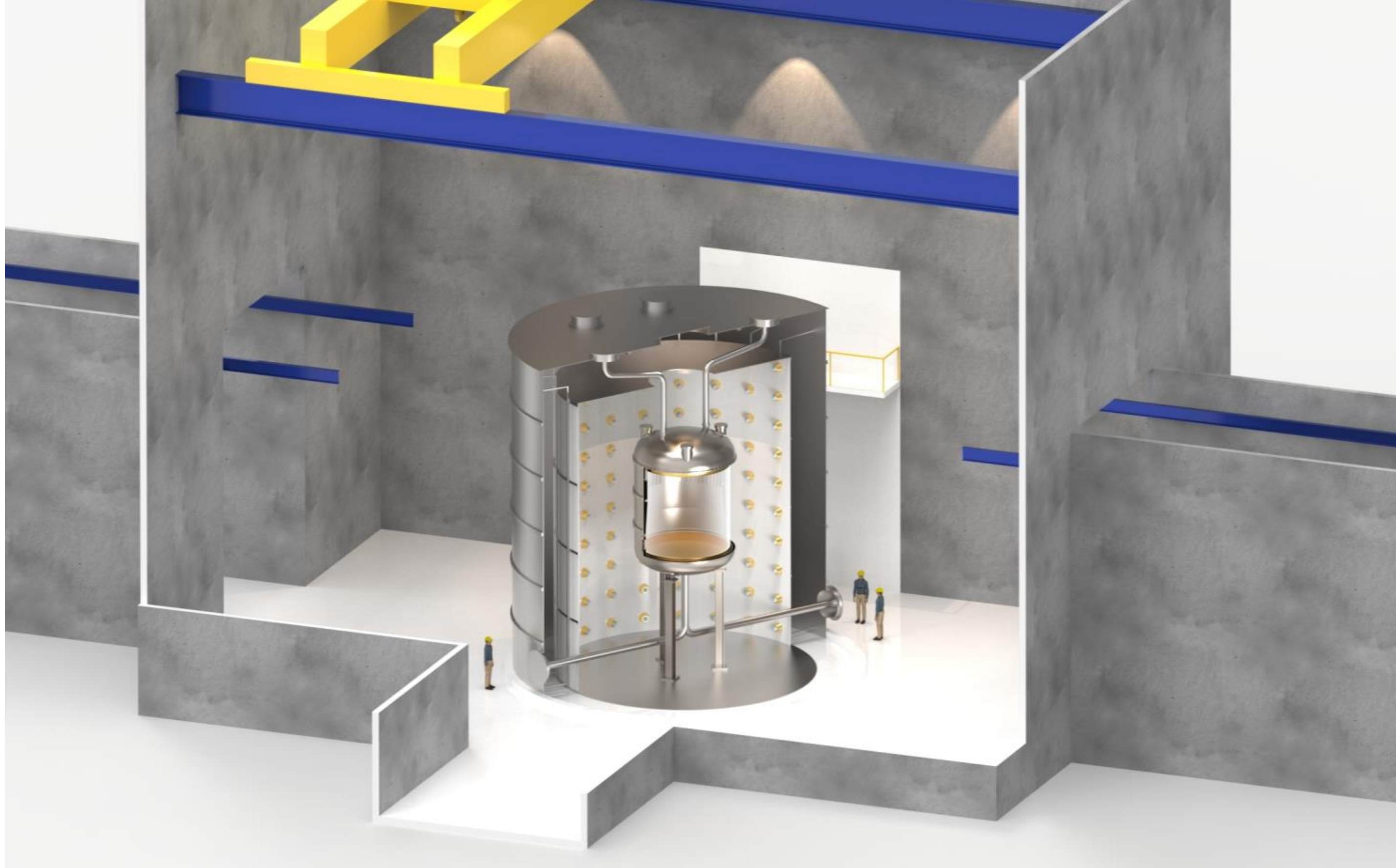
Liquid xenon rare-event observatory



ADAM BROWN

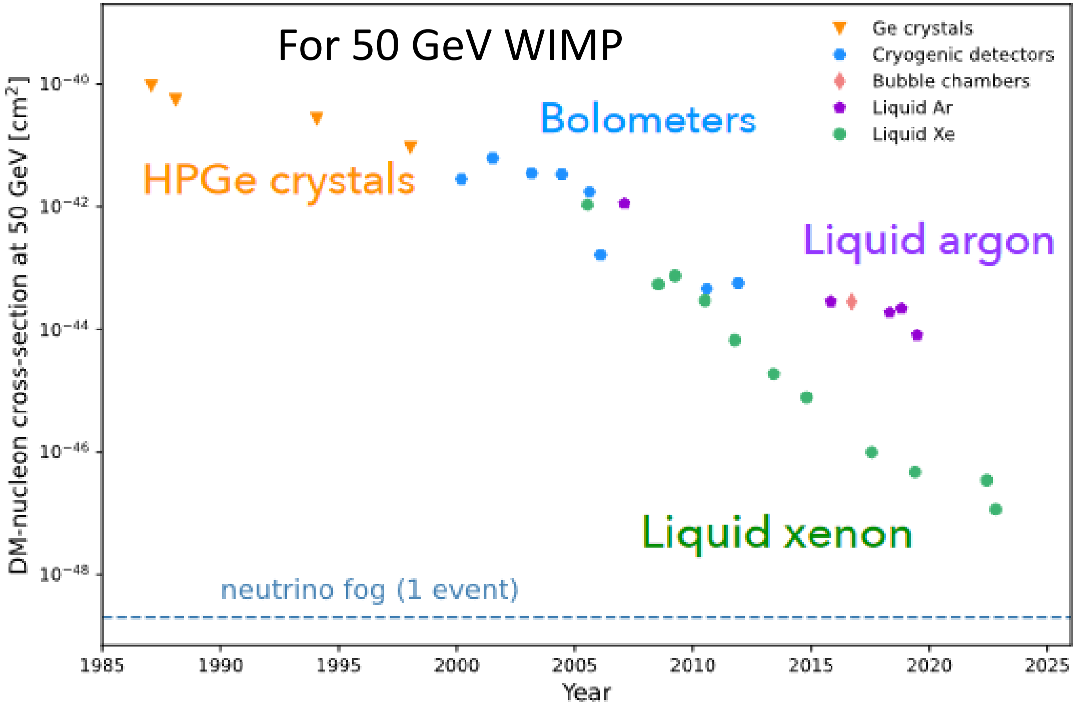
University of Sheffield

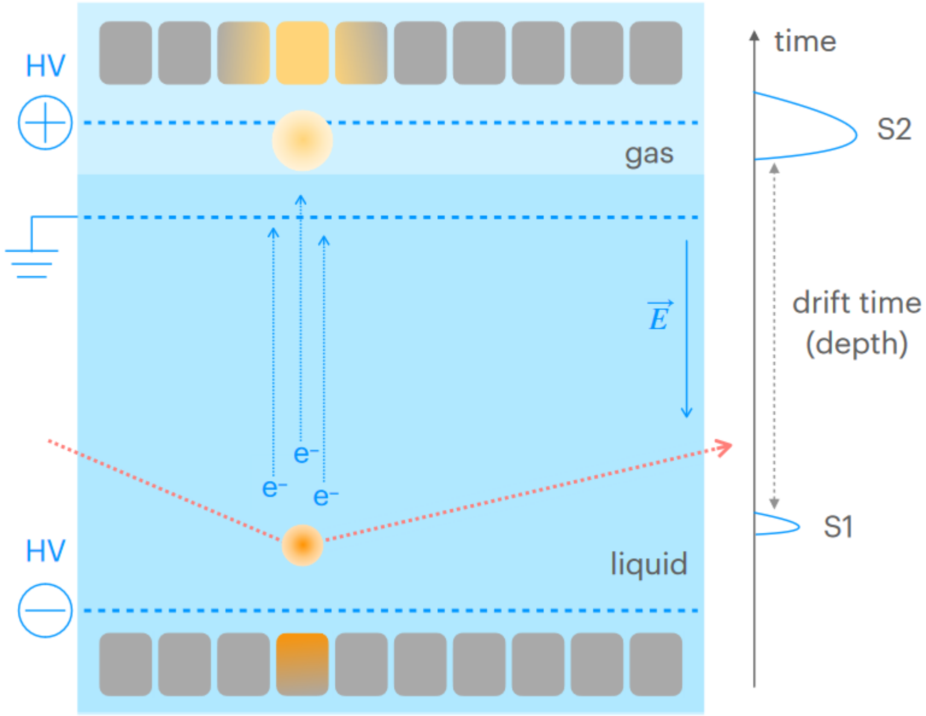
Liquid xenon for dark matter

Liquid xenon leads sensitivity to GeV+ mass WIMPs

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

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





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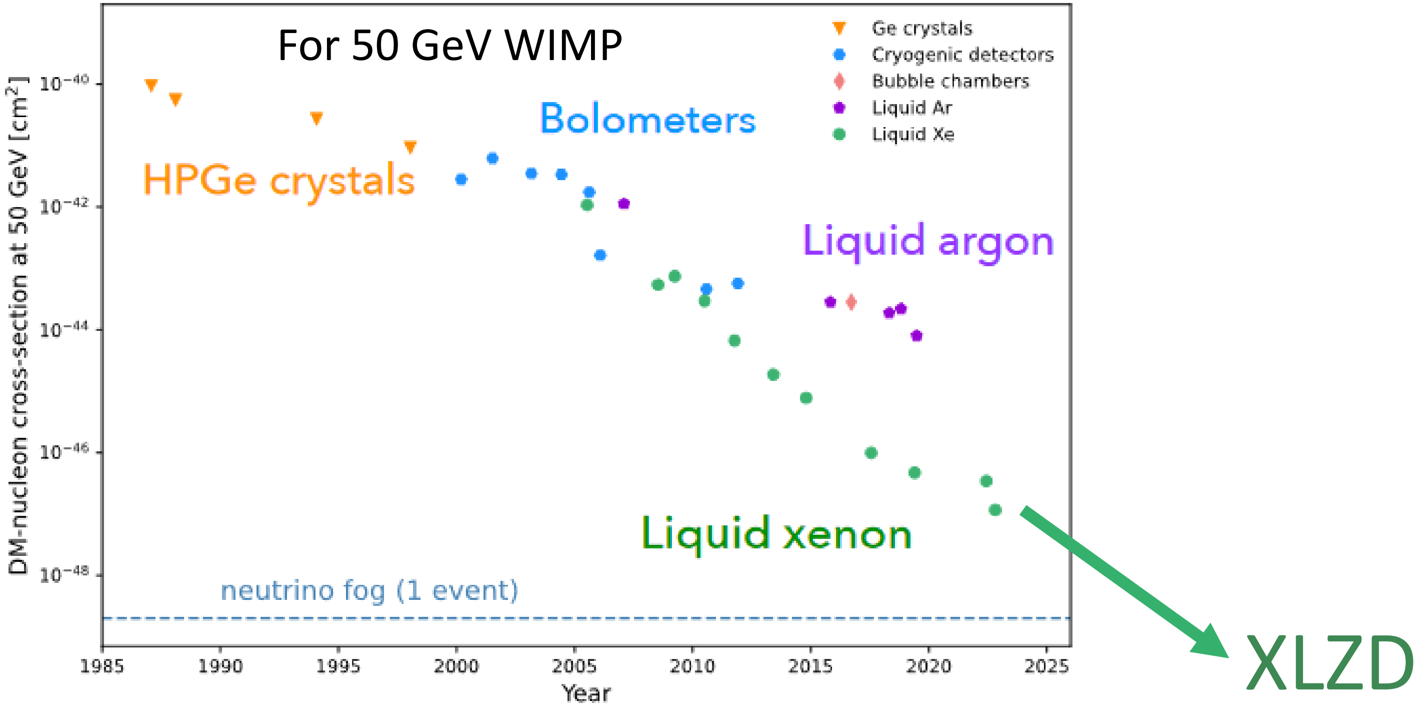
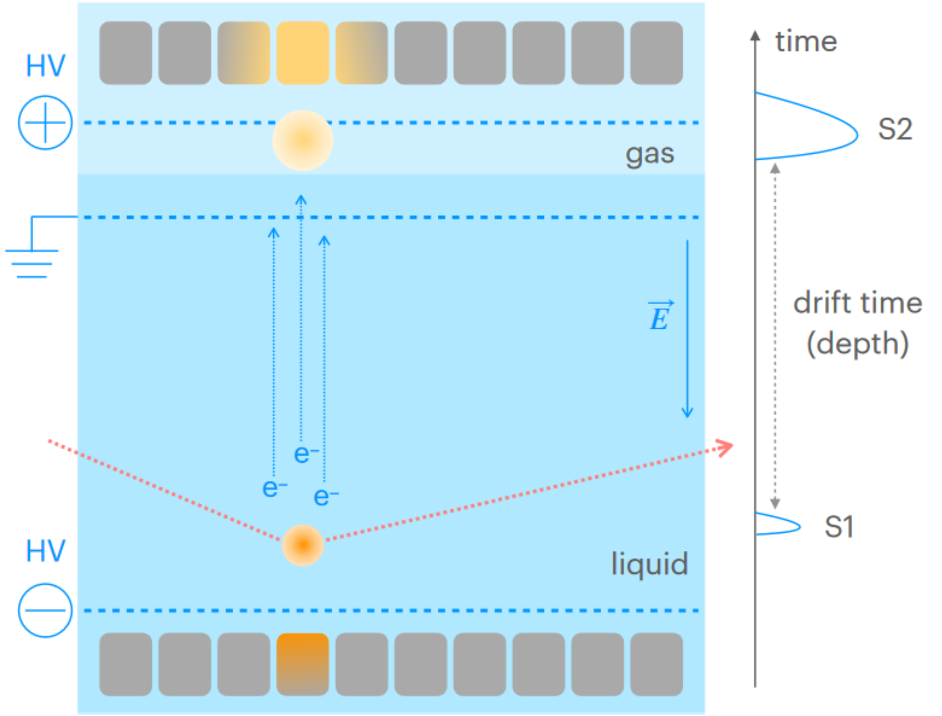




Who is XLZD?

