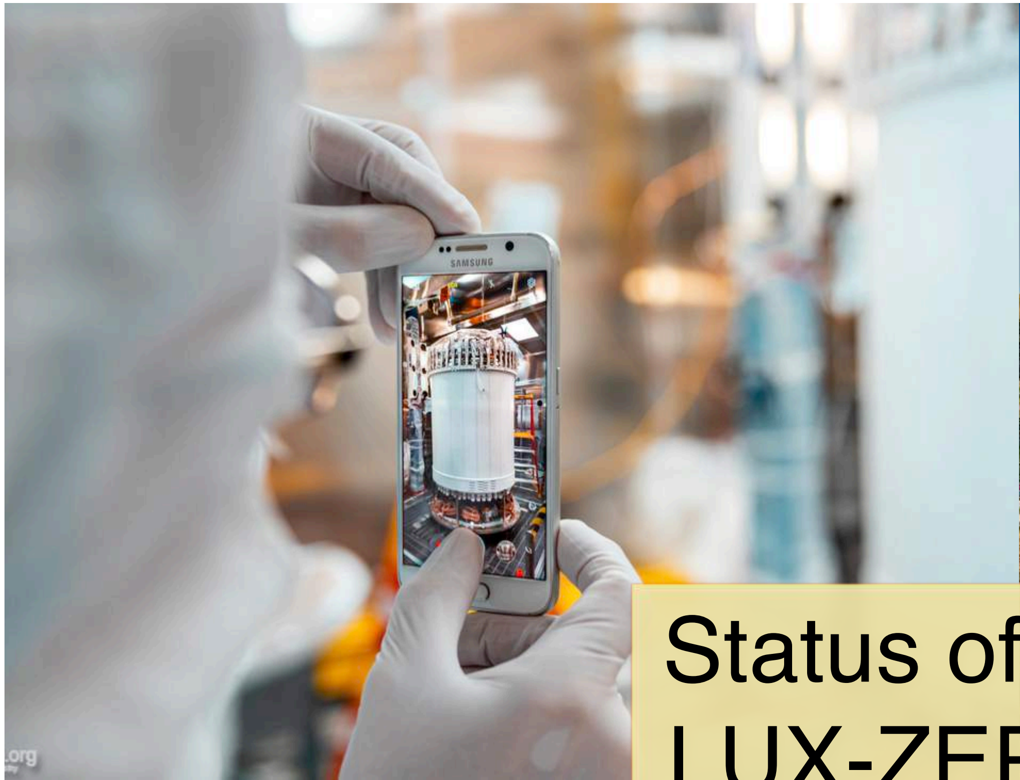
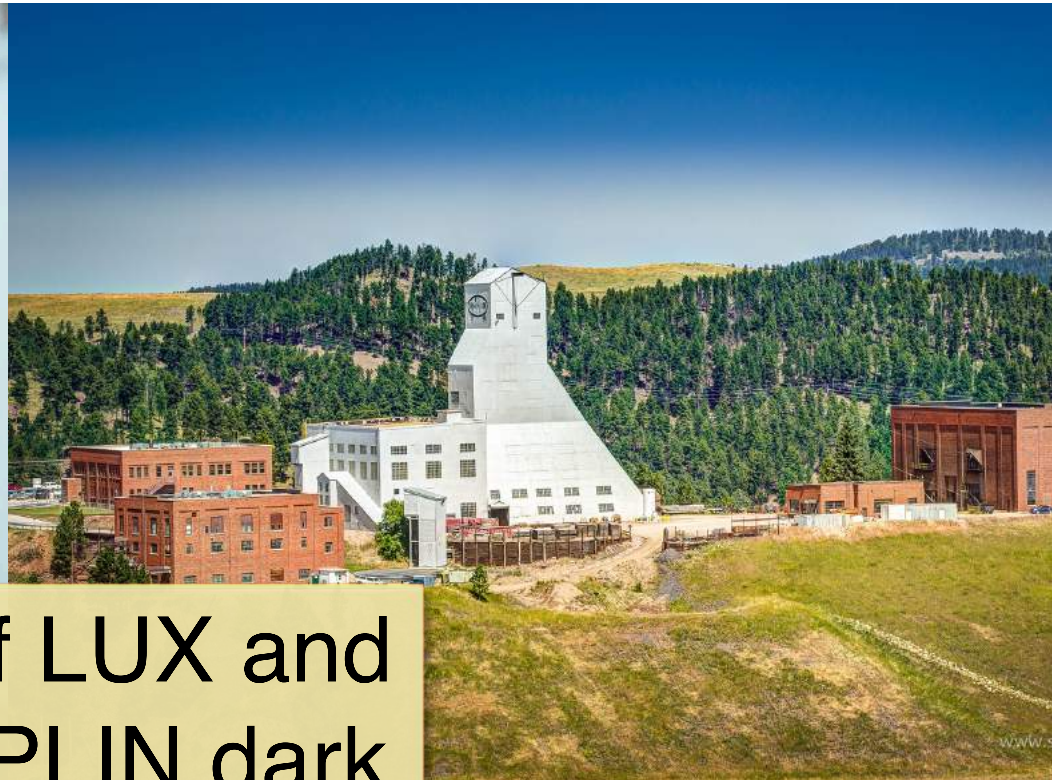
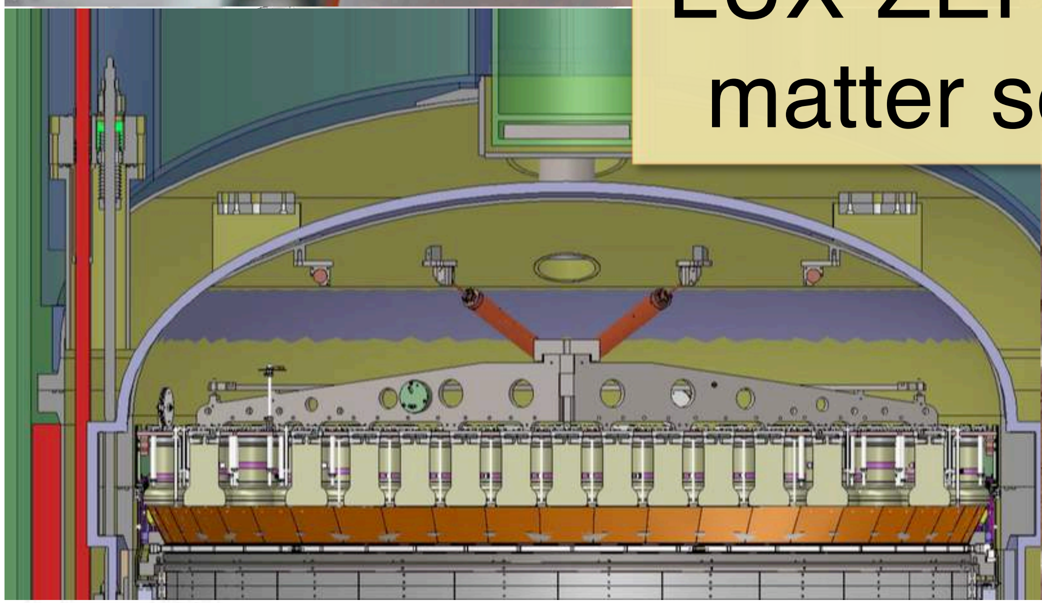




Status of LUX and LUX-ZEPLIN dark matter searches



LZ UK
University of BRISTOL
THE UNIVERSITY of EDINBURGH
Imperial College London
UNIVERSITY OF LIVERPOOL
UNIVERSITY OF OXFORD
Particle Physics
ROYAL HOLLOWAY UNIVERSITY OF LONDON
The University Of Sheffield.
UCL

The Team

Publish or perish…

LZ

Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment
D. Akerib et al. (E. Monzani)
Physical Review D, Accepted

The LUX-ZEPLIN Experiment
D. Akerib et al.
Nuclear Inst. and Methods in Physics Research, A (2019)163047

Measurement of the Gamma Ray Background in the Davis Cavern at the Sanford Underground Research Facility
D. Akerib et al. (S. Shaw)
Astroparticle Physics 116 (2020) 102391

The Science Capabilities of LUX-ZEPLIN: Searches for New Physics with low energy Electron Recoils
D. Akerib et al. (Edinburgh group)

Publish or perish…

LUX

Improved Modeling of Electronic Recoils in Liquid Xenon Using LUX Calibration Data
D. Akerib et al.

