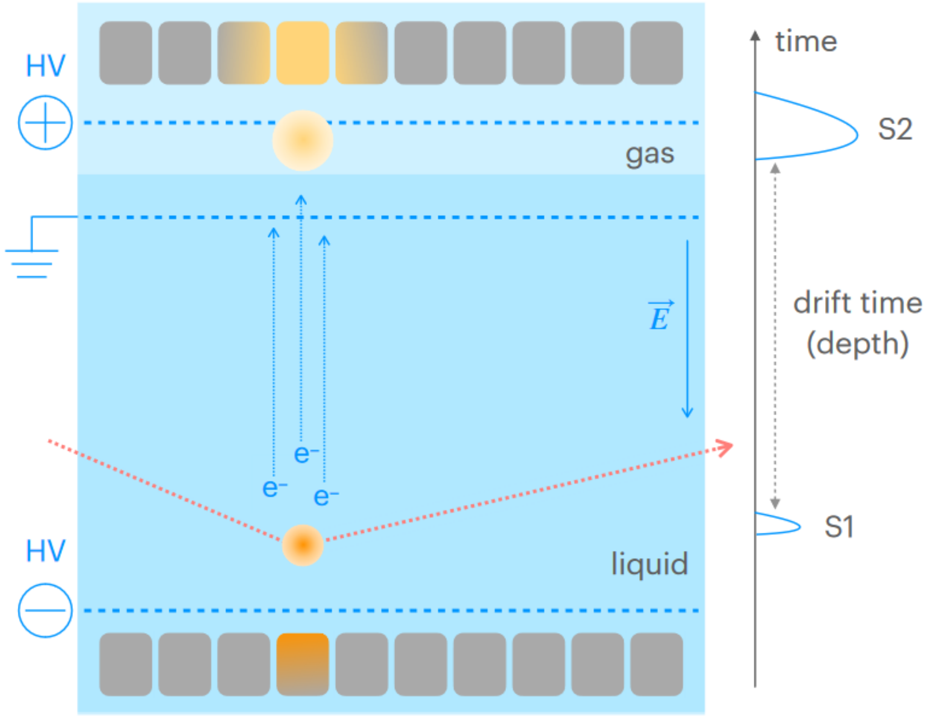
Liquid xenon for dark matter

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)



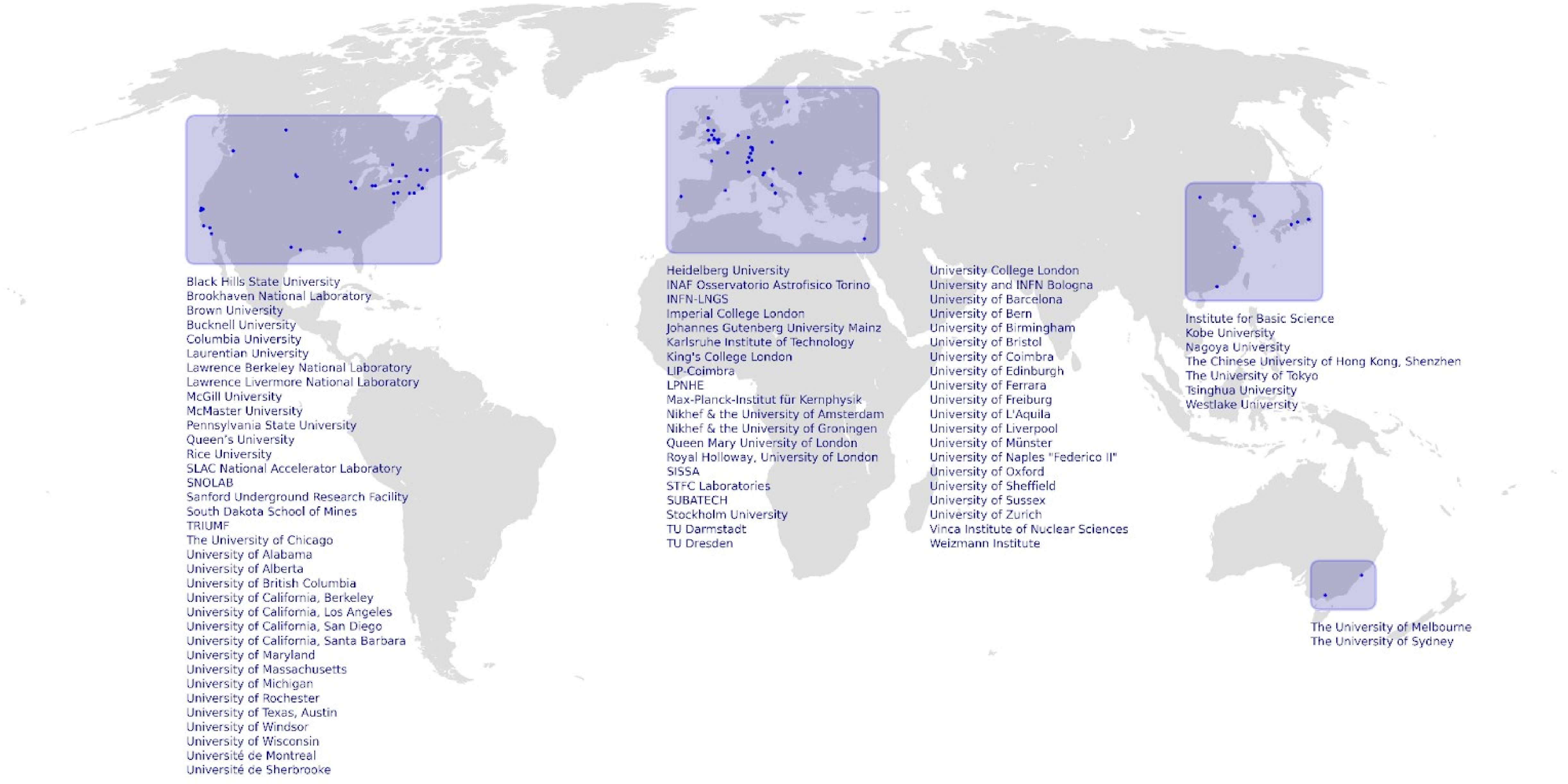


XLZD

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

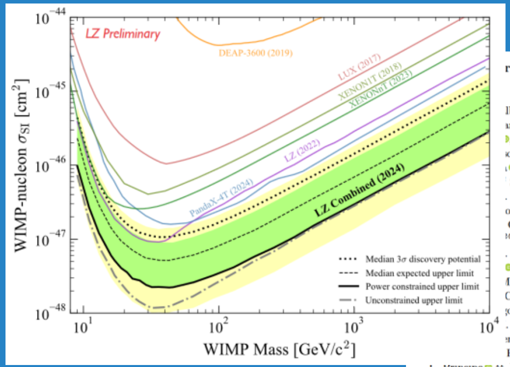
XENON and LZ: running experiments

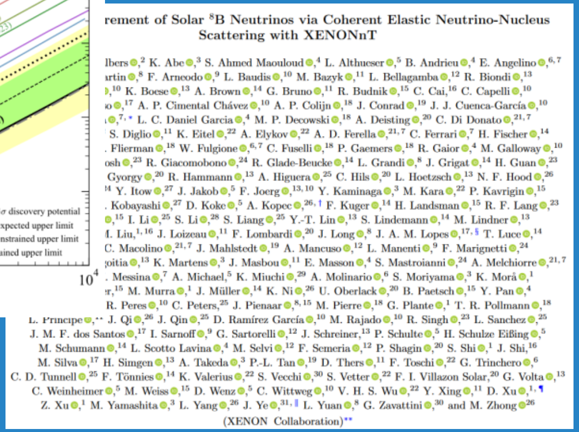
Two cutting edge liquid xenon experiments