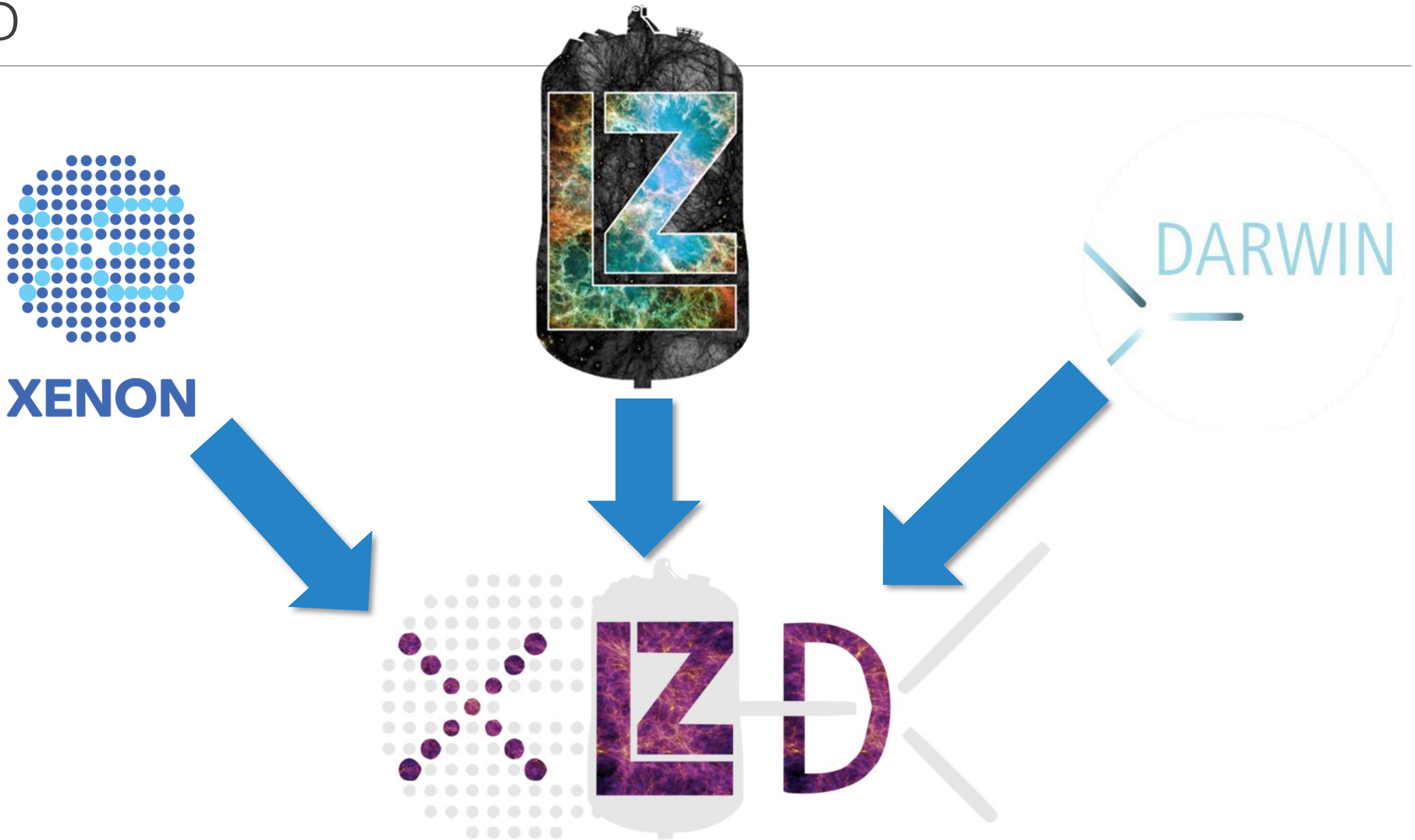
Pursuing future LXe experiment
MoU signed in 2021

350+ members from 60+ institutions

About to be constituted as formal collaboration

Already active with regular in-person meetings and active science and R&D studies

XLZD



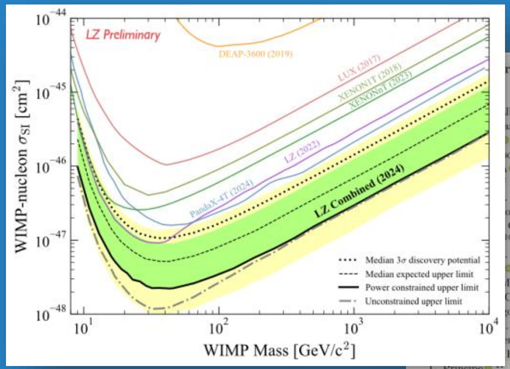
XENON and LZ: running experiments

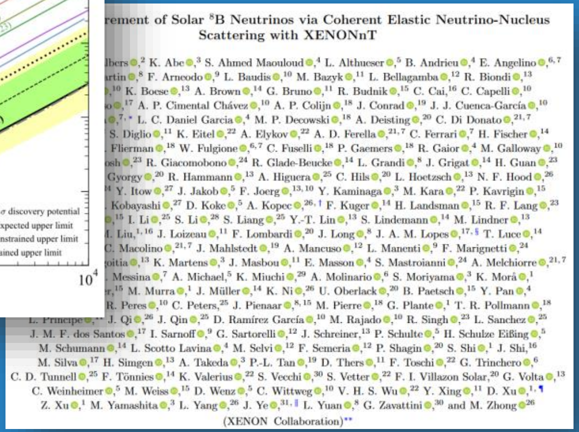
Two cutting edge liquid xenon experiments

With 6 t (XENONnT) and 7 t (LZ) xenon in TPC

World-leading constraints on
WIMP dark matter

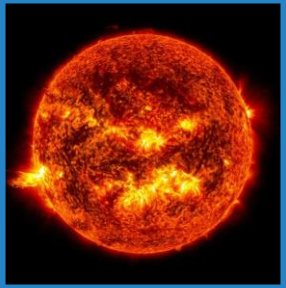
Increasingly sensitive to **other rare events**

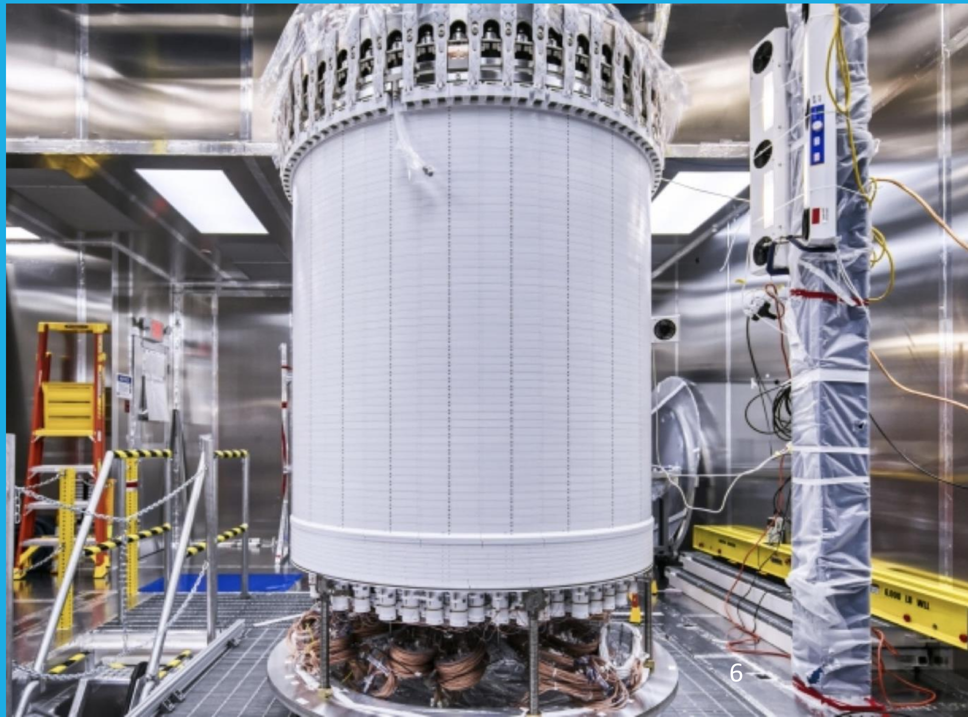



...rement of Solar ^{8}B Neutrinos via Coherent Elastic Neutrino-Nucleus Scattering with XENONnT

...lbers,[2] K. Abe,[3] S. Ahmed Maouloud,[4] L. Althueser,[5] B. Andrieu,[4] E. Angelino,[6,7] ...rtin,[8] F. Arneodo,[9] L. Baudis,[10] M. Bazyk,[11] L. Bellagamba,[12] R. Biondi,[13] ...,[10] K. Boese,[13] A. Brown,[14] G. Bruno,[11] R. Budnik,[15] C. Cai,[16] C. Capelli,[10] ...o,[17] A. P. Cimental Chávez,[10] A. P. Colijn,[18] J. Conrad,[19] J. J. Cuenca-García,[10] ...,[7,*] L. C. Daniel Garcia,[4] M. P. Decowski,[18] A. Deisting,[20] C. Di Donato,[21,7] ... S. Diglio,[11] K. Eitel,[22] A. Elykov,[22] A. D. Ferella,[21,7] C. Ferrari,[7] H. Fischer,[14] ... Flierman,[18] W. Fulgione,[6,7] C. Fuselli,[18] P. Gaemers,[18] R. Gaior,[4] M. Galloway,[10] ...osh,[23] R. Giacomobono,[24] R. Glade-Beucke,[14] L. Grandi,[8] J. Grigat,[14] H. Guan,[23] ... Gyorgy,[20] R. Hammann,[13] A. Higuera,[25] C. Hils,[20] L. Hoetzsch,[13] N. F. Hood,[26] ... Y. Itow,[27] J. Jakob,[5] F. Joerg,[13,10] Y. Kaminaga,[3] M. Kara,[22] P. Kavrigin,[15] ... Kobayashi,[27] D. Koke,[5] A. Kopec,[26,†] F. Kuger,[14] H. Landsman,[15] R. F. Lang,[23] ...,[15] I. Li,[25] S. Li,[28] S. Liang,[25] Y.-T. Lin,[13] S. Lindemann,[14] M. Lindner,[13] ...I. Liu,[1,16] J. Loizeau,[11] F. Lombardi,[20] J. Long,[8] J. A. M. Lopes,[17,§] T. Luce,[14] ...C. Macolino,[21,7] J. Mahlstedt,[19] A. Mancuso,[12] L. Manenti,[9] F. Marignetti,[24] ...oitia,[13] K. Martens,[3] J. Masbou,[11] E. Masson,[4] S. Mastroianni,[24] A. Melchiorre,[21,7] ... Messina,[7] A. Michael,[5] K. Miuchi,[29] A. Molinario,[6] S. Moriyama,[3] K. Morå,[1] ...r,[15] M. Murra,[1] J. Müller,[14] K. Ni,[26] U. Oberlack,[20] B. Paetsch,[15] Y. Pan,[4] ... R. Peres,[10] C. Peters,[25] J. Pienaar,[8,15] M. Pierre,[18] G. Plante,[1] T. R. Pollmann,[18] L. Principe, J. Qi,[26] J. Qin,[25] D. Ramírez García,[10] M. Rajado,[10] R. Singh,[23] L. Sanchez,[25] J. M. F. dos Santos,[17] I. Sarnoff,[9] G. Sartorelli,[12] J. Schreiner,[13] P. Schulte,[5] H. Schulze Eißing,[5] M. Schumann,[14] L. Scotto Lavina,[4] M. Selvi,[12] F. Semeria,[12] P. Shagin,[20] S. Shi,[1] J. Shi,[16] M. Silva,[17] H. Simgen,[13] A. Takeda,[3] P.-L. Tan,[19] D. Thers,[11] F. Toschi,[22] G. Trinchero,[6] C. D. Tunnell,[25] F. Tönnies,[14] K. Valerius,[22] S. Vecchi,[30] S. Vetter,[22] F. I. Villazon Solar,[20] G. Volta,[13] C. Weinheimer,[5] M. Weiss,[15] D. Wenz,[5] C. Wittweg,[10] V. H. S. Wu,[22] Y. Xing,[11] D. Xu,[1,¶] Z. Xu,[1] M. Yamashita,[3] L. Yang,[26] J. Ye,[31,‖] L. Yuan,[8] G. Zavattini,[30] and M. Zhong[26]