Internal review/Editor

Low-energy (0.7-74 keV) nuclear recoil calibration of the LUX dark matter experiment using D-D neutron scattering kinematics
D. Akerib et al.

Extending light WIMP searches to single scintillation photons in LUX
D. Akerib et al. (Nellie)
Physical Review D (2019*)*

First direct detection constraint on mirror dark matter kinetic mixing using LUX 2013 data
D. Akerib et al. (Elizabeth) PRD 2019 (with referees)

Search for two neutrino double electron capture of 124Xe and 126Xe in the full exposure of the LUX detector
D. Akerib et al. (MF Marzioni, ASM, Alex Lindote)
PRC 2019 Submitted

Improved Measurements of the beta-decay Response of Liquid Xenon with the LUX Detector
D. Akerib et al. (Jon B)
Physical Review D 100 (2019) 22002

Publish or perish…

LUX

Results of a search for sub-GeV dark matter using 2013 LUX data
D. Akerib et al (Lucie)
Physical Review Letters 122 (2019) 131301

Search for annual and diurnal rate modulations in the LUX experiment
D. Akerib et al. (Jingke Xu)
Physical Review D 98 (2018) 62005

Internal review/Editor

LUX Trigger Efficiency
D. Akerib et al. (Mongkol)
Nuclear Inst. and Methods in Physics Research, A 908 (2018) 401-410

Internal review/Editor

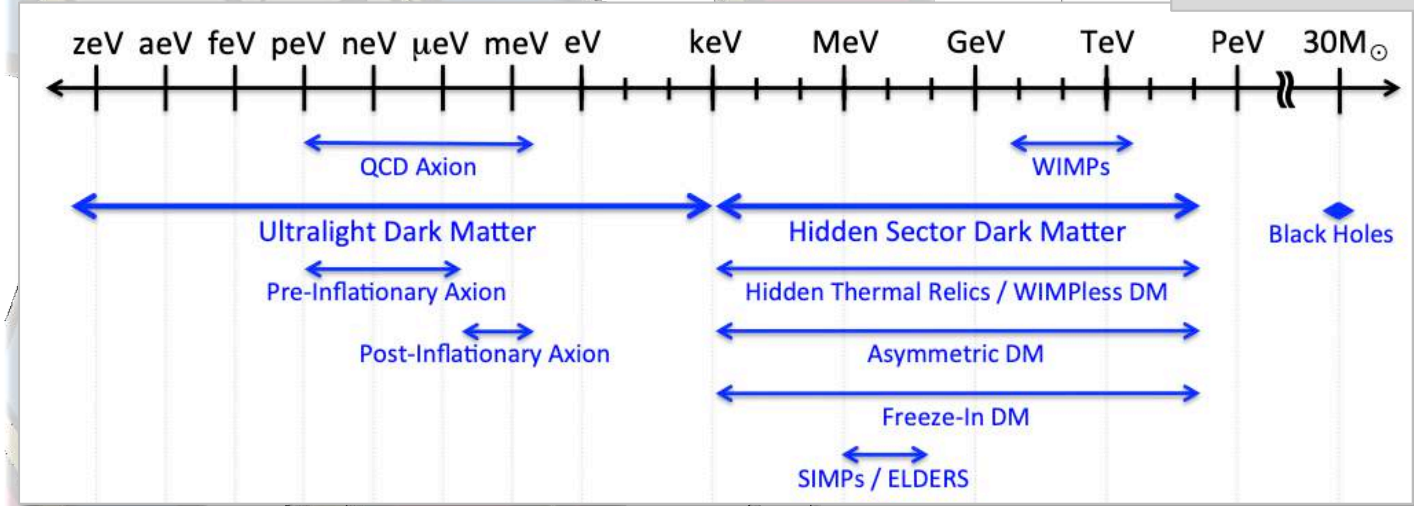
Liquid xenon scintillation measurements and pulse shape discrimination in the LUX dark matter detector
D. Akerib et al. (Dev)
Physical Review D 97 (2018) 112002

Calibration, event reconstruction, data analysis and limits calculation for the LUX dark matter experiment
D. Akerib et al. (Carmen)
Physical Review D 97 (2018) 102008

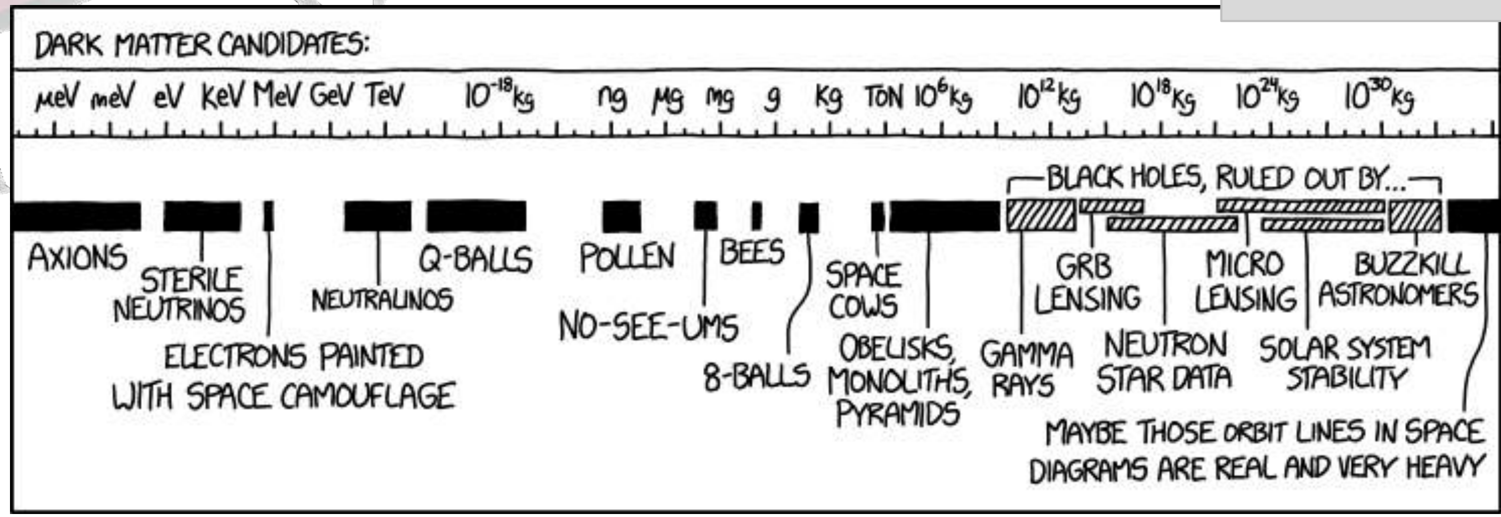
Internal review/Editor

What are we looking for?