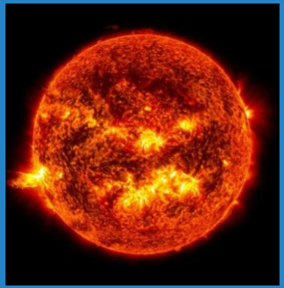
With 6 t (XENONnT) and 7 t (LZ) instrumented xenon

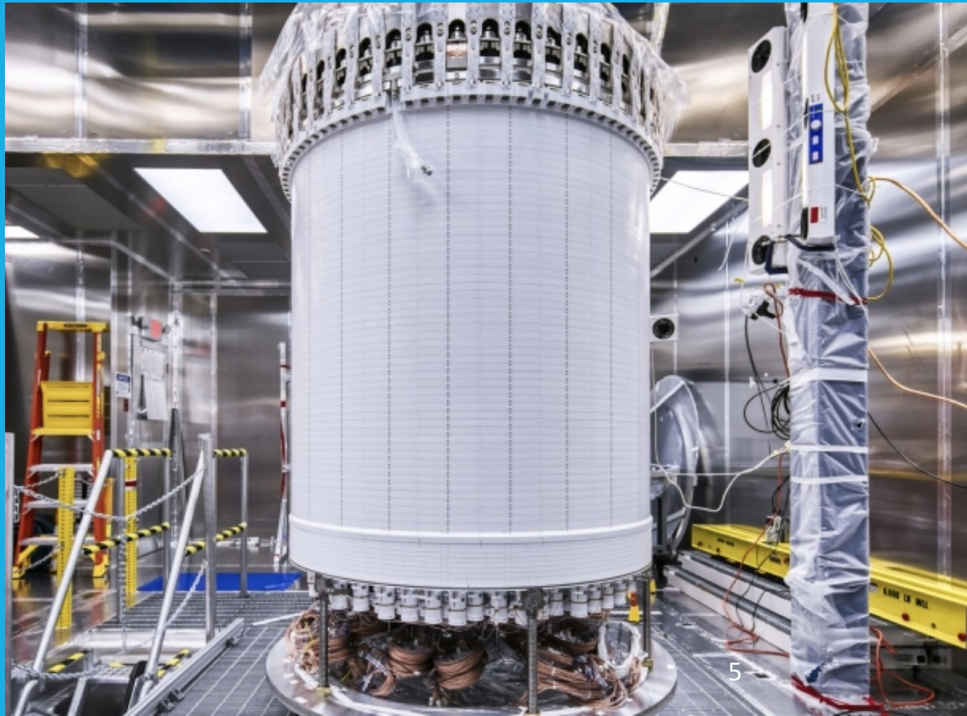
World-leading constraints on **WIMP dark matter**

Increasingly sensitive to **other rare events**









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

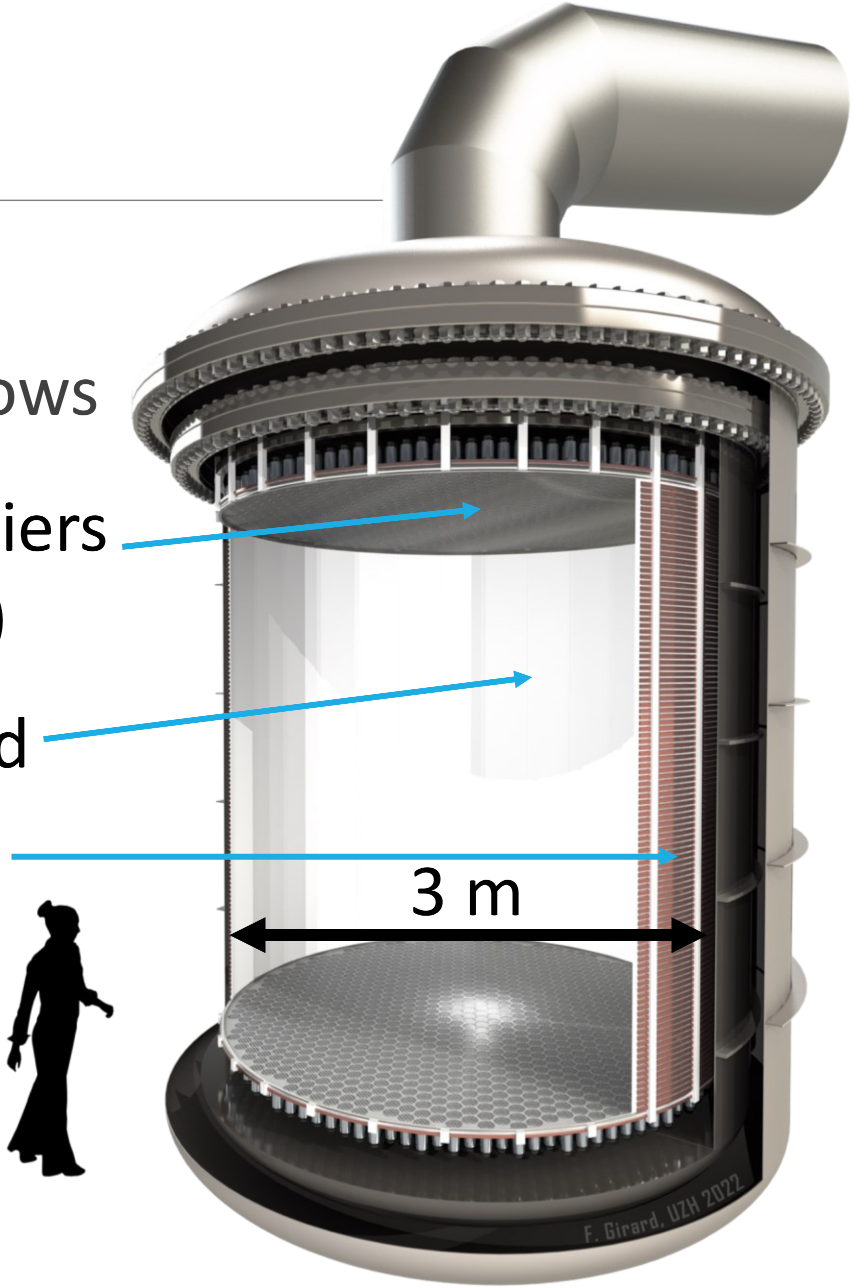
Design book

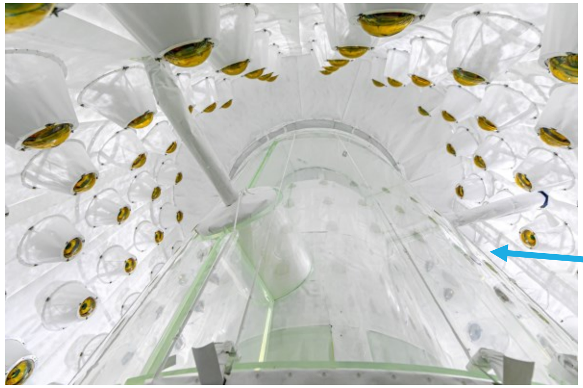
[arXiv 2410.17137]

3” photomultipliers
(1182 per array)