(XENON Collaboration)[**]

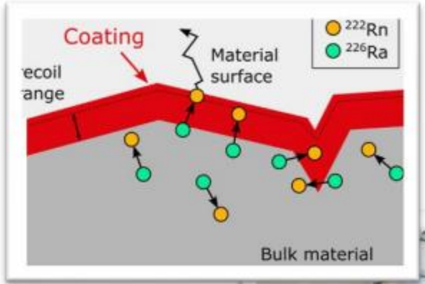


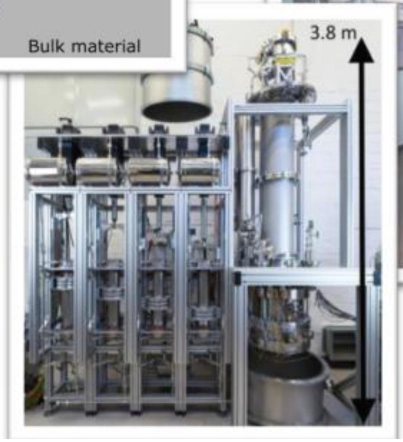


DARWIN: R&D

Efforts to design a next-generation liquid xenon experiment

Active R&D in several areas:
background mitigation, PMTs, test platforms, novel technologies…





R&D also underway outside DARWIN – e.g. the Xenon Futures R&D Project in the UK

Main XLZD goals

Be most sensitive rare event xenon observatory

Search for WIMP dark matter down to neutrino fog

Search for $0\nu\beta\beta$ with natural Xe competing with dedicated experiments

Start science soon after end of current experiments

XLZD baseline design

Design book in preparation

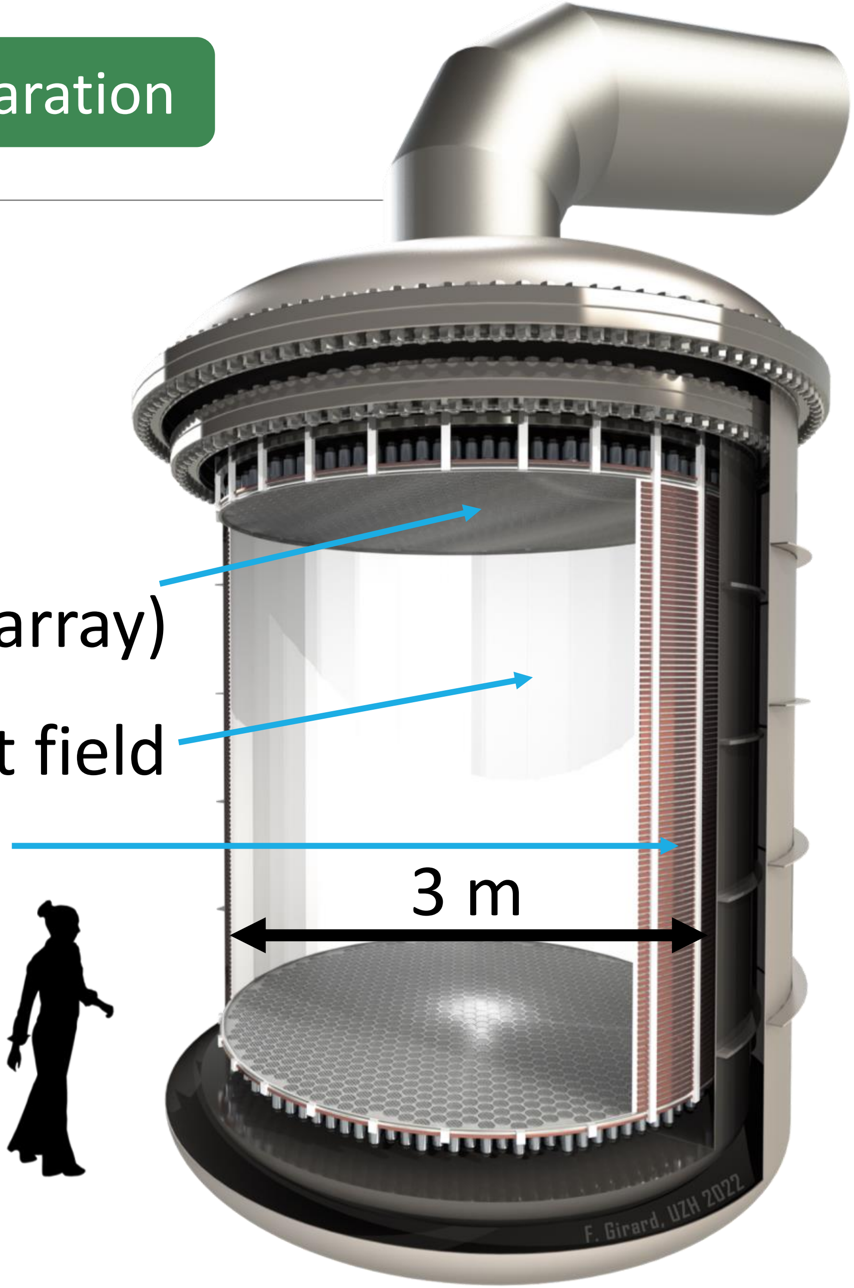
Nominal plan: 60 t in 1:1 ratio (3 m x 3 m)
Possibility of 80 t if Xe market permits

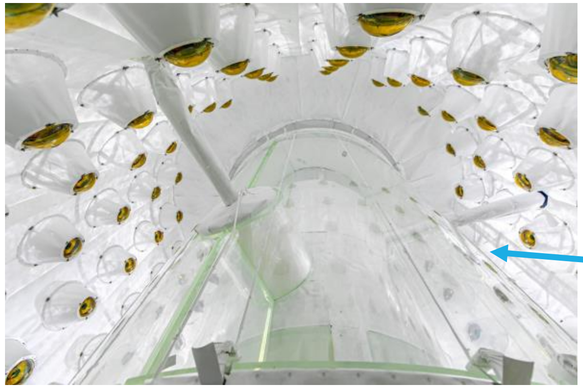
Early science with a shorter 40 t detector

3” photomultipliers (1182 per array)

240-290 V/cm drift field

LXe skin detector





Plus outer detector
as n, μ veto

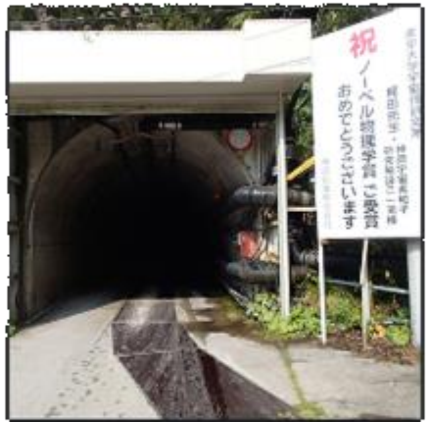
Where might XLZD go?

Five locations under consideration

Boulby

North Yorkshire, UK

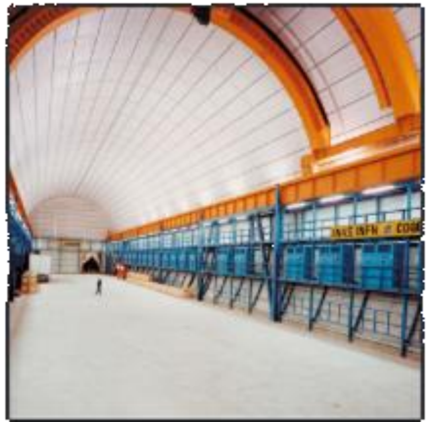
The Boulby Underground Laboratory, the UK's deep underground science facility, located 1100m (vertical access) below ground in an active salt mine extending below the North Sea



Kamioka

Japan

The location of historic neutrino experiments in the converted Mozumi mine in the Okuhida mountains (1000m - horizontal access)



LNGS

Gran Sasso, Italy

Located under the Gran Sasso mountain (1400m - horizontal access) this laboratory is the largest underground laboratory in the world devoted to neutrino and astroparticle physics

SNOLAB

Ontario, Canada

Canada's deep underground research laboratory, located in Vale's Creighton active mine (2070m - vertical access)

SURF

South Dakota, US

The deepest underground laboratory in the United States, with about 12 miles for science activities on the 4850 Level (1490m - vertical access). Future location of the DUNE experiment

Where might XLZD go?

Five locations under consideration

Boulby has a lot to offer, XLZD@Boulby project is underway

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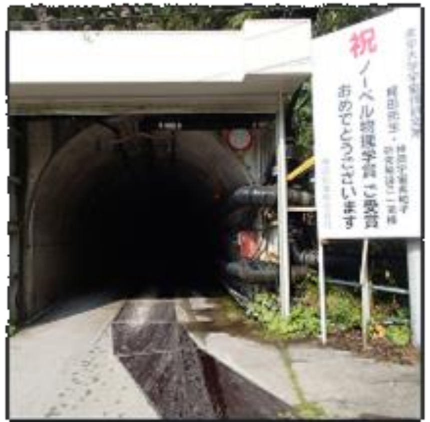

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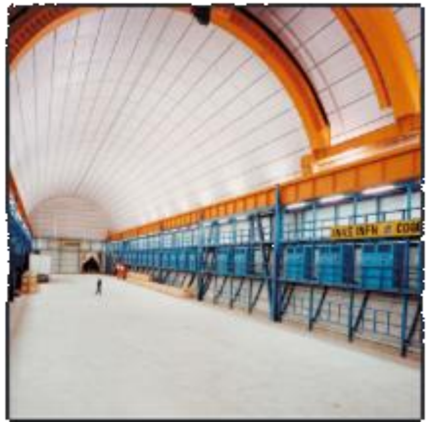