Cosmic Visions report (2017)

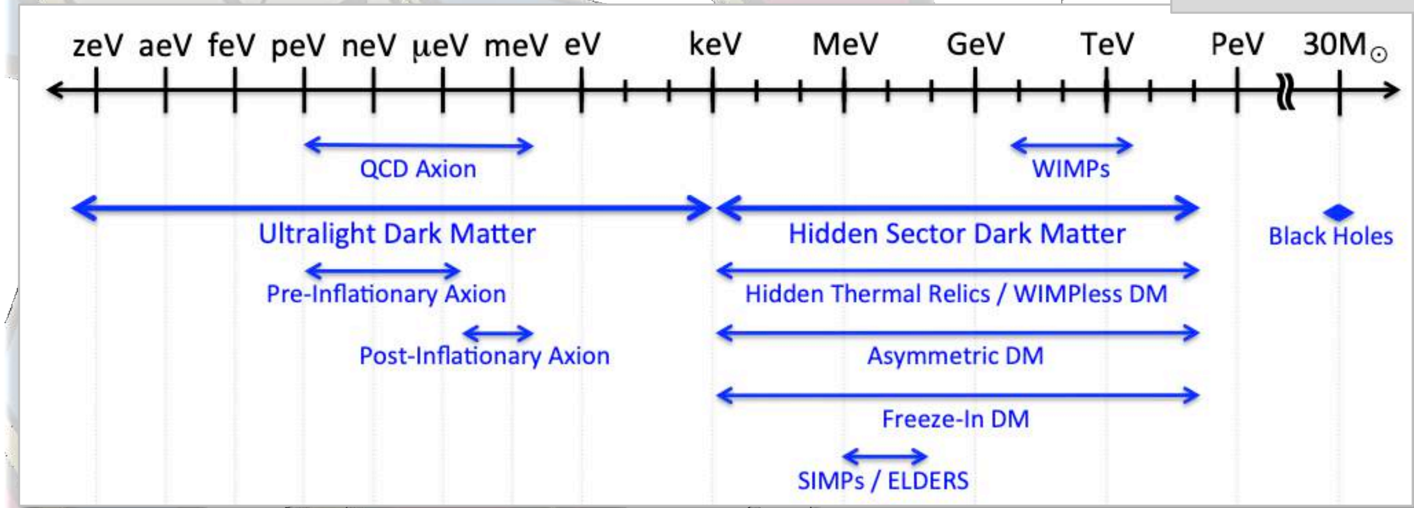


xkcd:2035

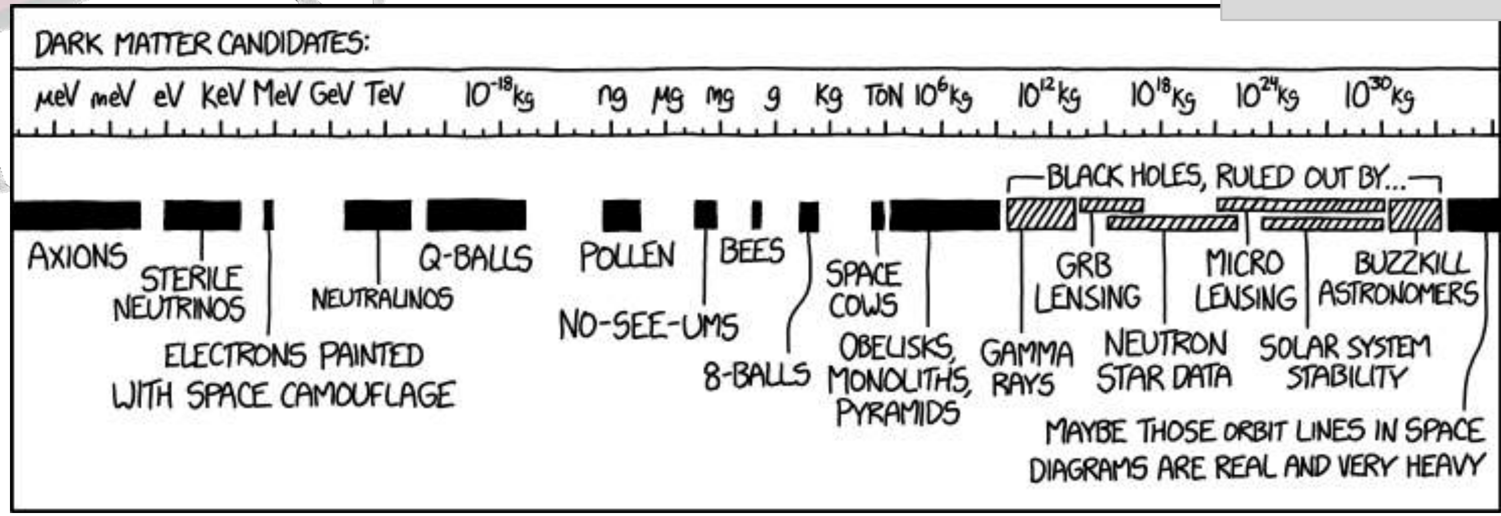


What are we looking for?