250 V/cm drift field

LXe skin detector





Plus outer detector
as n, μ veto

Backgrounds

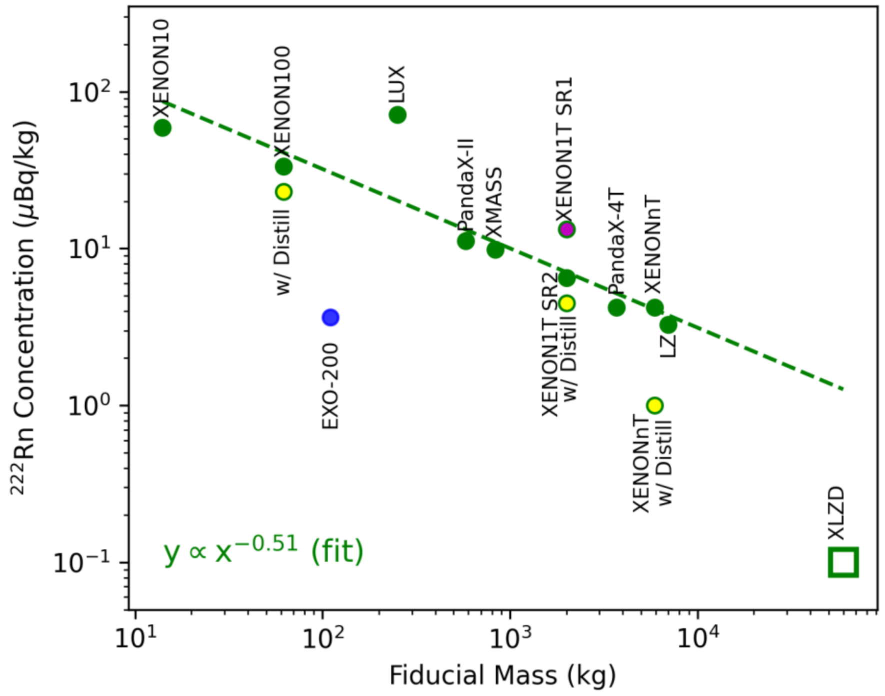
Material backgrounds factor 4—10 lower than current generation

Intrinsic backgrounds at low-E subdominant to solar neutrinos

Rn concentration < 0.1 µBq/kg

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

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

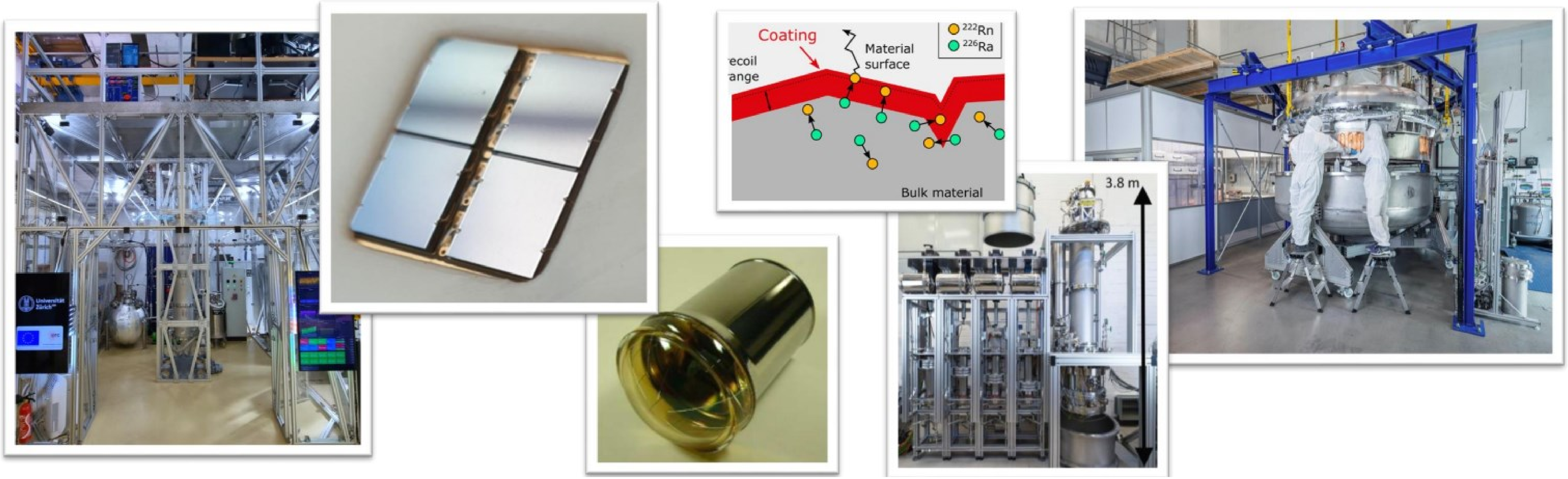


R&D

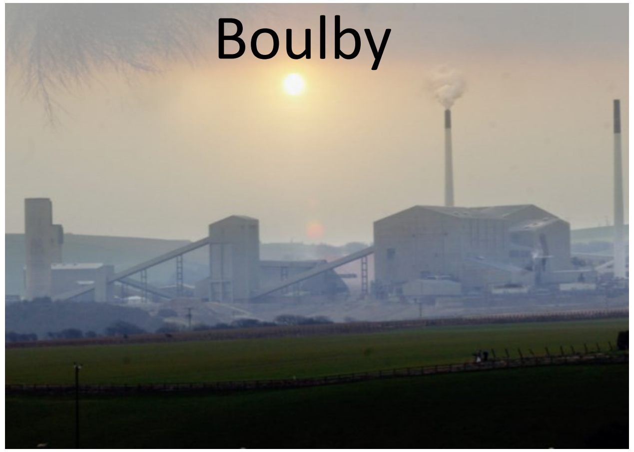
Active R&D in several areas:

Background mitigation, PMTs, test platforms, novel technologies…

See poster #21 by Rebecca Hampp



Candidate sites



Key requirements:

Depth for cosmogenic backgrounds

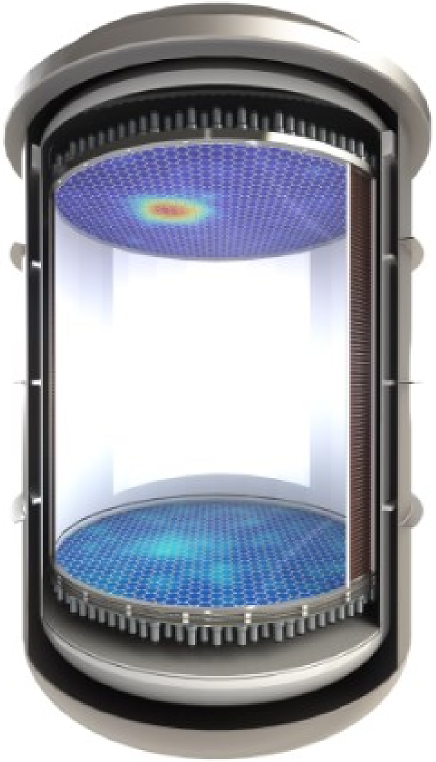
Space for construction

Possibility of transporting large items underground

Site reviews ongoing

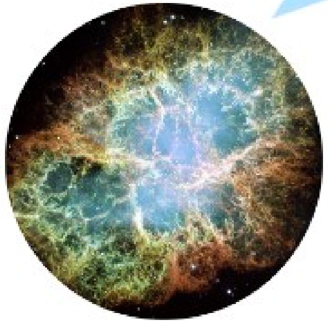
Site	Depth (m)	Depth (m w.e.)	μ flux ($/(\mathrm{m}^2\ \mathrm{d})$)	^{137}Xe rate (/(t year))	SS ROI rate (evt/(t year keV))
SNOLAB	2070	5890	<0.3	0.007	1.29×10^{-6}
SURF	1490	4300	4.6	0.142	2.72×10^{-5}
Boulby	1300	3330	14.6	0.404	7.73×10^{-5}
LNGS	1400	3800	29.7	0.822	1.57×10^{-4}
Kamioka	1000	2700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