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Boulby stage 1

Expansion of lab for future underground science use

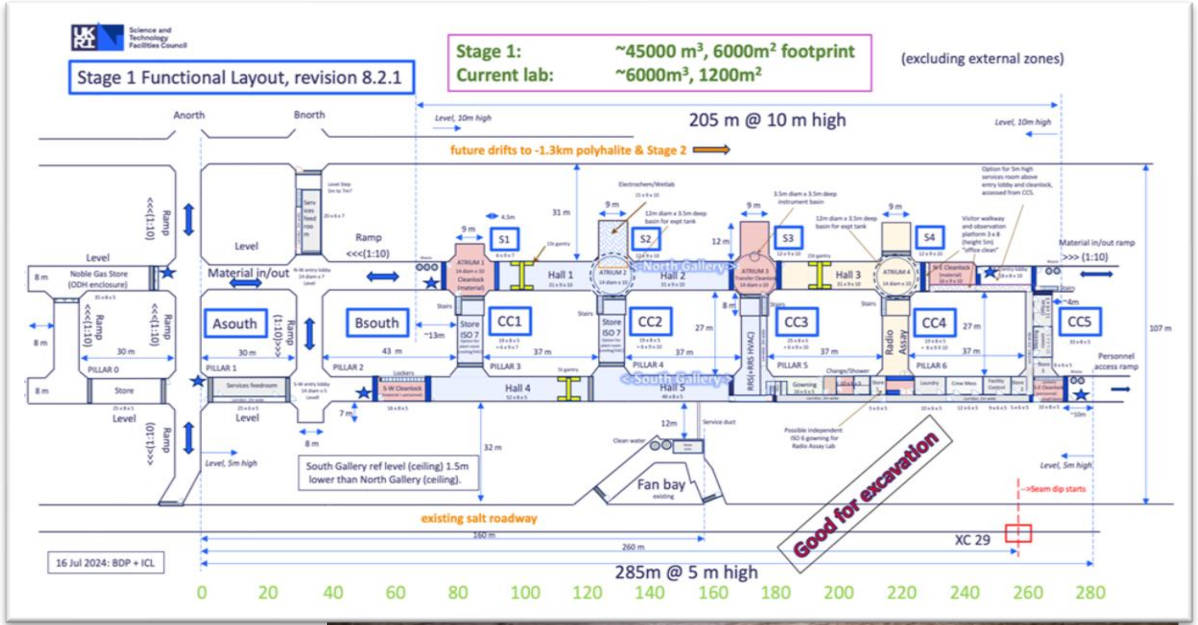
Initial stage at 1100 m in salt

Clean manufacturing for XLZD

Past bottleneck (shaft)

Could host mid-scale experiments

Excavations underway



Progress in August 24

Boulby stage 2

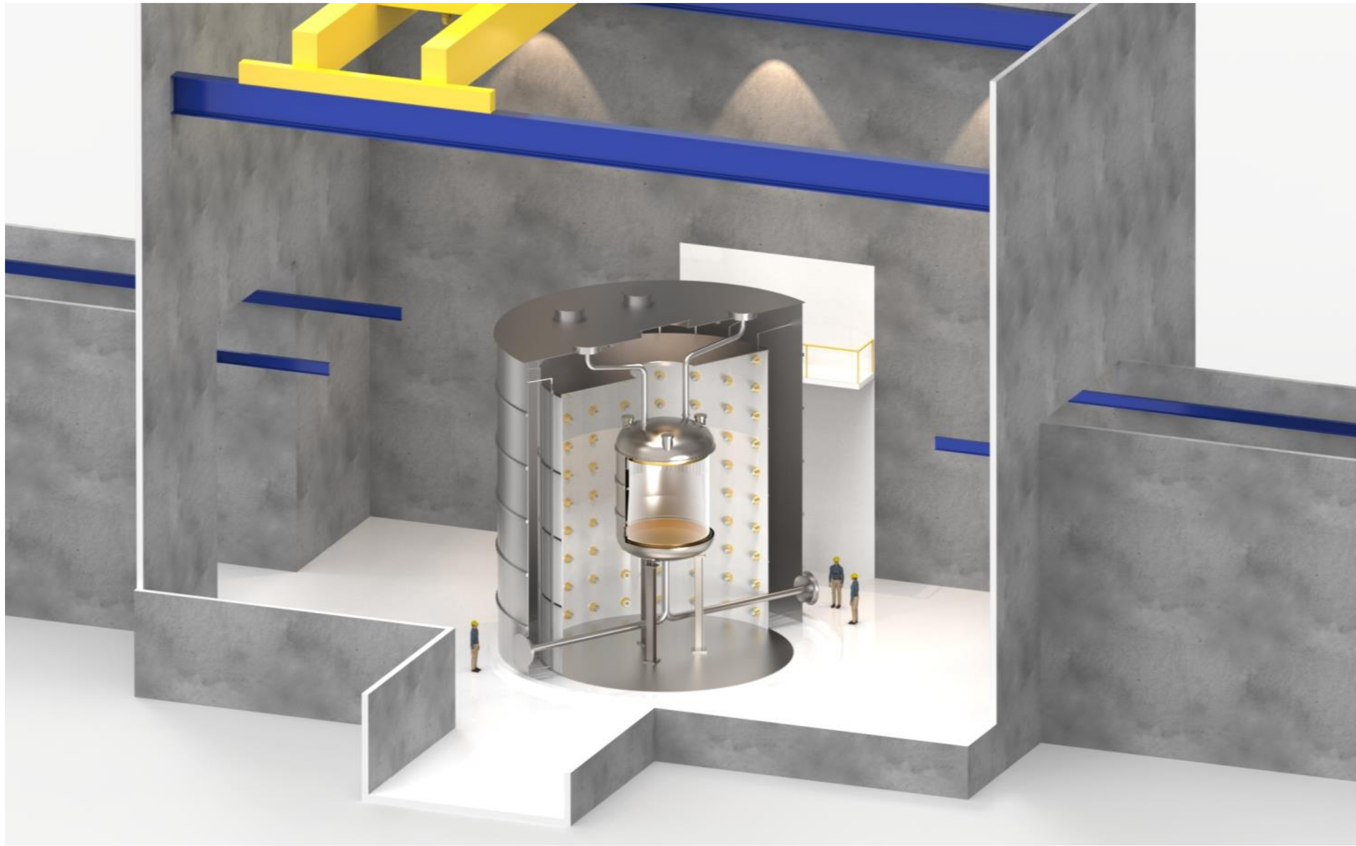
Stage 2: experimental lab at 1300 m

Ready around 2030

Purpose-designed for XLZD

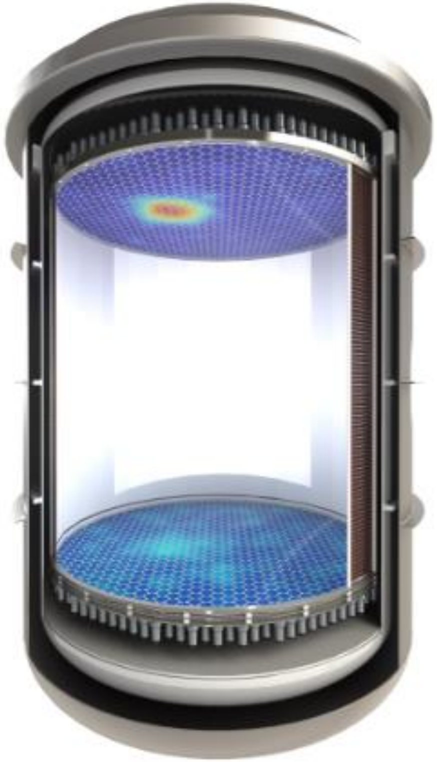
32m L x 22m W x 26m H
main hall with space
for water tank

Clean lab space (ISO 7) with
even cleaner assembly area (ISO 6)



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

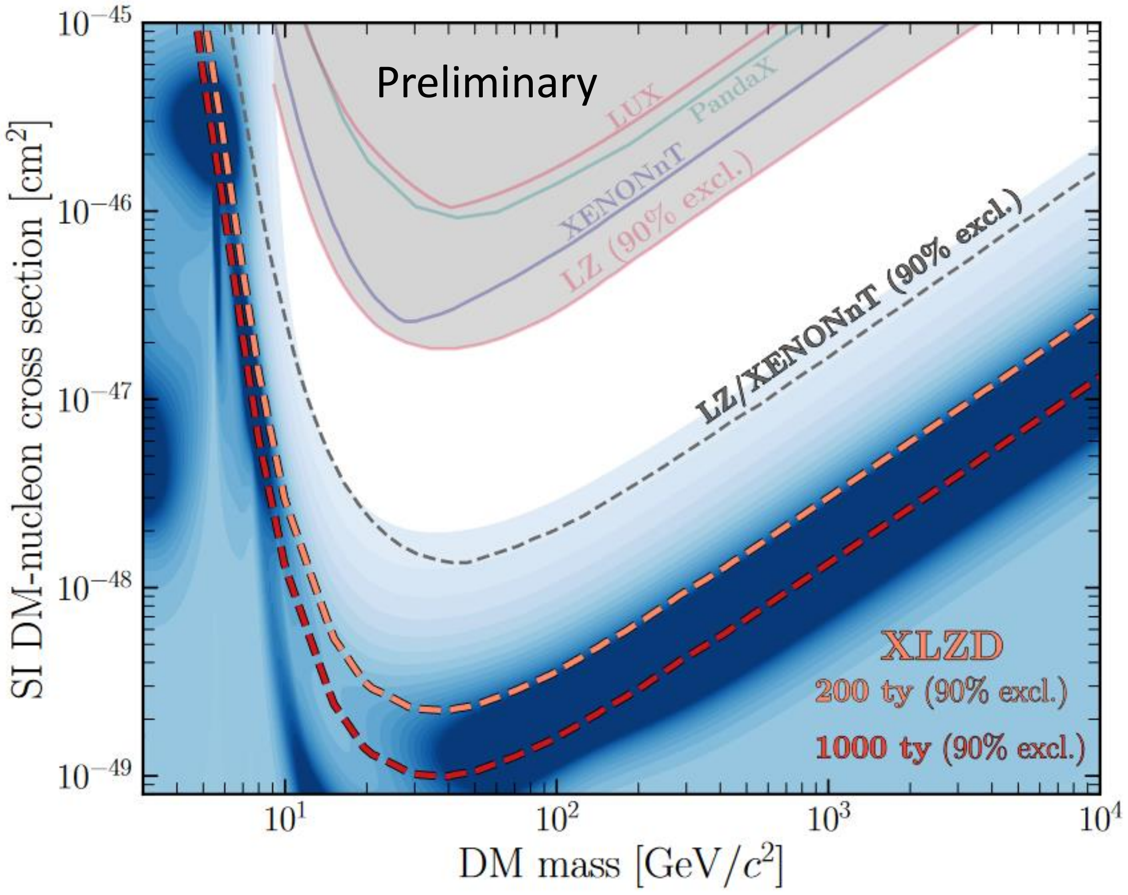
Sun
pp neutrinos
Solar metallicity
^{7}Be, ^{8}B, hep