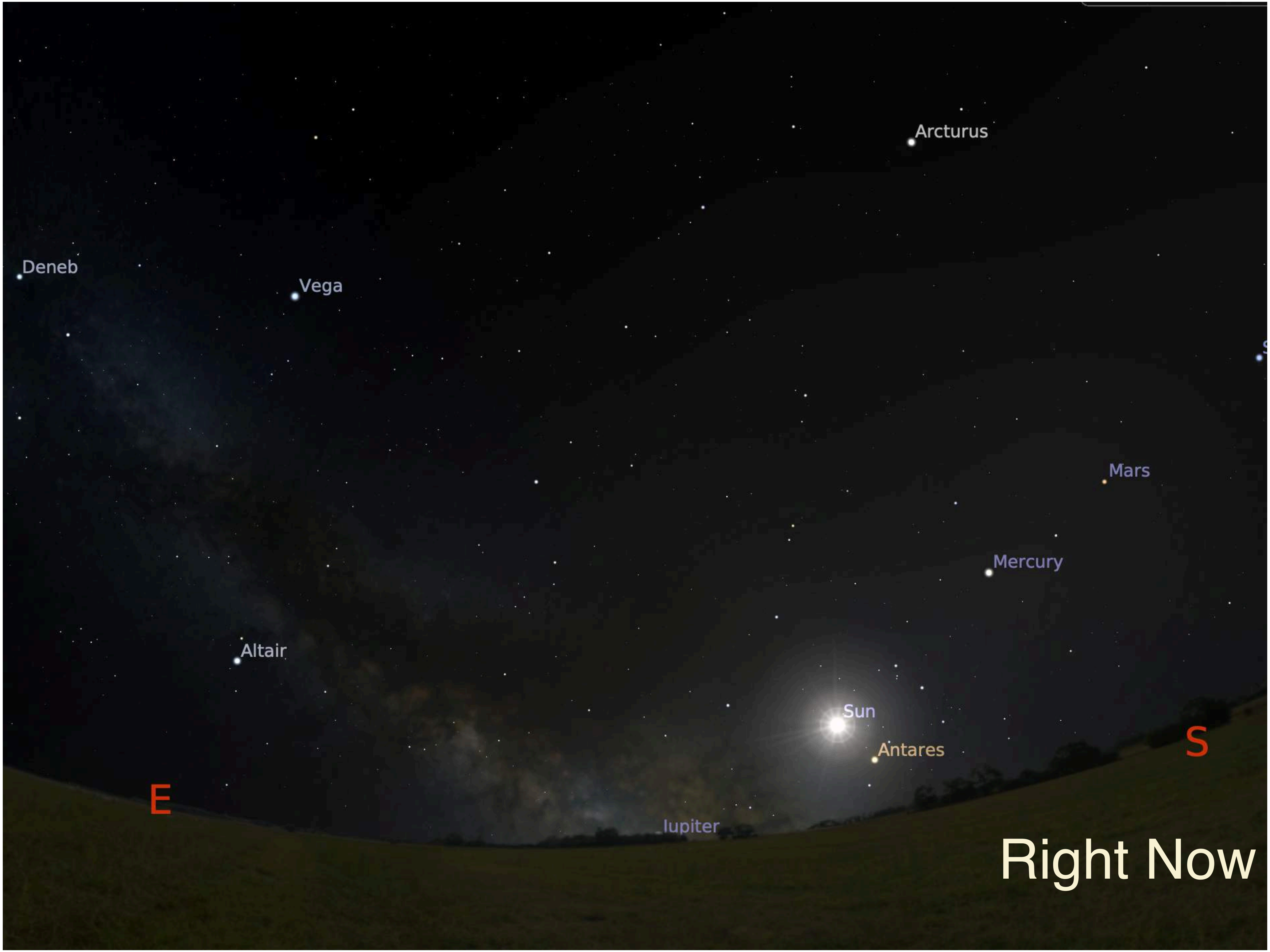
Cosmic Visions report (2017)