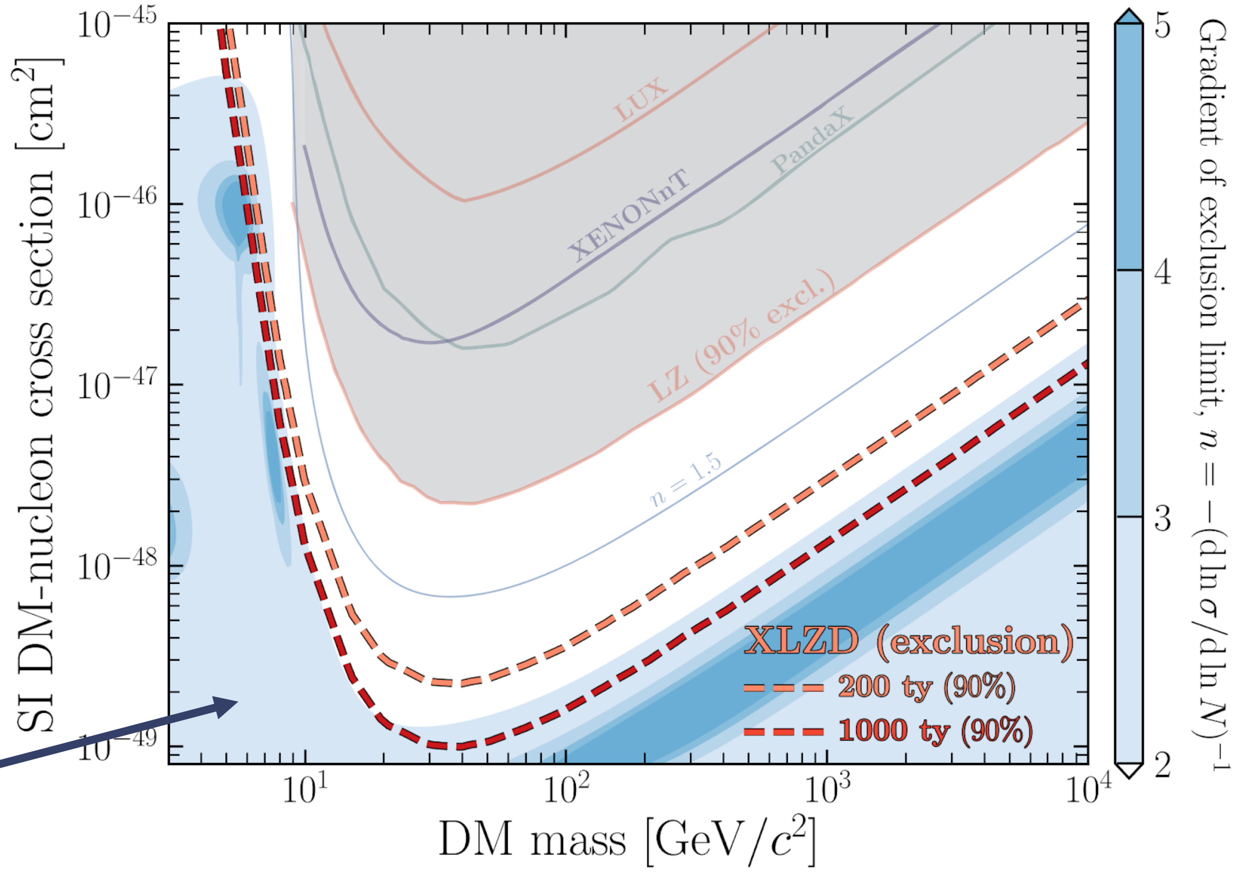
Sun
pp neutrinos
Solar metallicity
^{7}Be, ^{8}B, hep

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 3×10^{-49} cm^2 at 40 GeV



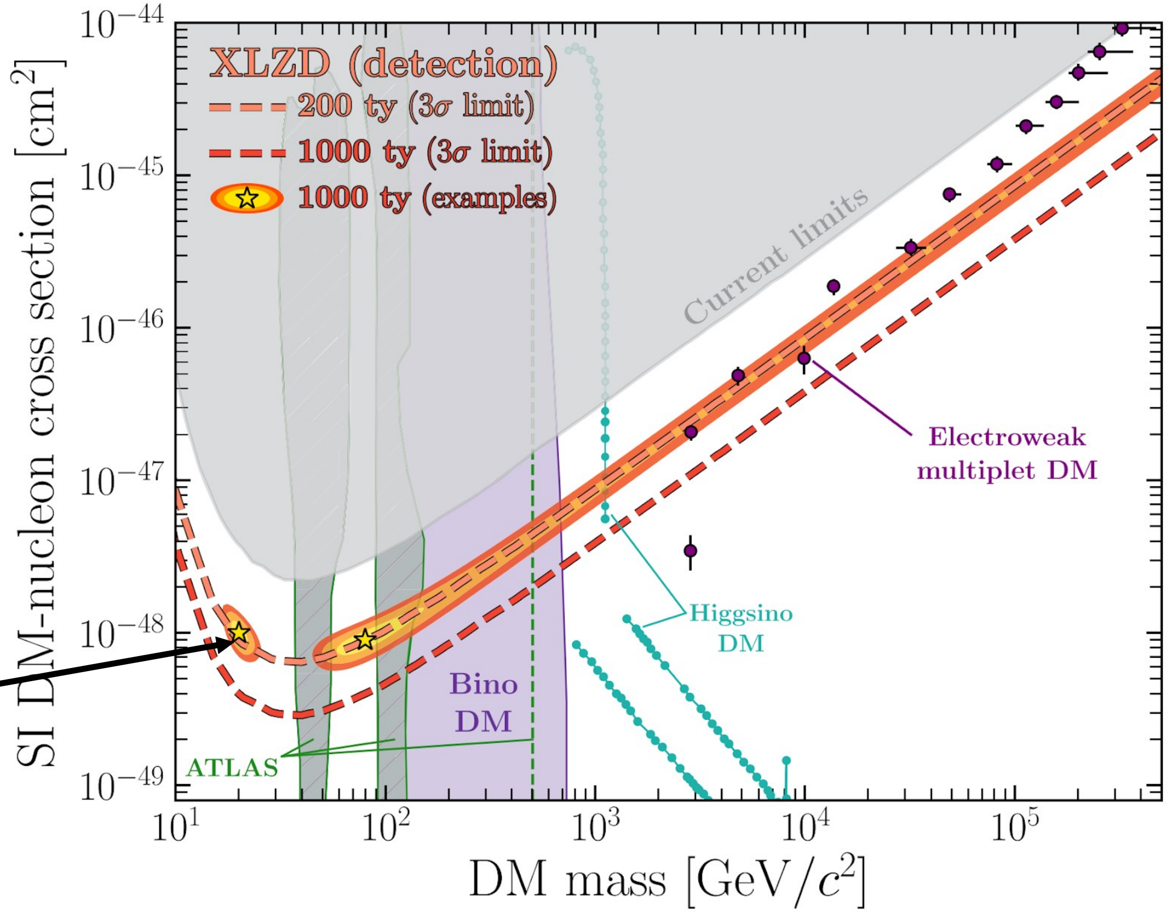
At contour n, improving limit by 10× requires 10^n× the exposure

WIMP sensitivity

Definitive search for medium to high WIMP masses

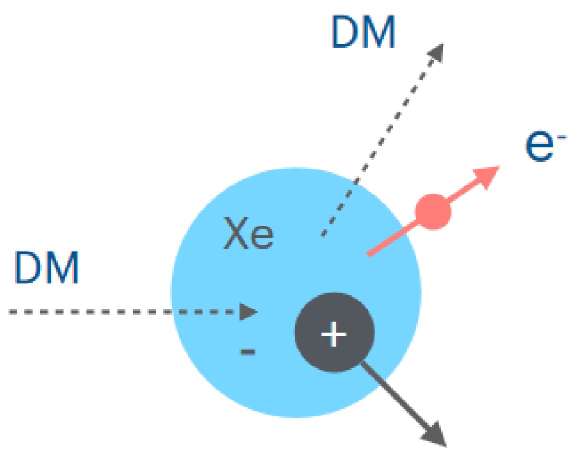
Reach into the neutrino fog after ~ 1000 t yr exposure