WIMP sensitivity

Definitive search for medium to high WIMP masses

Reach into the neutrino fog after ~ 1000 tonnes years exposure

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



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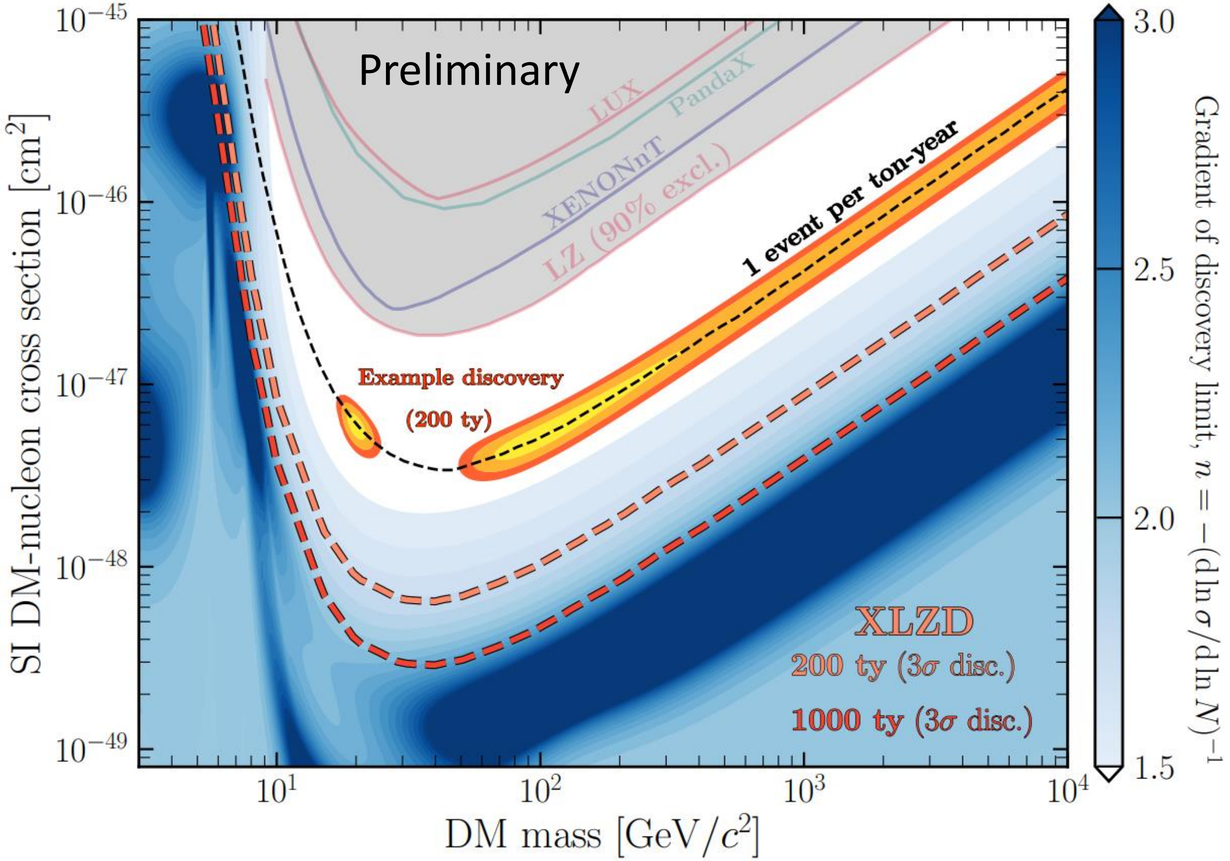
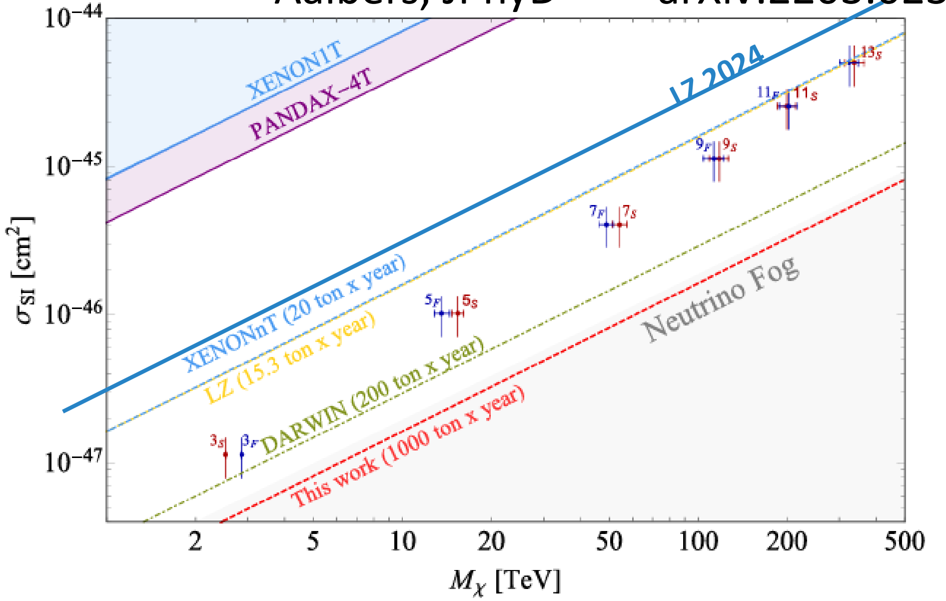
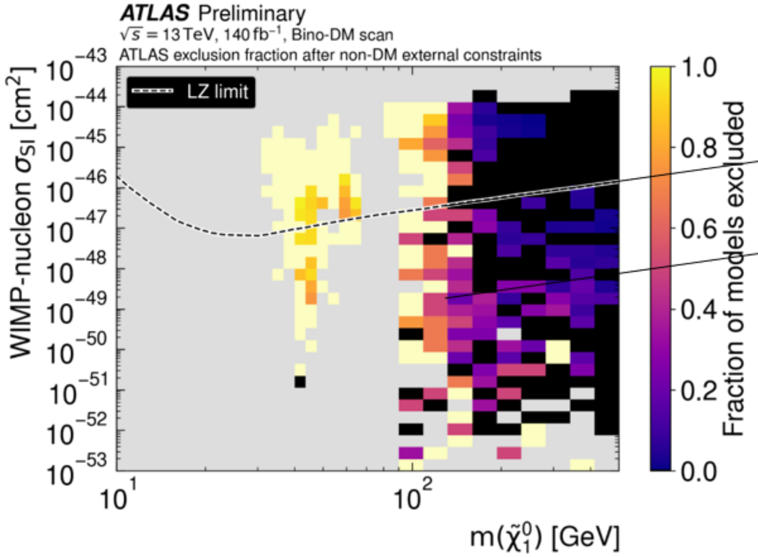


WIMP sensitivity

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

Aalbers, JPhyD arXiv:2203.02309





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

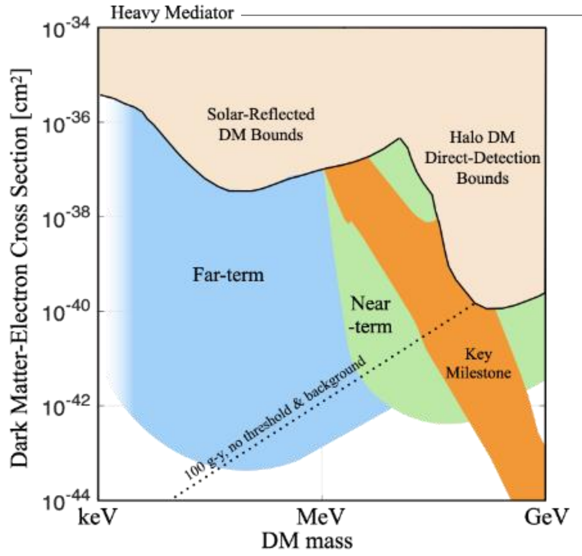
XLZD, 90% CL sensitivity

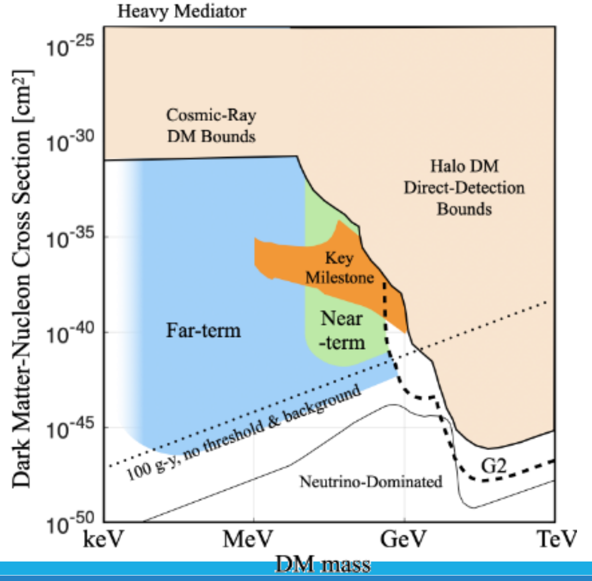
Probe higher-energy
SUSY models inaccessible to the LHC

23

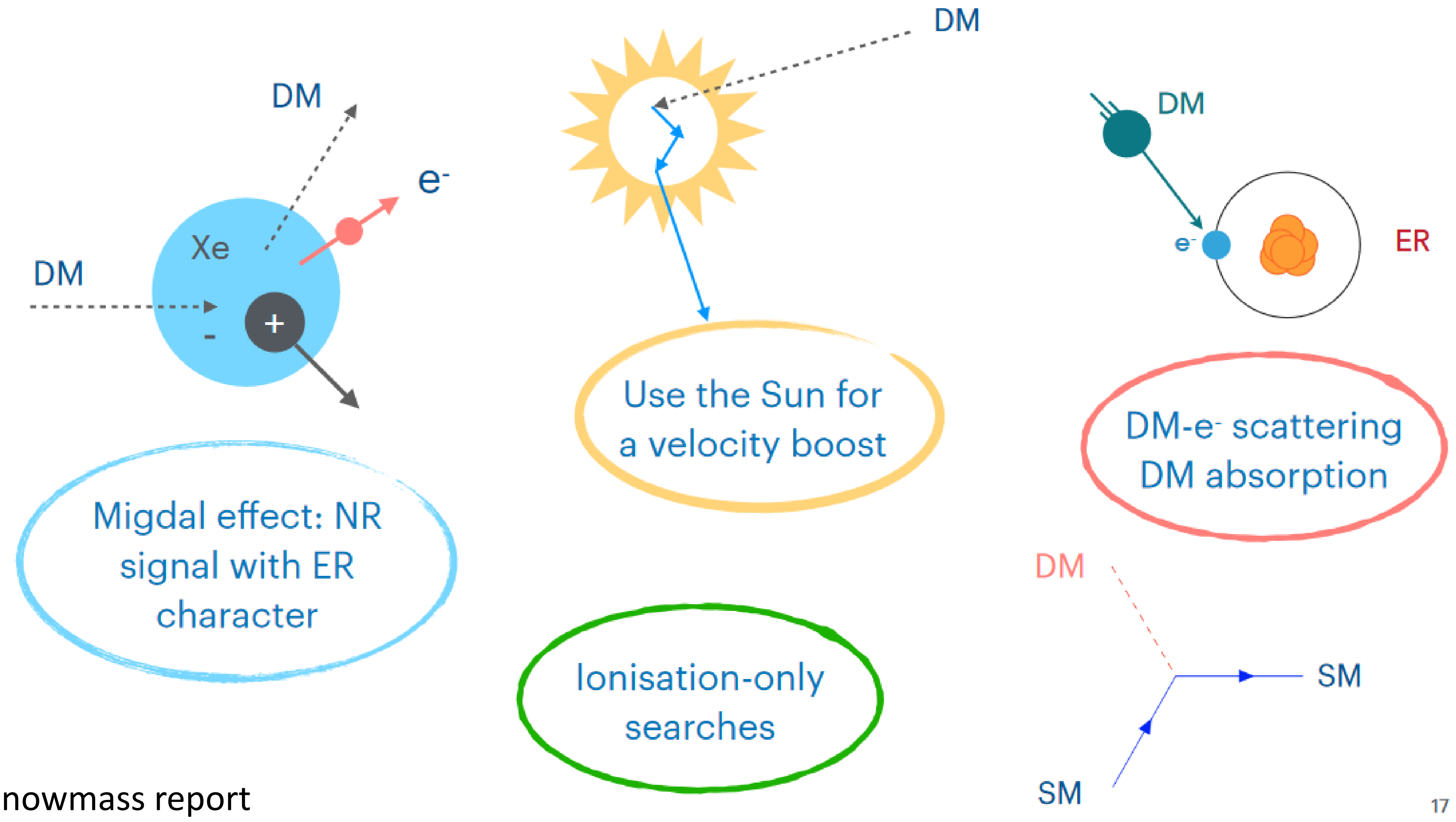
https://atlas.cern/Updates/Physics-Briefing/SUSY-Dark-Matter