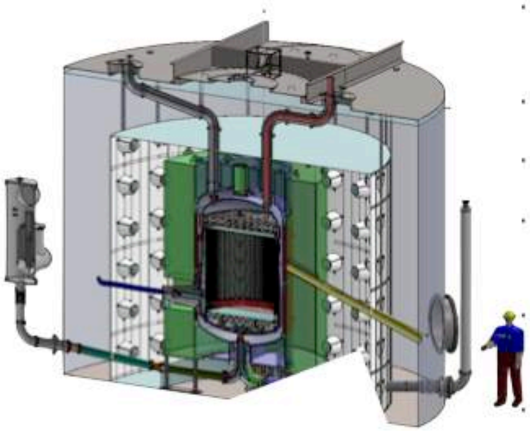
xkcd:2035



→ Strong incentive for searches to be as broad as possible

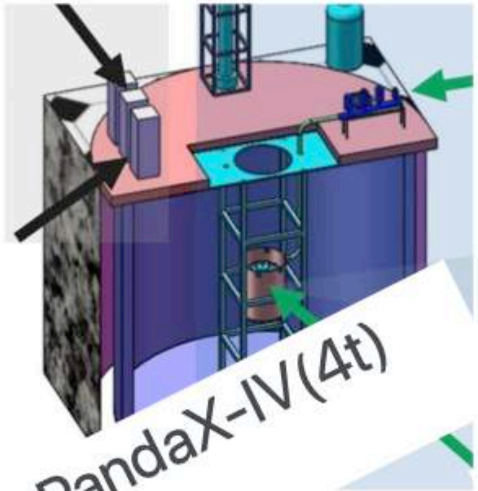

Arcturus
Deneb
Vega
Mars
Mercury
Altair
Sun
Antares
S
E
Iupiter
Right Now

New kids on the block…

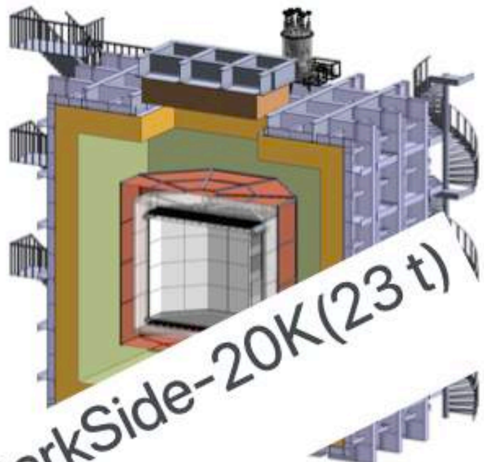


LZ(7t)
2020-

XENONnT (5.9t)
2019-

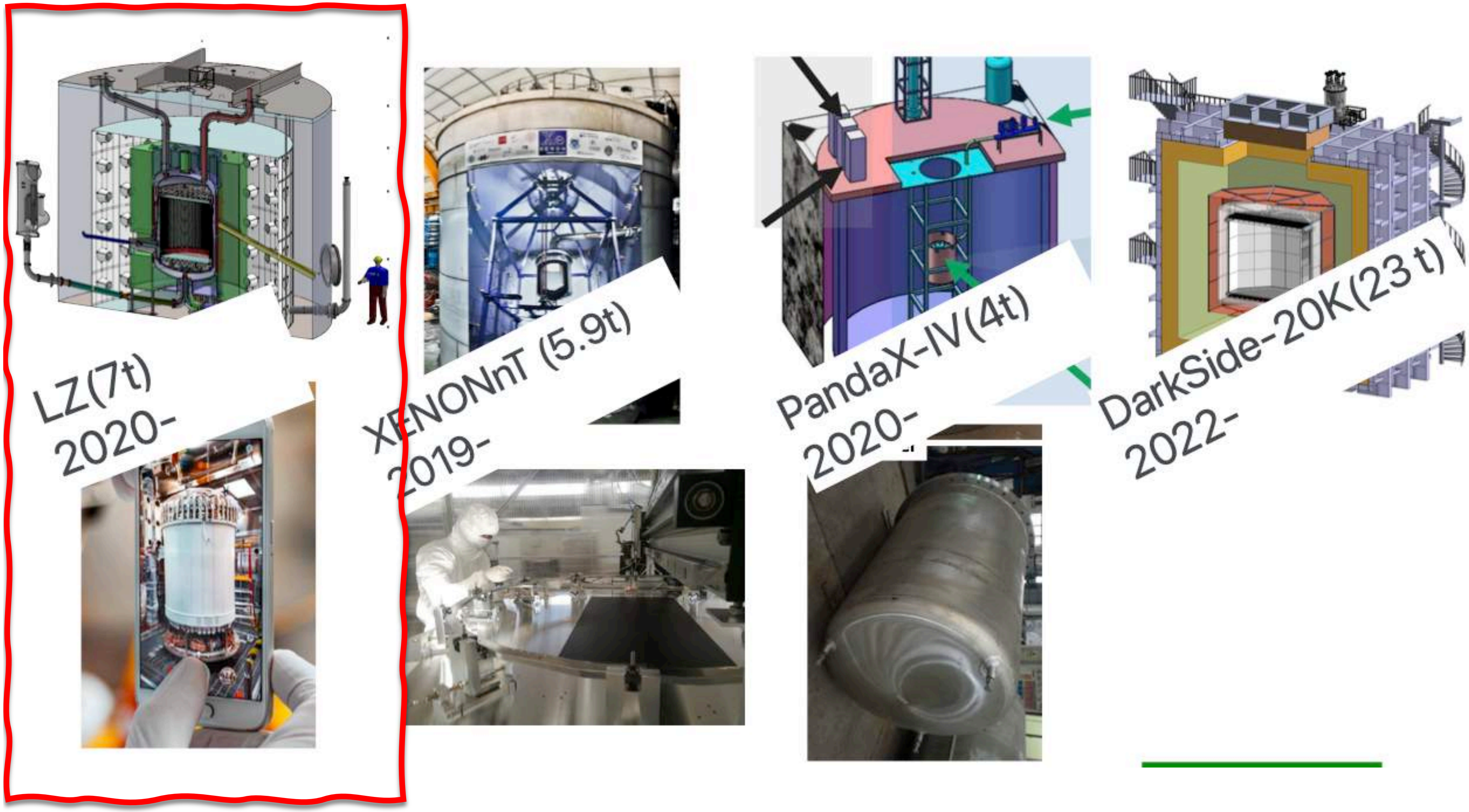


PandaX-IV(4t)
2020-