3-σ discovery potential at SI cross section of 3×10^{-49} cm^2 at 40 GeV

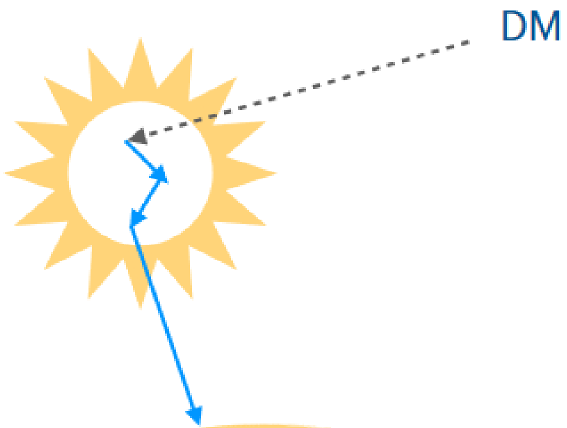


Example confidence intervals for 1000 t yr exposure

Lighter dark matter

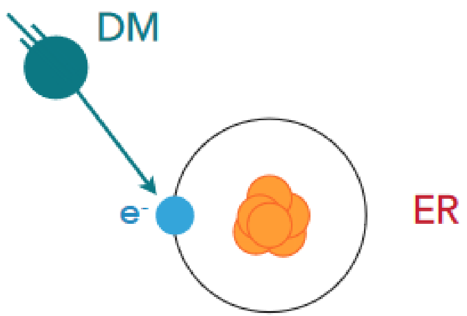


Migdal effect: NR signal with ER character

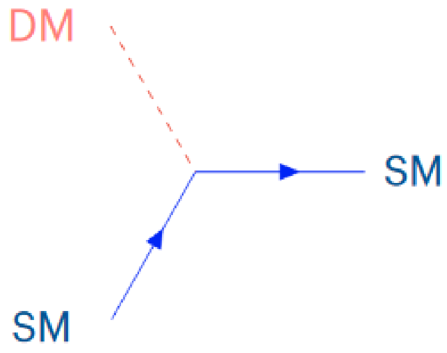


Use the Sun for a velocity boost

Ionisation-only searches



DM-e- scattering
DM absorption



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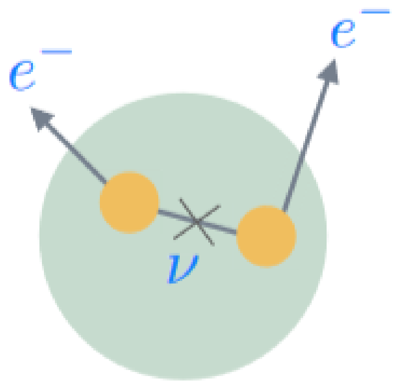
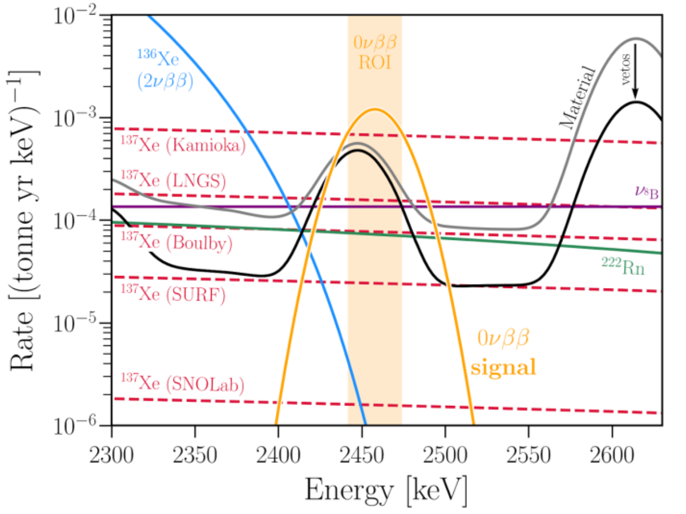
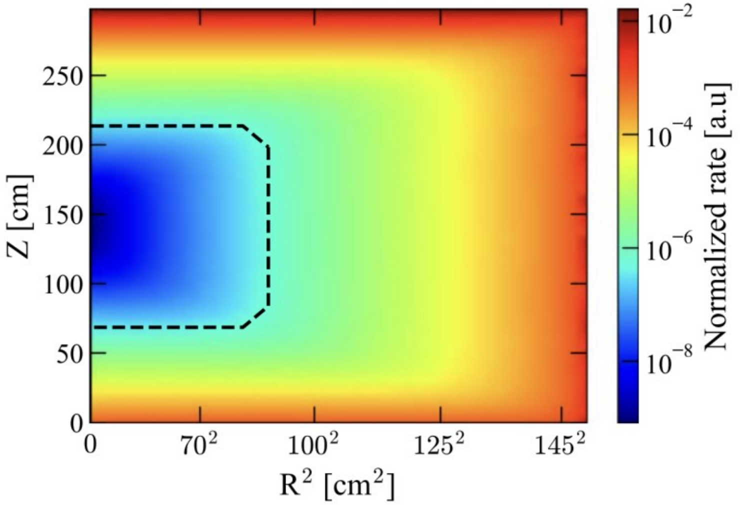
Neutrinoless double beta decay







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

Search for 0νββ peak at Q=2.458 MeV

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

Detector materials dominate background – targeting 4–10× 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

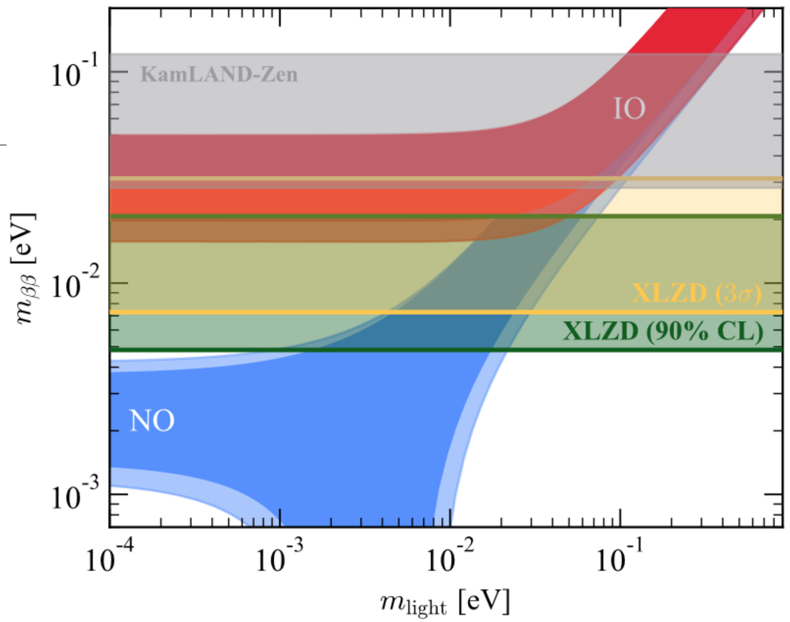
XLZD competitive with dedicated experiments

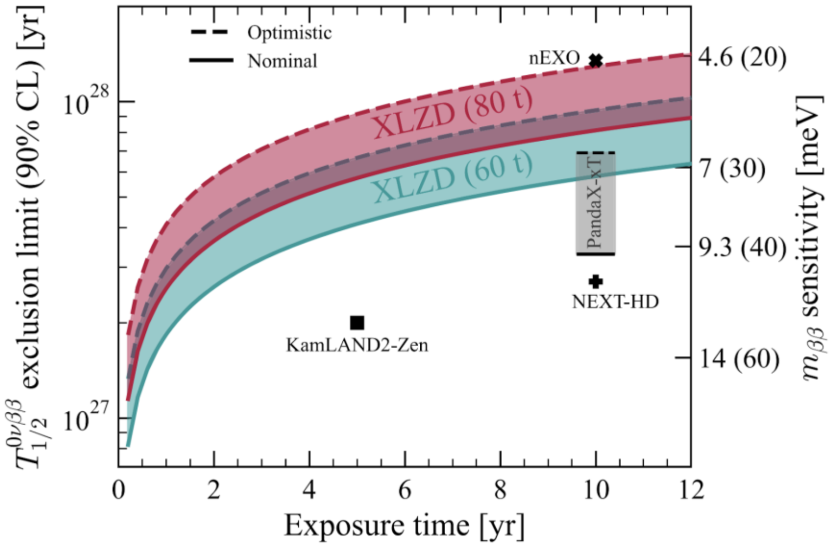
Published sensitivity based on scaling LZ BGs:
5.7×10^{27} yr discovery after 10 yr
1.3×10^{28} yr exclusion at 90%