Lighter dark matter





Snowmass report 2203.08297



More dark matter

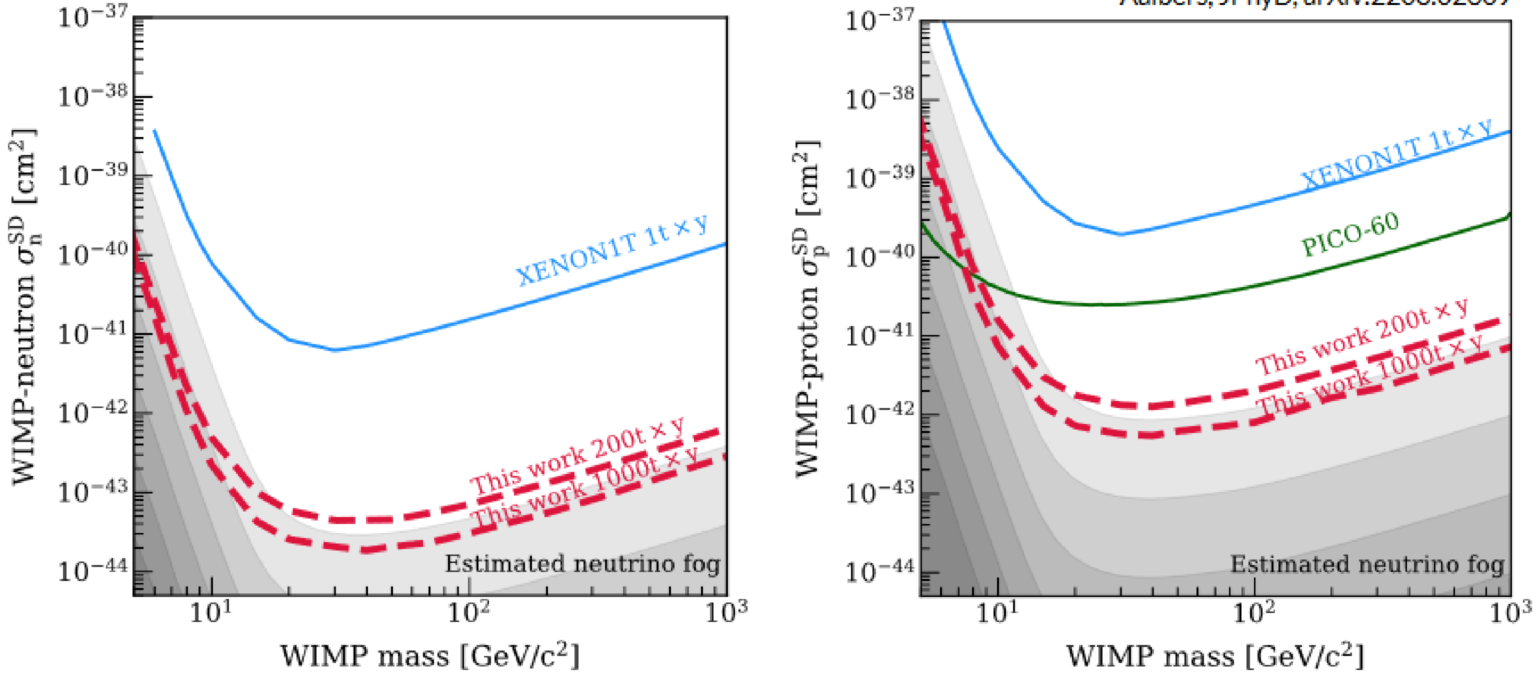
Two Xe isotopes carry spin, making up almost half the target

^{129}Xe (spin ½, 26%) and ^{131}Xe (spin 3/2, 21%)

Sensitivity to spin-dependent WIMP interactions

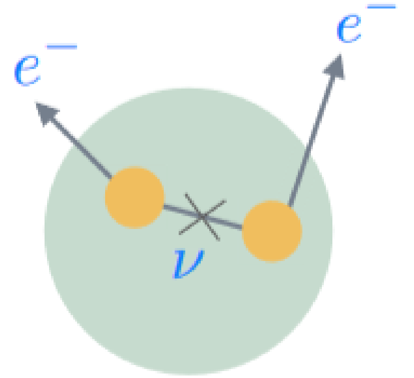
Type	Abbrev.	Operator ($\mathcal{Q}$)	Dimension	Coherent enhancement	Coefficients
Magnetic Dipole	-	$\bar{\chi}\sigma^{\mu\nu}\chi F_{\mu\nu}$	5	Partial	C_F
Electric Dipole	-	$\bar{\chi}\sigma^{\mu\nu}\chi \tilde{F}_{\mu\nu}$	5	Yes	$\tilde{C}_F$
Vector⊗Vector	VV	$\bar{\chi}\gamma^{\mu}\chi\bar{q}\gamma_{\mu}q$	6	Yes	$C^{VV}_{u,d,s}$
Axial-vector⊗Vector	AV	$\bar{\chi}\gamma^{\mu}\gamma_5\chi\bar{q}\gamma_{\mu}q$	6	Yes	$C^{AV}_{u,d}$
Tensor⊗Tensor	TT	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	6	Yes	$C^{TT}_{u,d,s}$
Pseudo-tensor⊗Tensor	$\widetilde{TT}$	$\bar{\chi}\sigma^{\mu\nu}i\gamma_5\chi\bar{q}\sigma_{\mu\nu}q$	6	Yes	$\tilde{C}^{TT}_{u,d,s}$
Scalar⊗Scalar	SS	$\bar{\chi}\chi m_q\bar{q}q$	7	Yes	$C^{SS}_{u,d,s}$
Scalar-gluon	S_g	$\alpha_s\bar{\chi}\chi G^a_{\mu\nu}G^{\mu\nu}_a$	7	Yes	C^S_g
Pseudo-scalar - gluon	$\tilde{S}_g$	$\alpha_s\bar{\chi}i\gamma_5\chi G^a_{\mu\nu}G^{\mu\nu}_a$	7	Yes	$\tilde{C}^S_g$
Pseudo-scalar⊗Scalar	PS	$\bar{\chi}i\gamma_5\chi m_q\bar{q}q$	7	Yes	$C^{PS}_{u,d,s}$
Spin-2	-	$\bar{\chi}\gamma_{\mu}i\partial_{\nu}\chi\bar{\theta}^{\mu\nu}_{q(g)}$	8	Yes	$C^{(2)}_{u,d,s,g}$
Axial-vector⊗Axial-vector	AA	$\bar{\chi}\gamma^{\mu}\gamma_5\chi\bar{q}\gamma_{\mu}\gamma_5 q$	6	No	$C^{AA}_{u,d,s}$

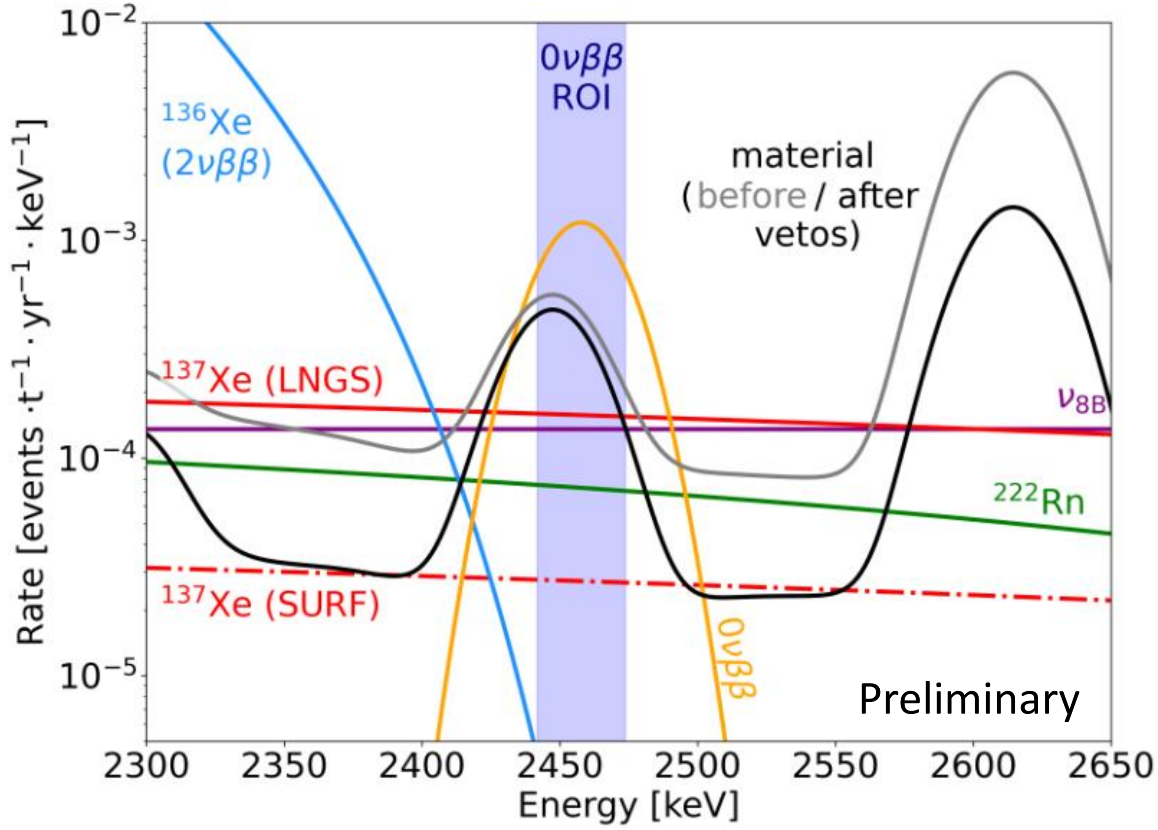
Aalbers, JPhyD, arXiv:2203.02309



Plus: Inelastic dark matter, Inelastic scattering, ALPs, dark photons, solar axions…

Neutrinoless double-beta decay





BSM process
possible for Majorana neutrinos

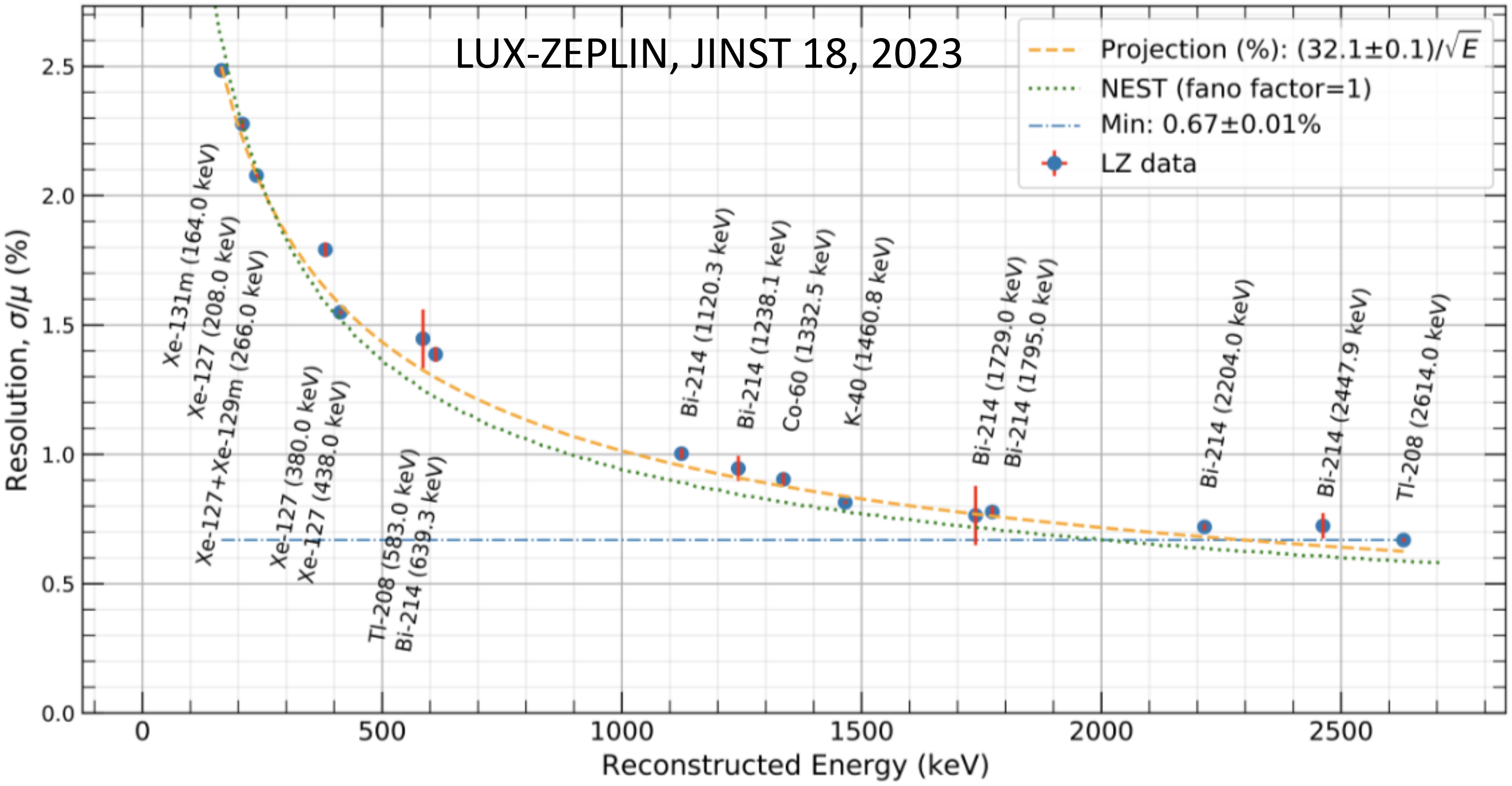
^{136}Xe (8.9%) undergoes
double beta decay ($2\nu\beta\beta$)
half-life 2×10^{21} yr

Search for peak at Q=2458 MeV

Critical backgrounds are gamma decay of ^{214}Bi (2447 MeV) and flat background: ^{222}Rn, ^{8}B neutrinos and ^{137}Xe