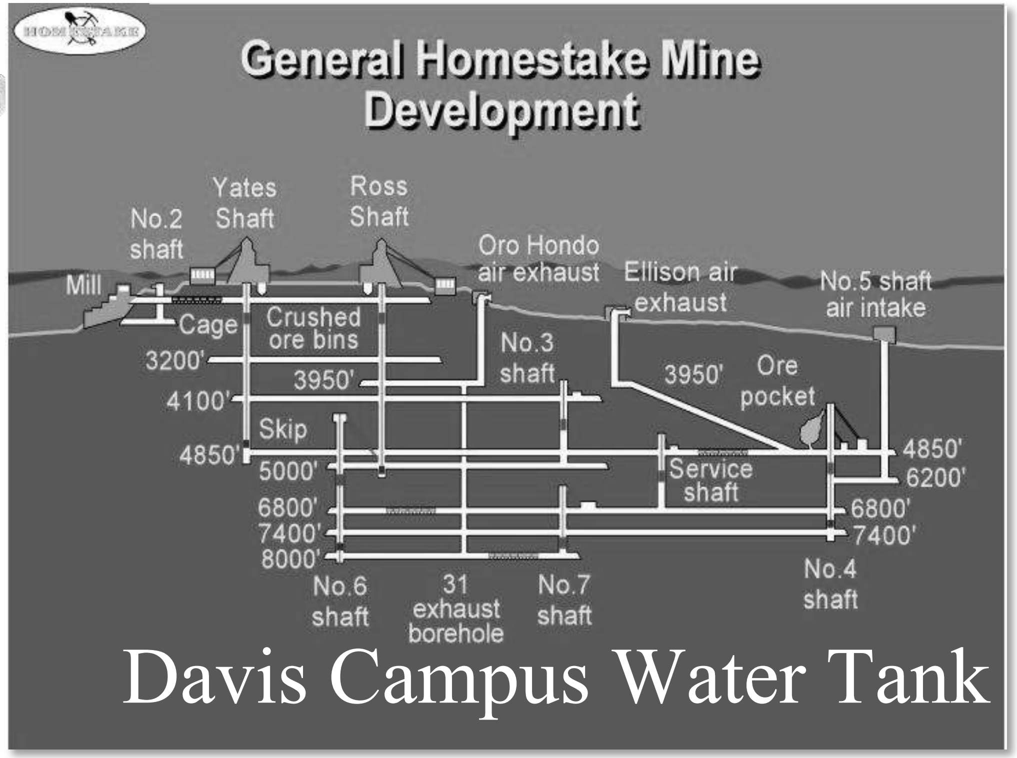


DarkSide-20K(23 t)
2022-

New kids on the block…

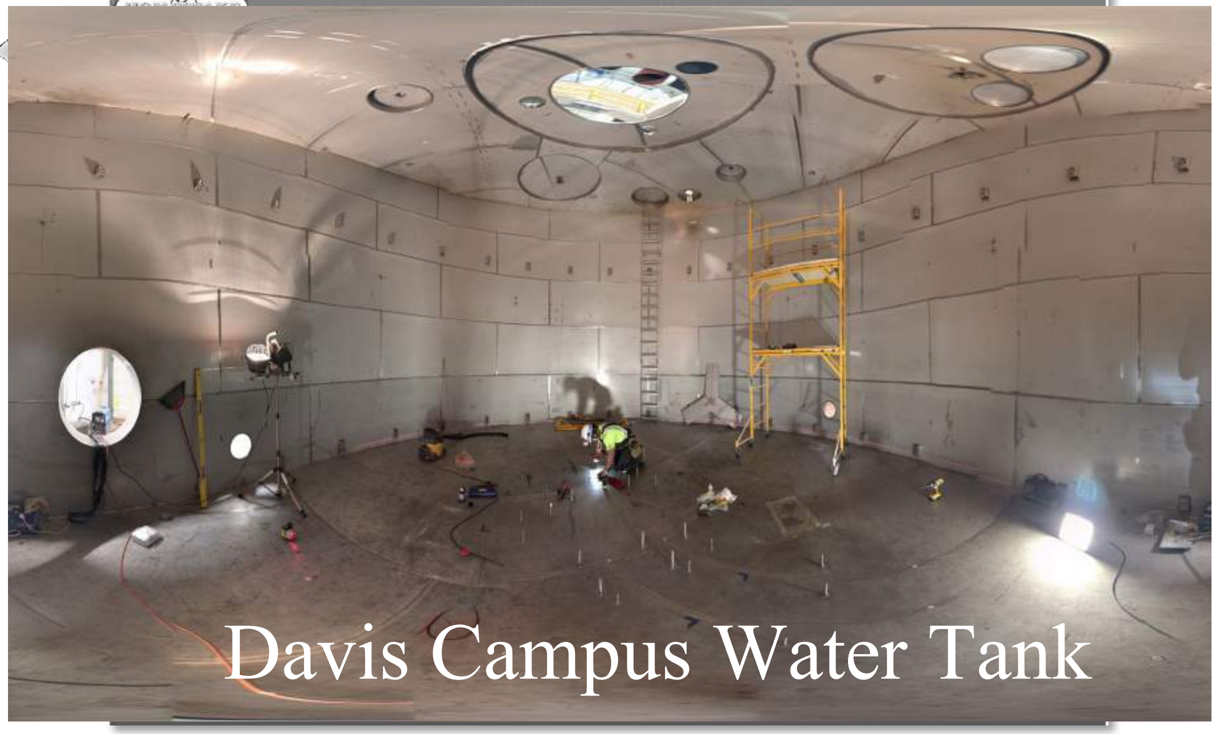


Sanford Underground Research Facility
Lead, South Dakota, USA



Davis Campus Water Tank

Sanford Underground Research Facility
Lead, South Dakota, USA



Davis Campus Water Tank

1/12/2019

Science in an extreme environment

…

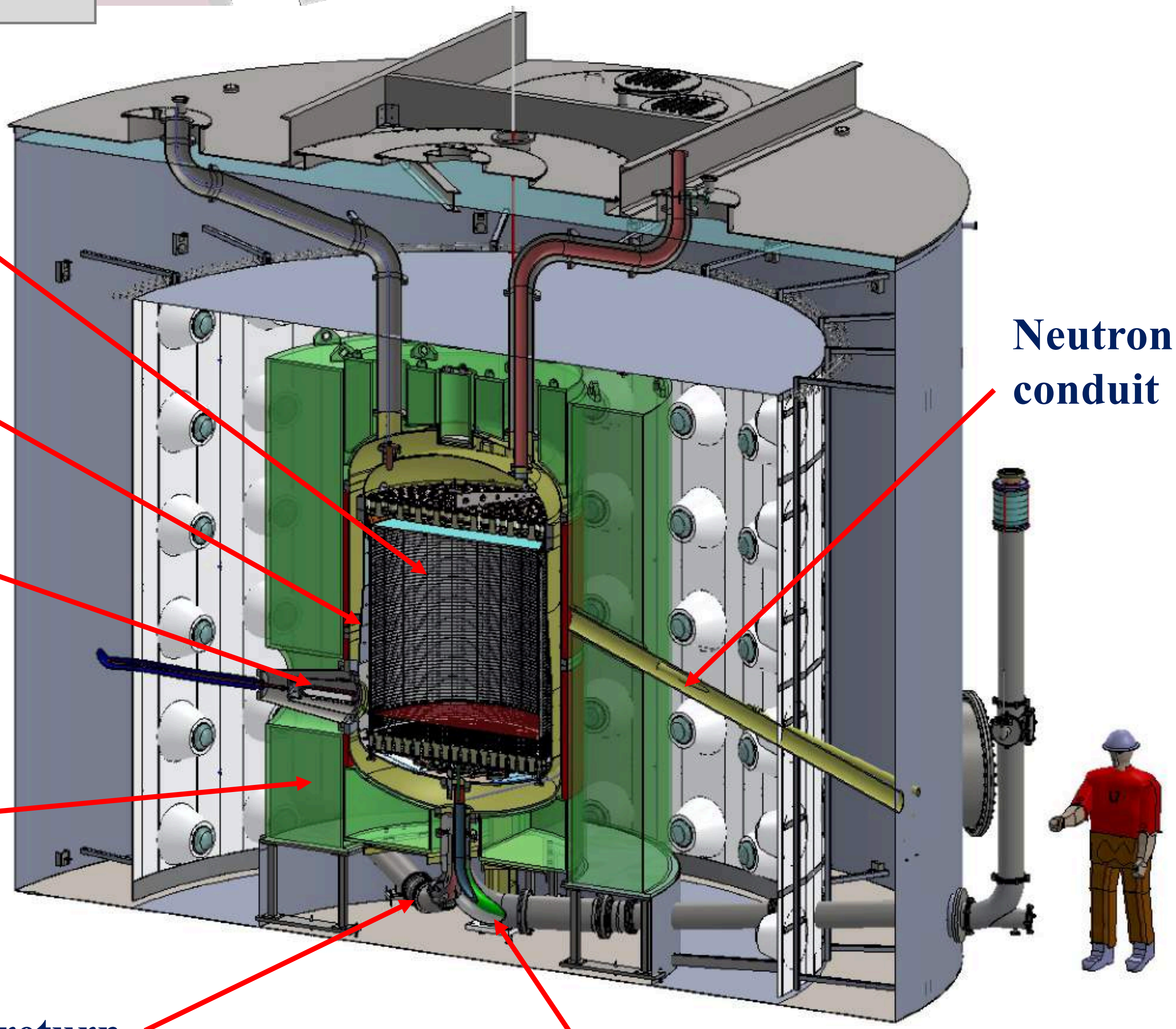
LUX-ZEPLIN (LZ)