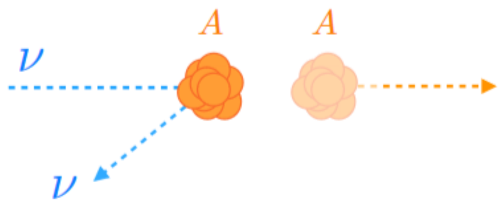
Can cover IO for a wide range of NMEs

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 (^{8}B)

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

High precision measurement possible with 1000 t yr exposure

Solar pp neutrinos

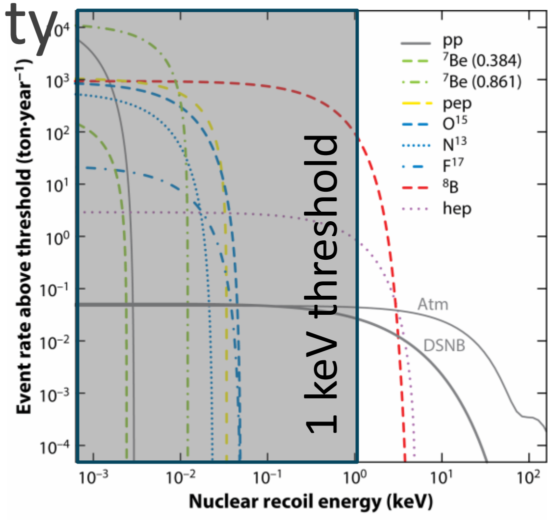
~5% precision on low-E survival probability

Test of solar and neutrino physics

Supernova neutrinos

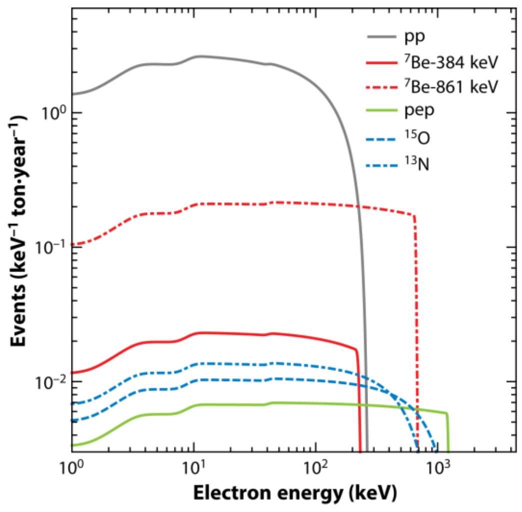
Sensitivity to type-II SN beyond SMC

NRs (CEvNS)



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

ERs (all other reactions)



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

Conclusions

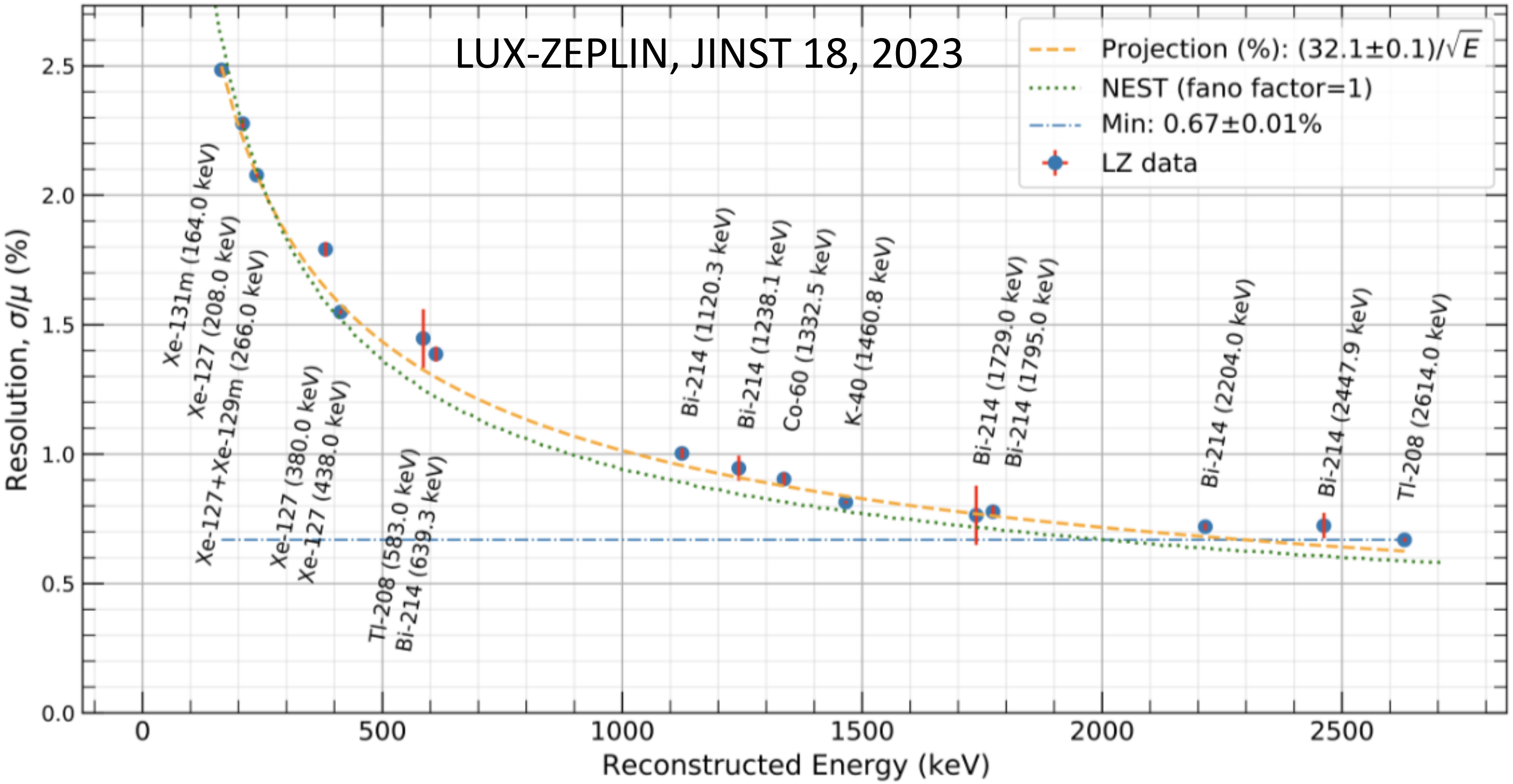
Definitive WIMP search with liquid xenon