Neutrinoless double-beta decay

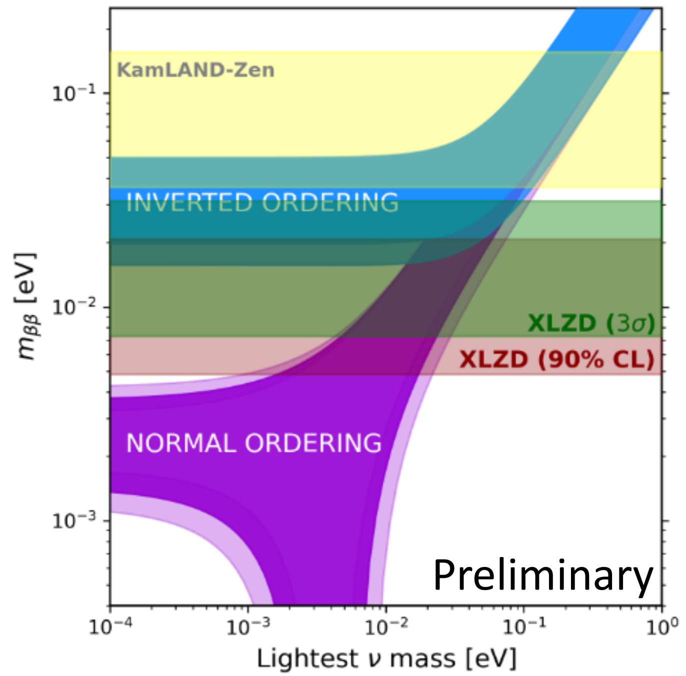
Energy resolutions < 1% achieved by current detectors

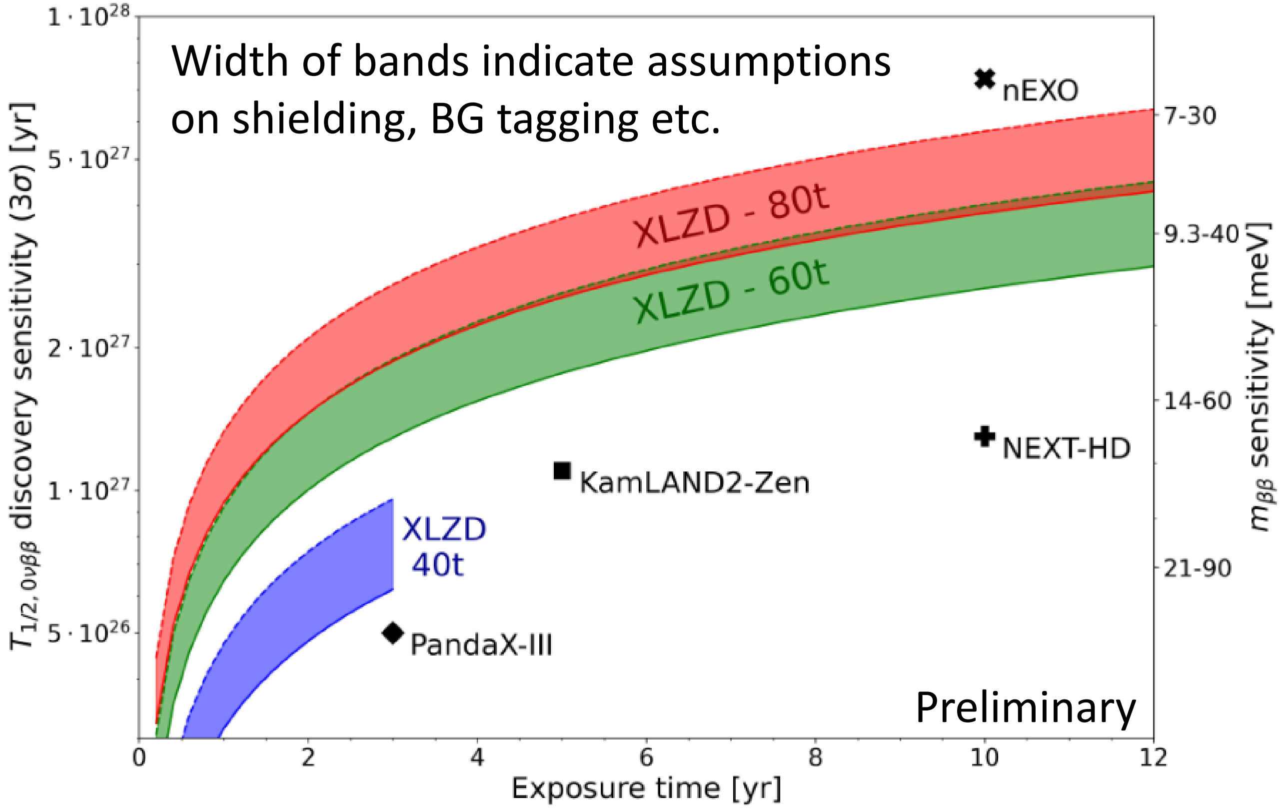


Neutrinoless double-beta decay

XLZD competitive with dedicated experiments

Cover inverted mass heirarchy



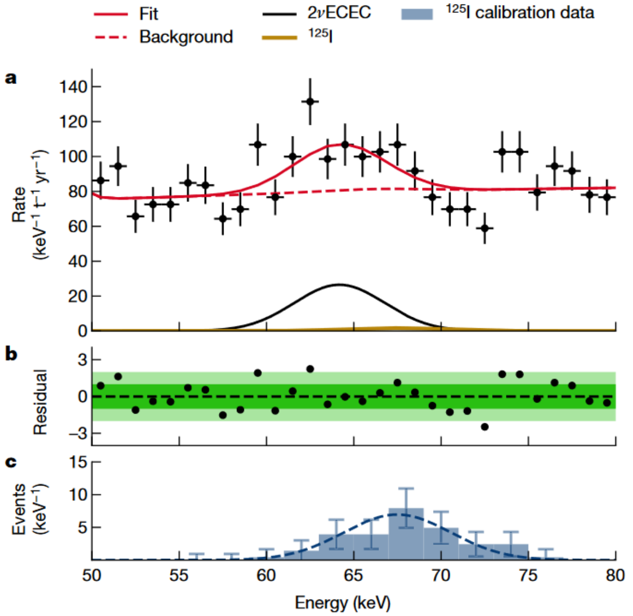


Other second order decays

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

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

2νECEC Detected in XENON1T

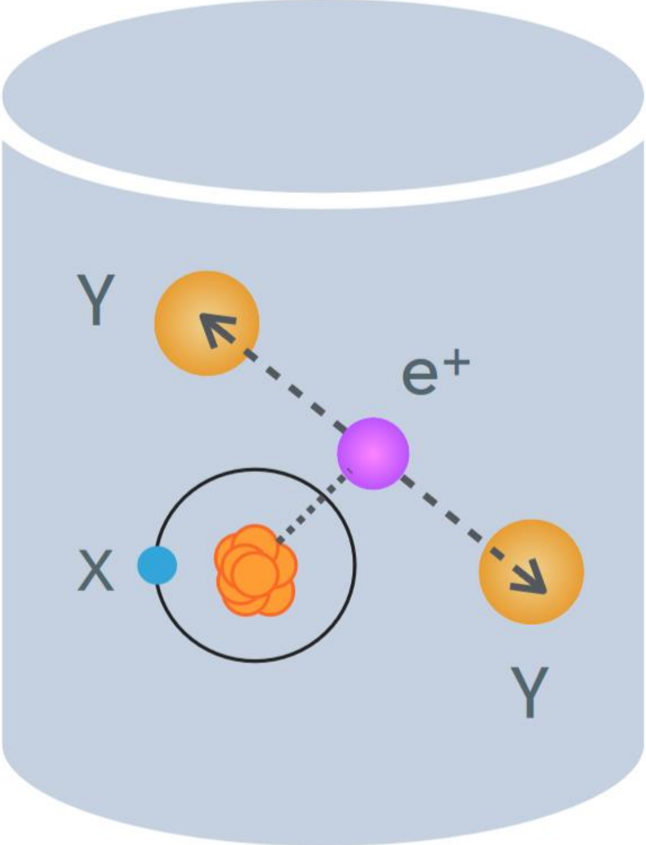


XENON, Nature 568, 2019

Predicted but not observed

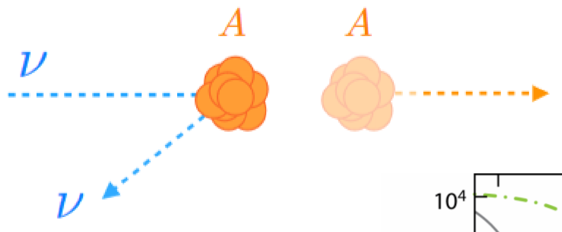
More interesting topologies
$0\nu/2\nu EC\beta^+$, $0\nu/2\nu\beta^+\beta^+$

Tests of SM & nuclear physics

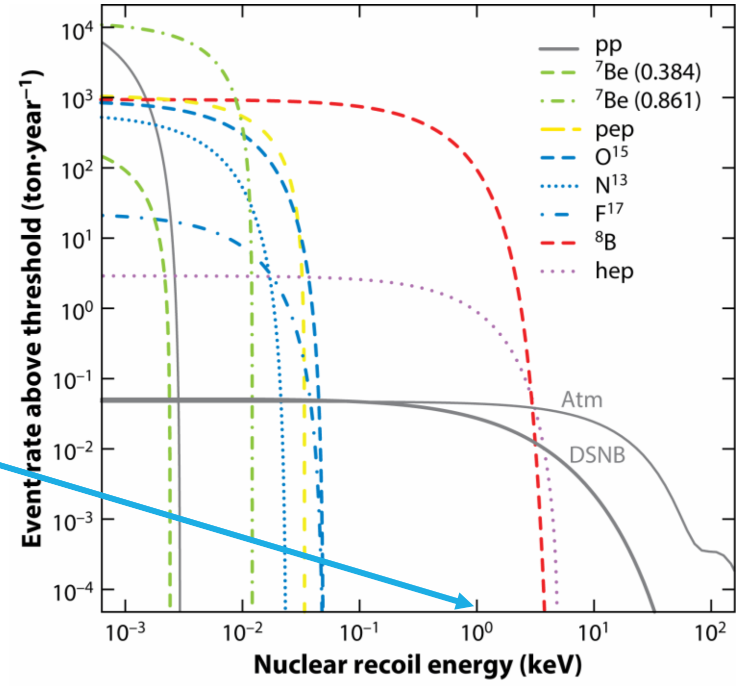


Astrophysical neutrinos

Neutrinos detected as NRs (CEvNS)

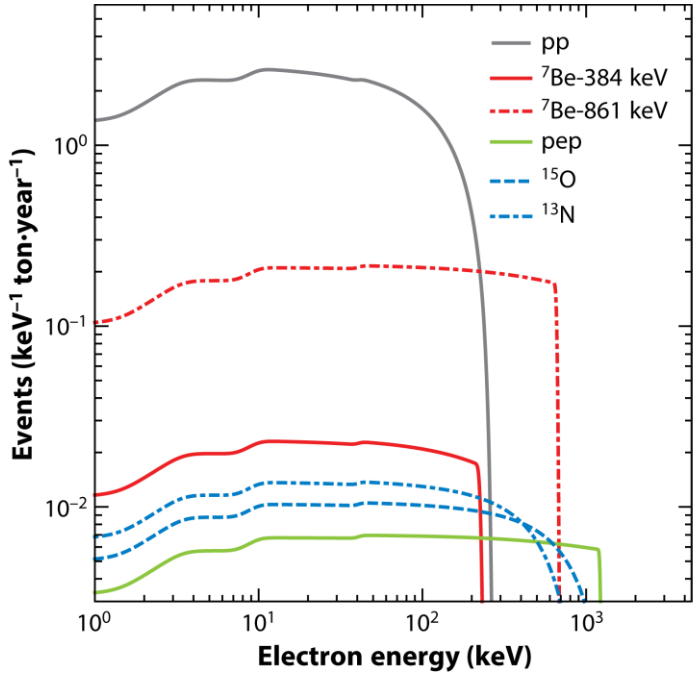


1 keV threshold



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

ERs (all other reactions)