7.0 T active LXe
5.6T fiducial

Instrumented
Xe skin detector

50 kV cathode
high voltage

17 tonnes
Gd-LS
Outer
Detector

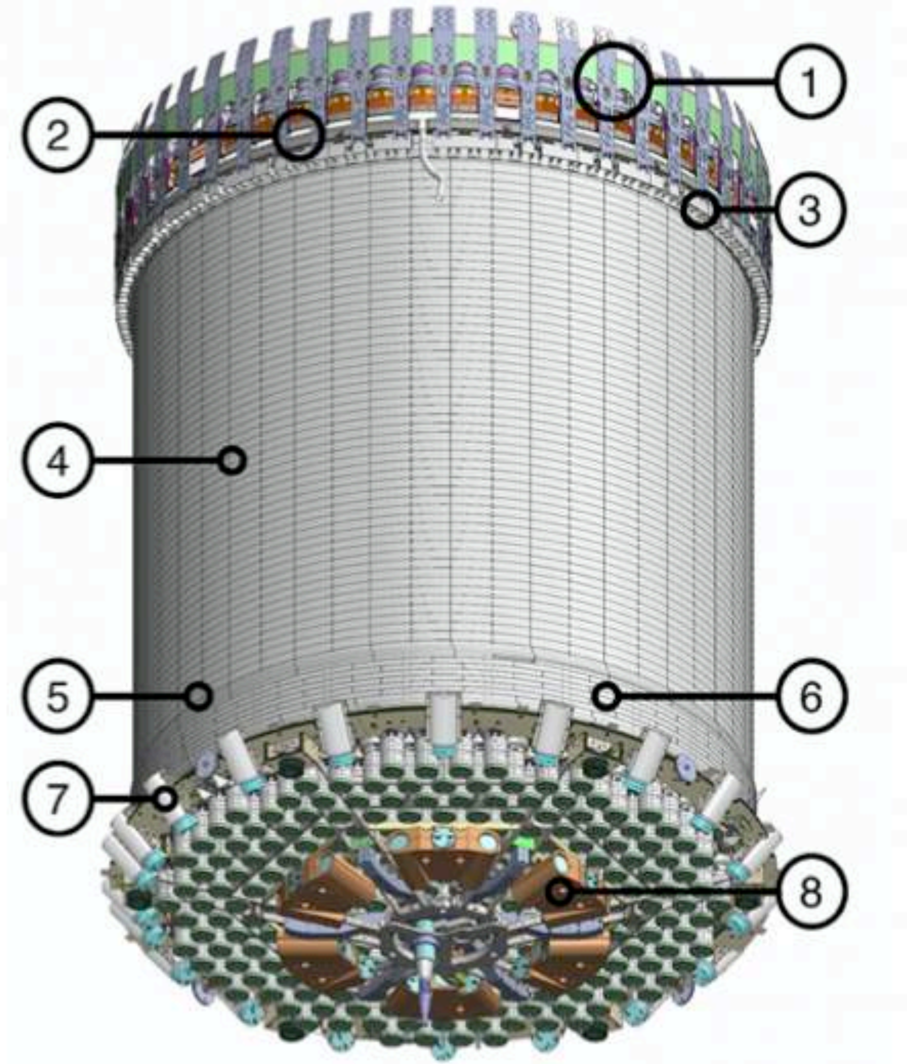


Neutron
conduit

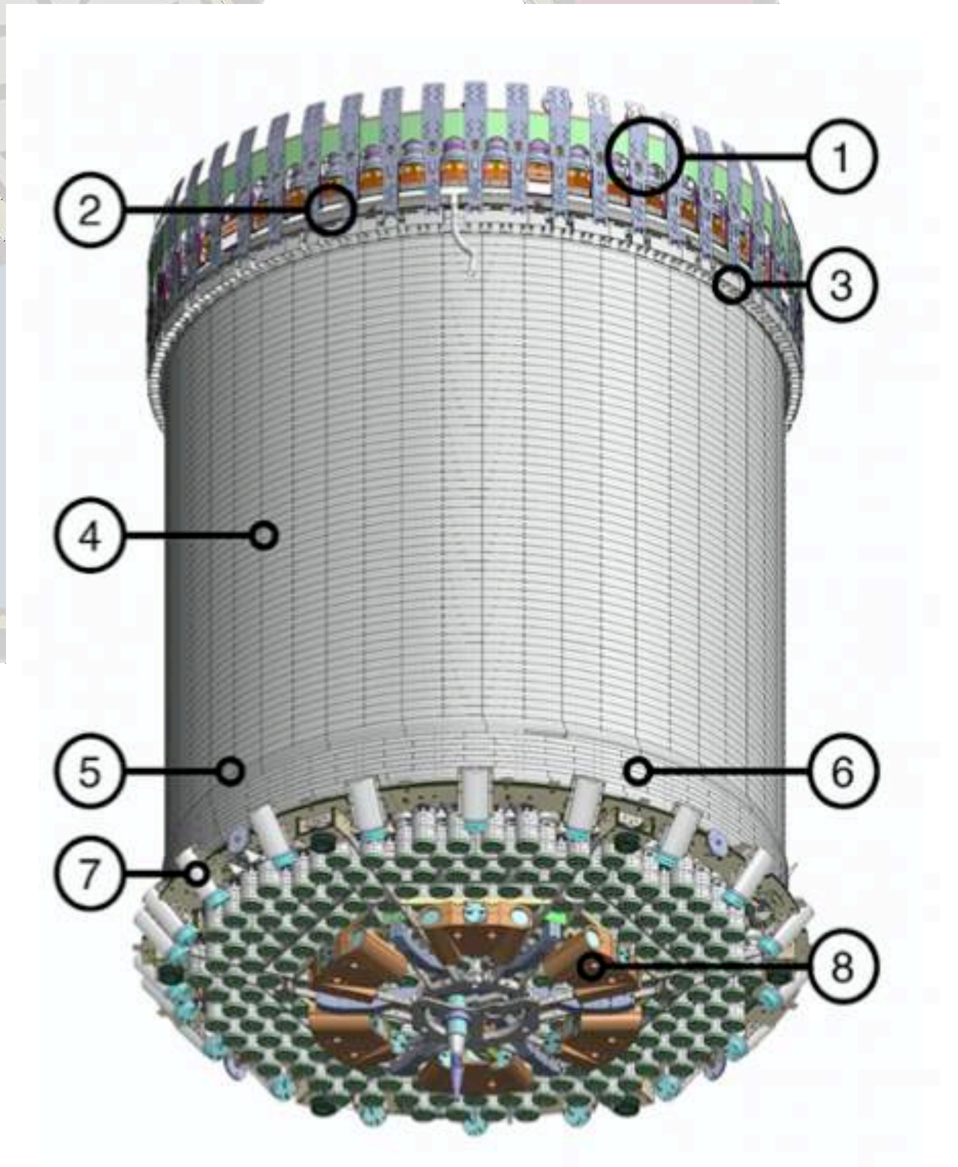
LXe supply & return

Lower PMT cable conduit

arXiv:1910.09124



arXiv:1910.09124

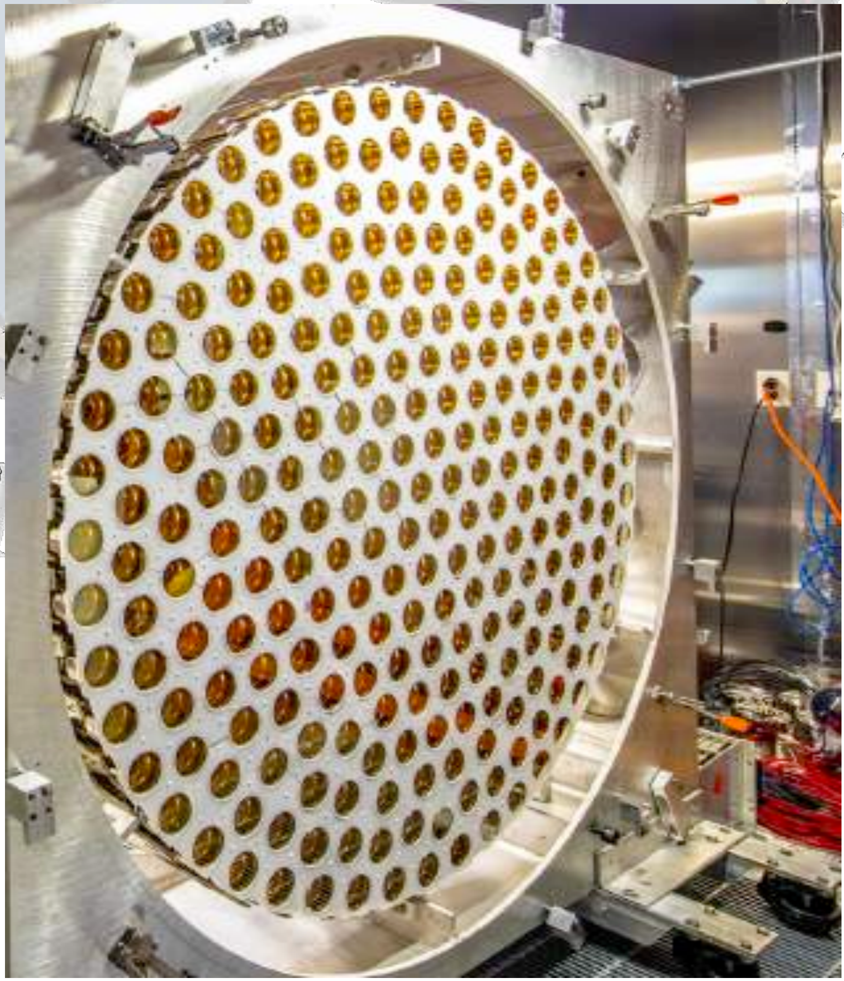


arXiv:1910.09124

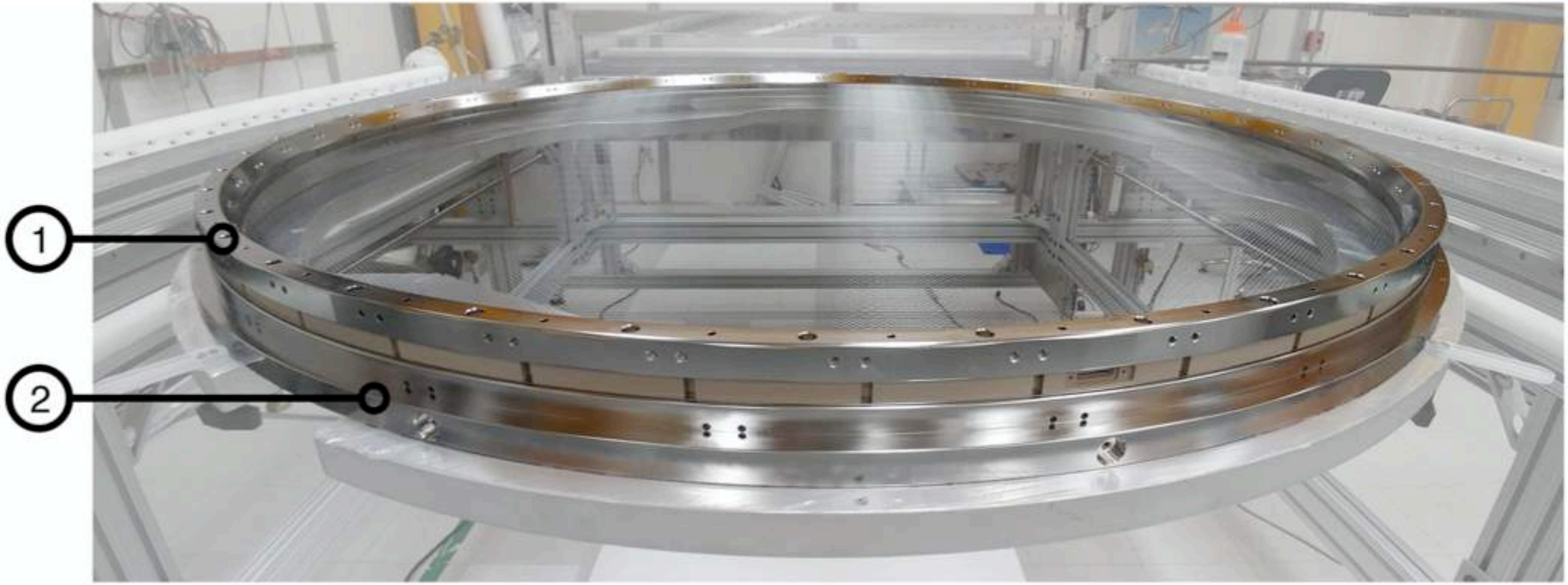
PMTs

3” Hamamatsu R11410-22

Average QE: 31% (cold); Average Gain: 3.5×10^{6} ;Top array: 253 units; Bottom array: 241 units



Grids



Electrode	Voltage (kV)	Diam. (μm)	Pitch (mm)	Num.
Anode	+5.75	100	2.5	1169
Gate	−5.75	75	5.0	583
Cathode	−50.0	100	5.0	579
Bottom	−1.5	75	5.0	565

Cryostats (inner, outer)

Astroparticle Physics 96 (2017) 1–10

Contents lists available at ScienceDirect

ELSEVIER

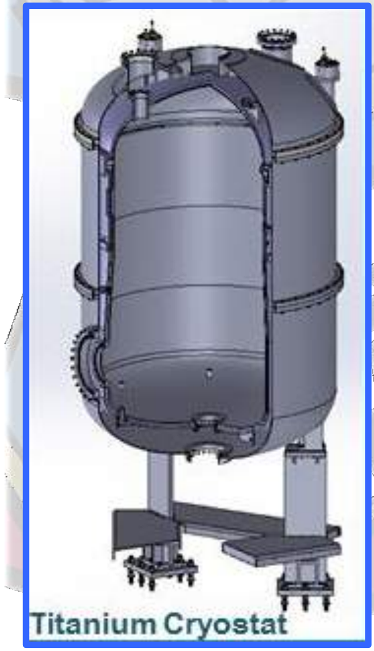
Astroparticle Physics

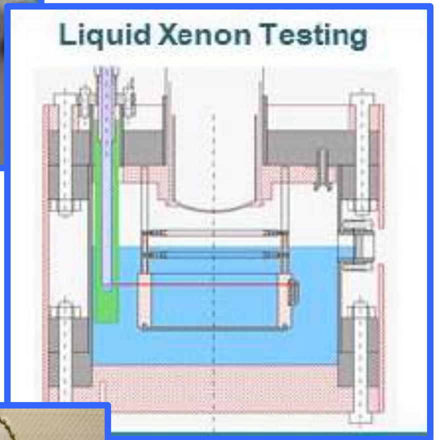
journal homepage: www.elsevier.com/locate/astropartphys

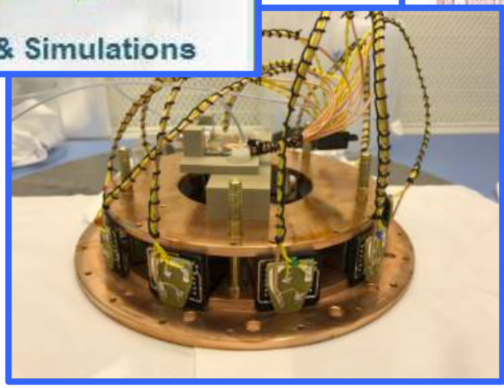