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

Rich array of neutrino physics

Neutrinoless double-beta decay

Energy resolutions < 1% achieved by current detectors

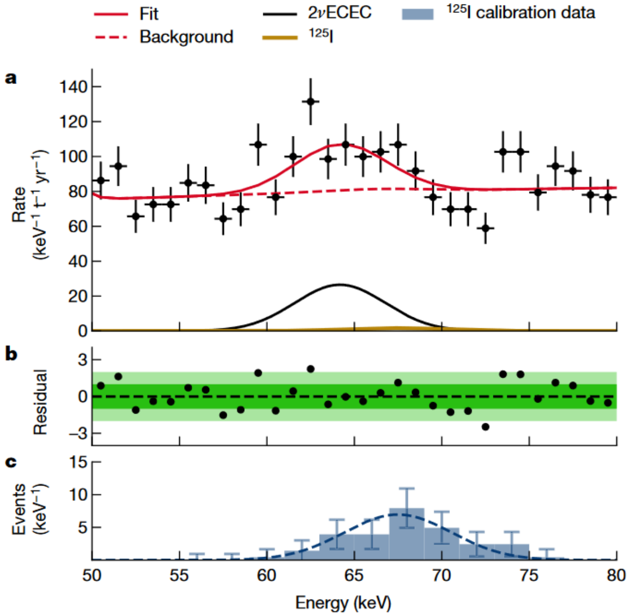


Other second order decays

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

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

2νECEC Detected in XENON1T

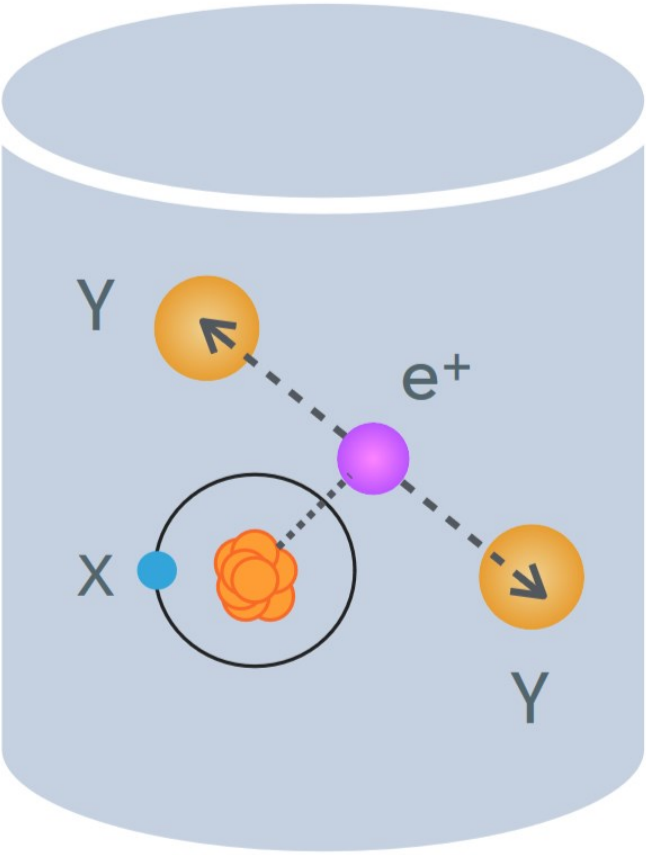


XENON, Nature 568, 2019

Predicted but not observed

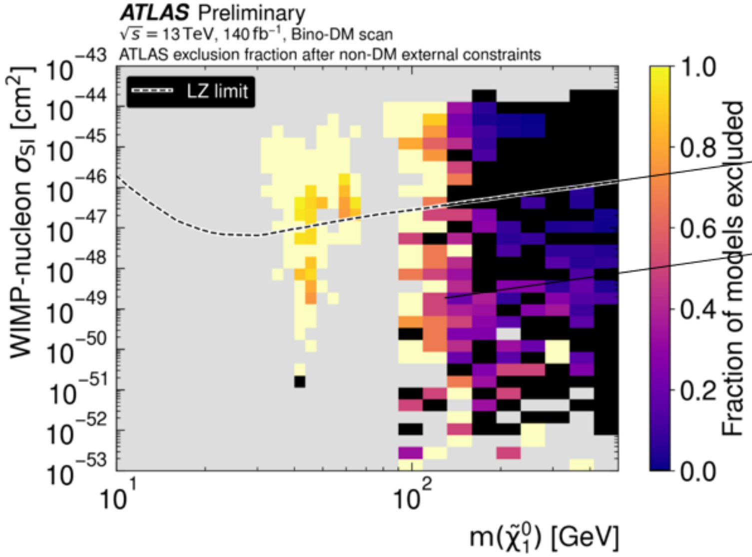
More interesting topologies
$0\nu/2\nu EC\beta^+$, $0\nu/2\nu\beta^+\beta^+$

Tests of SM & nuclear physics



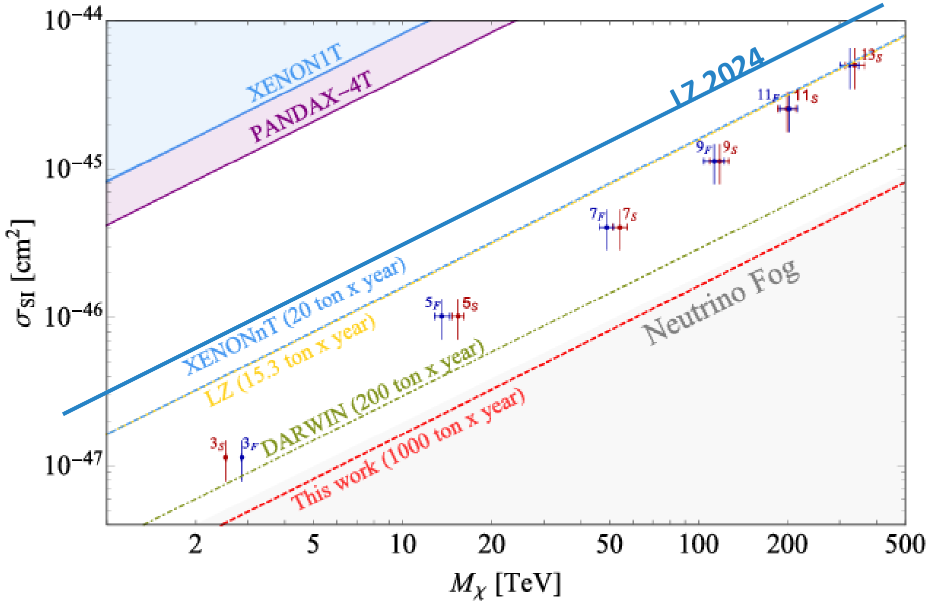
WIMP sensitivity

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

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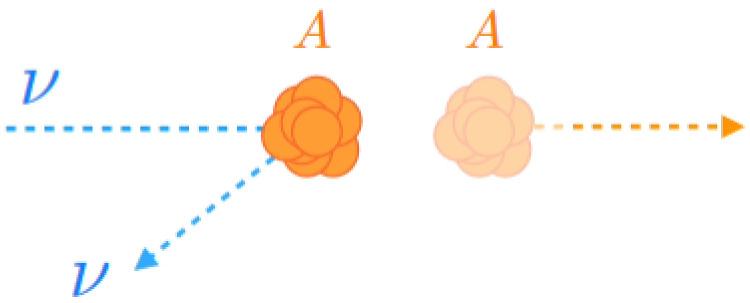
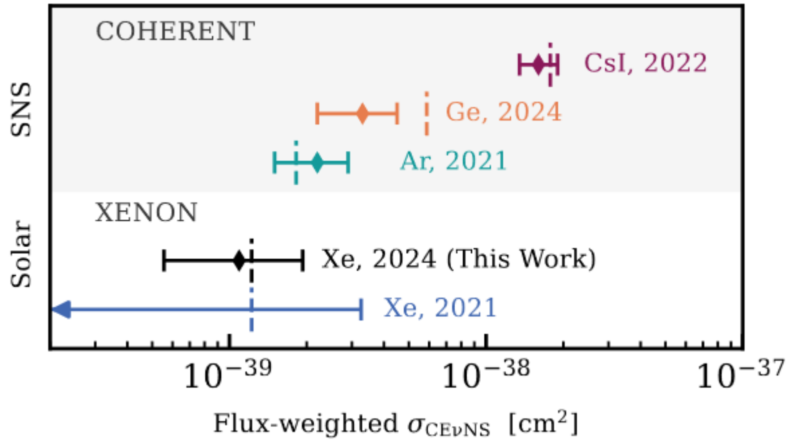
^{8}B neutrinos