Dutta B, Strigari LE. 2019.
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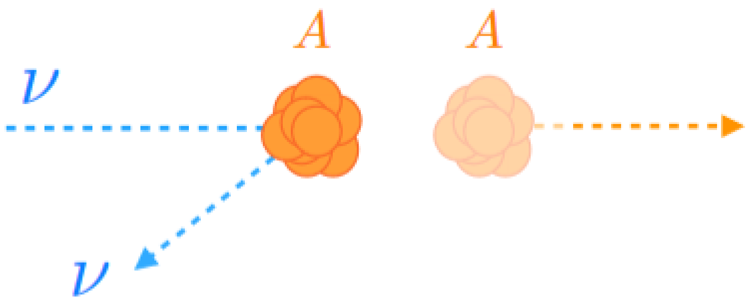
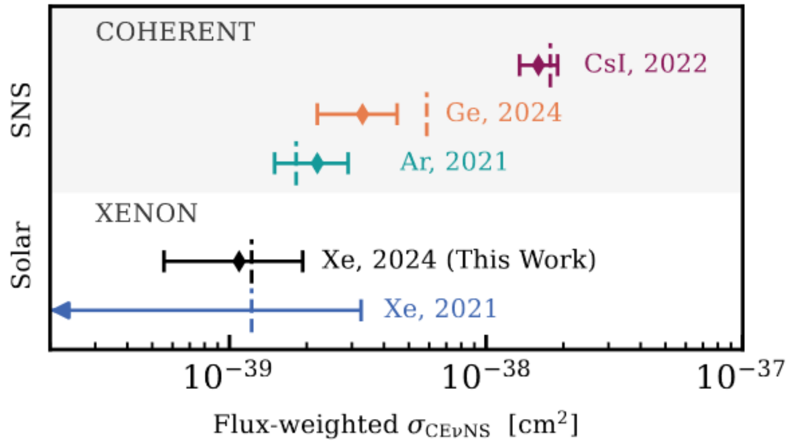
^{8}B neutrinos

Measured by XENONnT (2.73σ), PandaX (2.64σ)

Significance will be far higher in XLZD

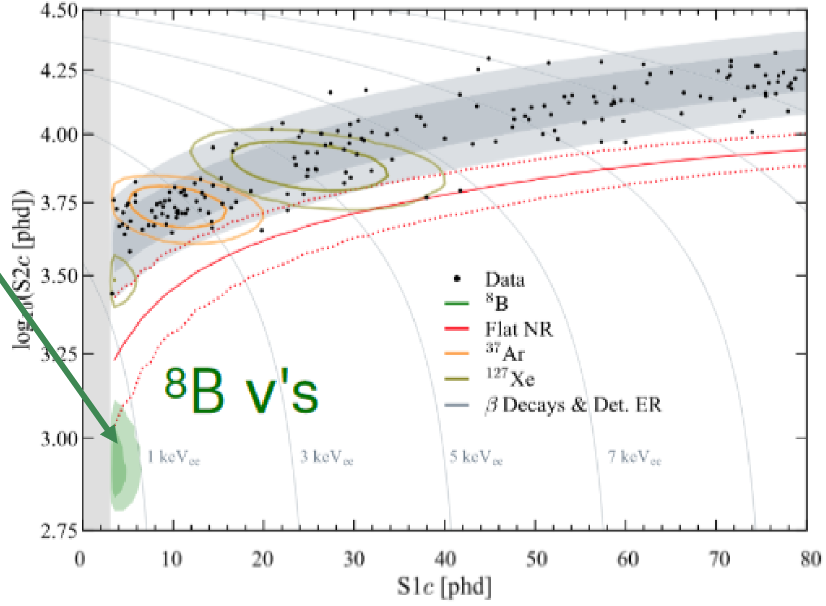


XENON, 2408.02877



Signal very close to threshold

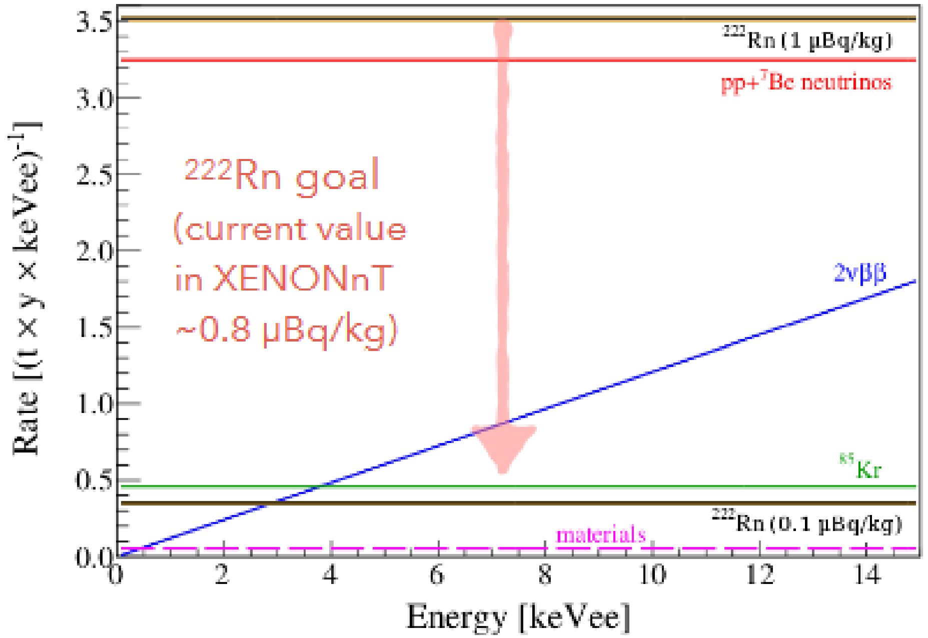
LZ, PRD 108, 2023

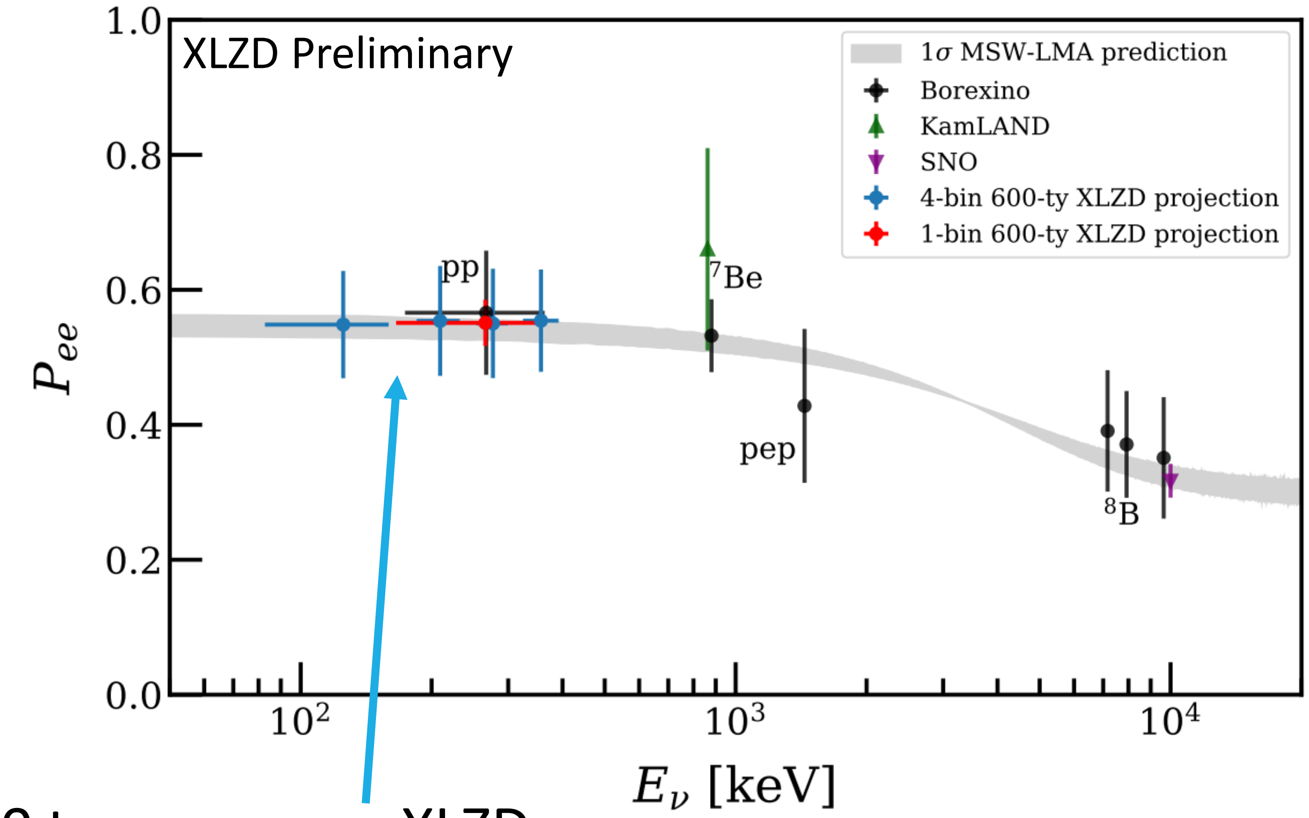


Astrophysical neutrinos – pp neutrinos

Most ERs from pp neutrinos

Main challenge: ^{222}Rn rate 10x lower than pp neutrinos (0.1 µBq/kg)



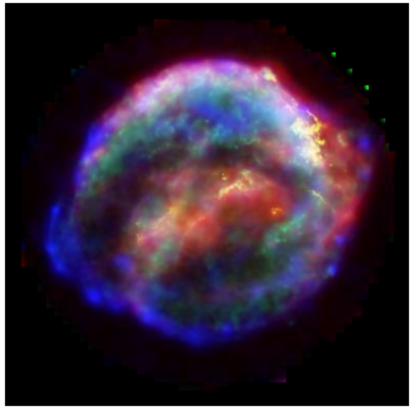


600 t yr exposure XLZD, one or four bins

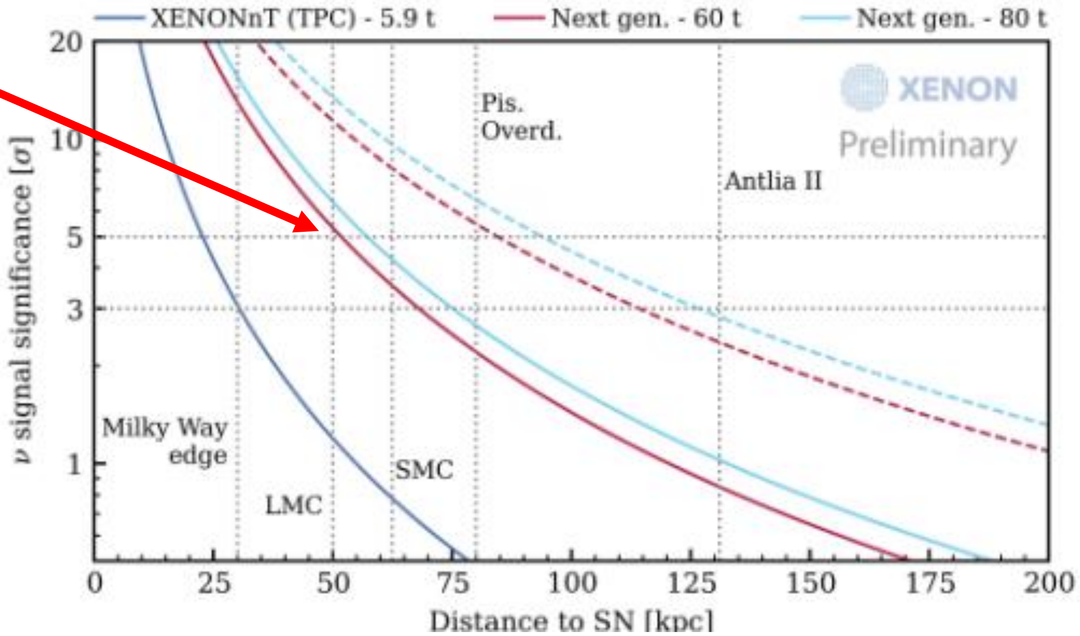
Supernova neutrinos

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



Summary

LXe TPCs lead search for dark matter, enormous potential for $0\nu\beta\beta$

LZ and XENONnT will continue to take data for design exposure

DARWIN and XLZD-UK performing R&D for next generation

XLZD : a new collaboration to build a 60 tonne LXe TPC

Test WIMPs down to neutrino fog

Sensitive to many other dark matter candidates

Rich physics reach for neutrinos and beyond

XLZD could be best in the UK