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

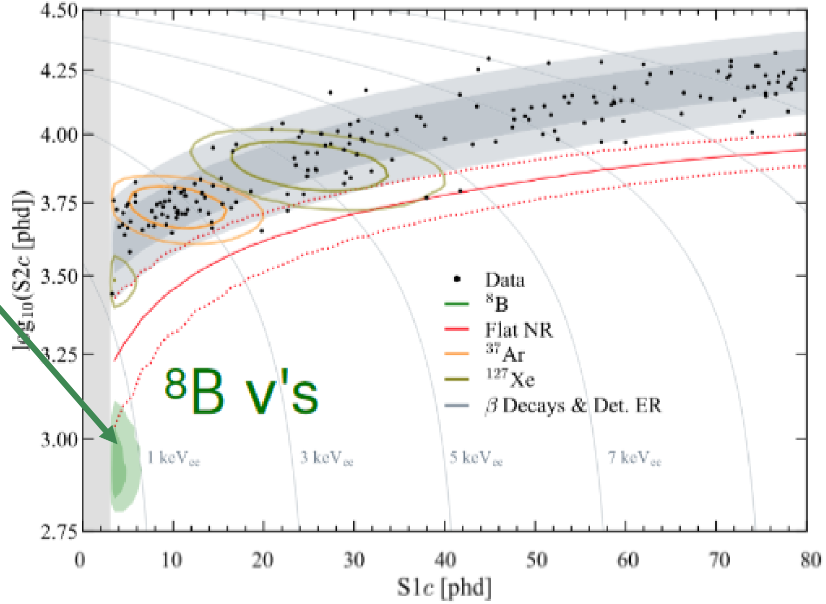
Significance and precision will be far higher in XLZD

XENON, 2408.02877



Signal very close to threshold

LZ, PRD 108, 2023

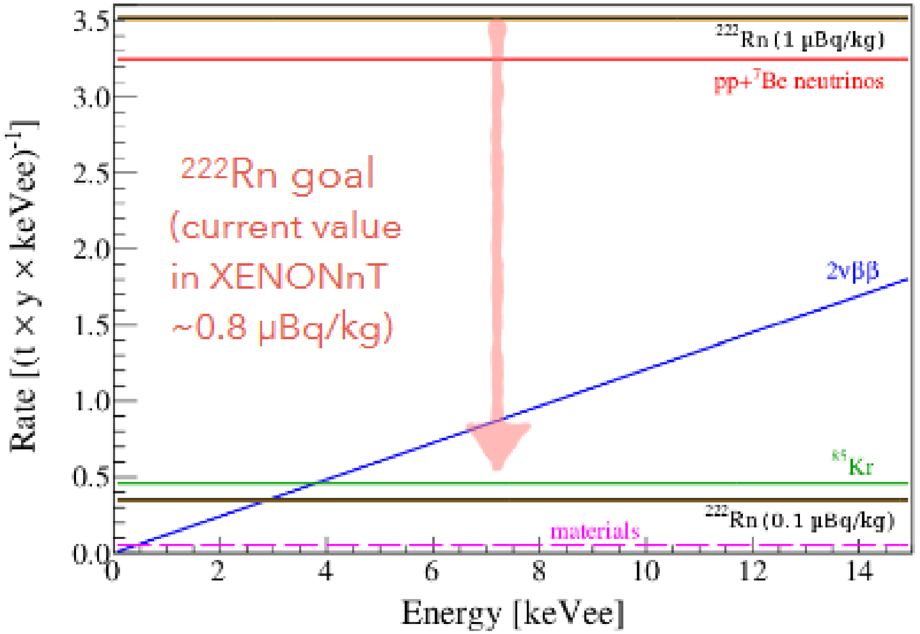


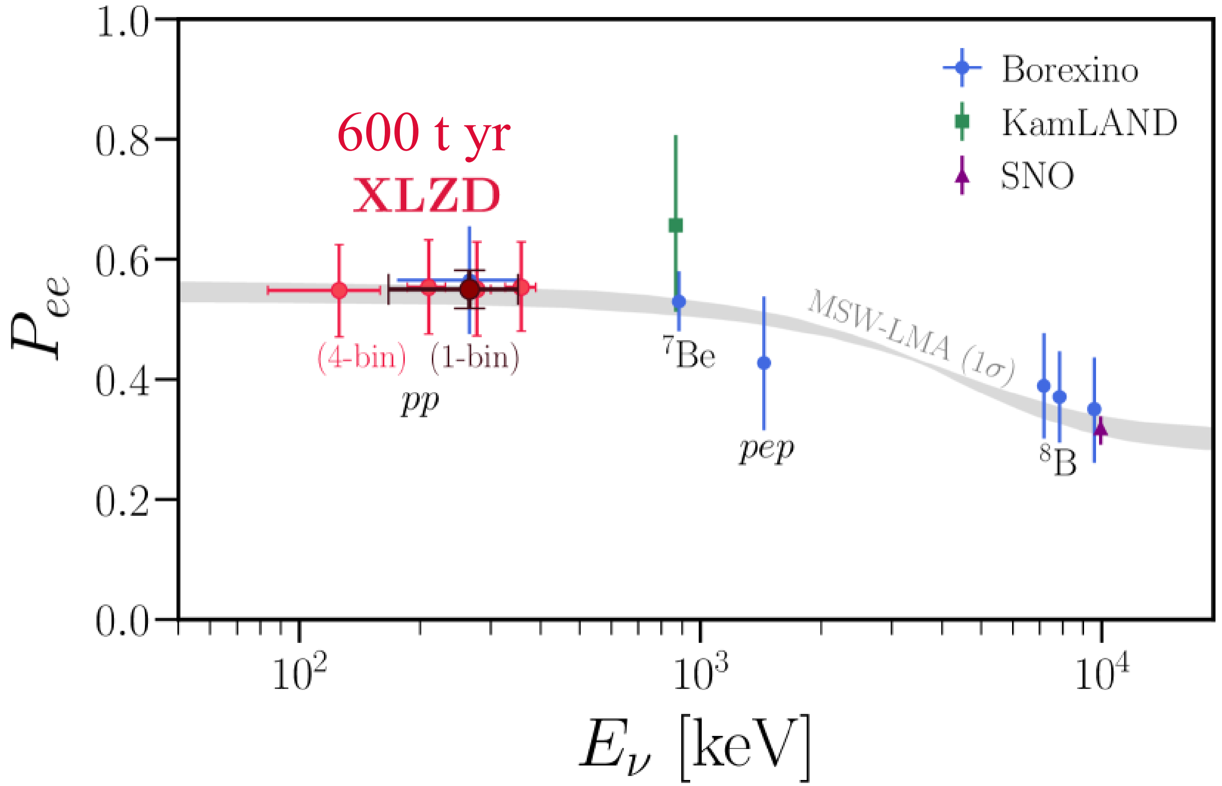
Astrophysical neutrinos – pp neutrinos

Intrinsic and material backgrounds subdominant to solar pp neutrinos

~5% measurement of low-E survival probability

Test solar and neutrino physics

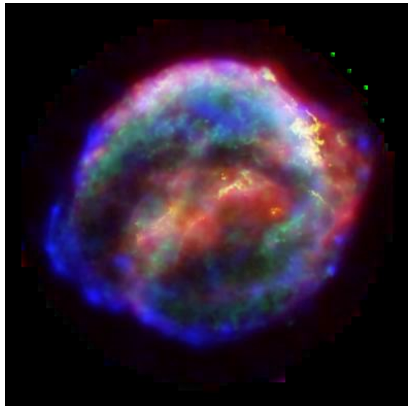




Supernova neutrinos

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



SNEWS
SUPERNOVA EARLY
WARNING SYSTEM