Identification of radiopure titanium for the LZ dark matter experiment and future rare event searches

CrossMark

LZ-UK status







All UK hardware contributions *complete*

ASSAY CAMPAIGN

MONTE CARLO SIMULATION

Known source event rates

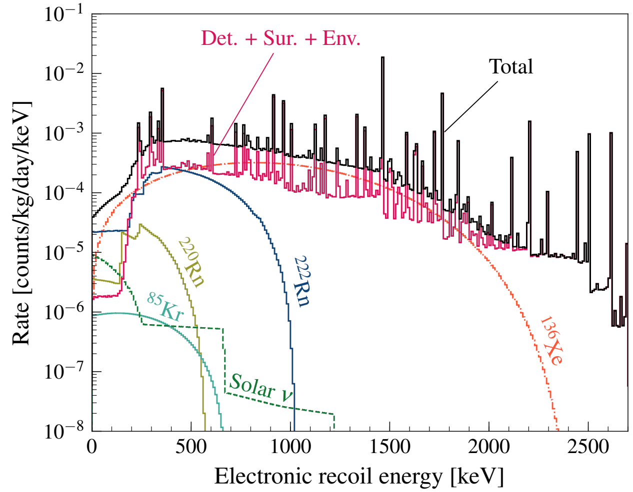
Assay campaign

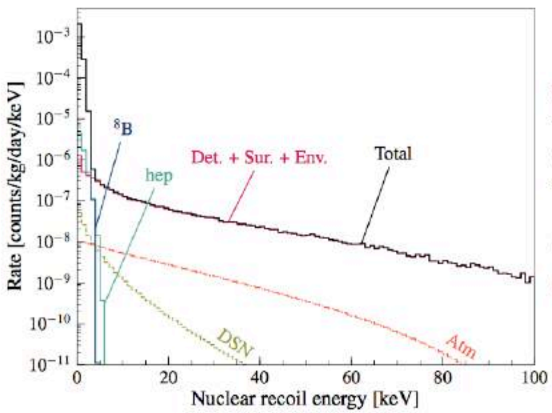
Technique	Isotopic Sensitivity	Typical Sensitivity	Sample Mass	Sampling Duration	Destructive/Non-destructive and Notes	Locations (and Number of Systems if > 1)	Samples Assayed
HPGe	^{238}U, ^{235}U, ^{232}Th chains, ^{40}K, ^{60}Co, ^{137}Cs any γ-ray emitter	5×10^{-11} g/g U, 10^{-10} g/g Th	kg	Up to 2 weeks	Non-destructive, very versatile, not as sensitive as other techniques, large samples	SURF $\times 6$, LBNL $\times 1$, U. Alabama $\times 2$, Boulby $\times 7$	926
ICP-MS	^{238}U, ^{235}U, ^{232}Th (top of chain)	10^{-12} g/g	mg to g	Days	Destructive, requires sample digestion, preparation critical	UCL, IBS, BHUC, U. Alabama	157
NAA	^{238}U, ^{235}U, ^{232}Th (top of chain), K	10^{-12} g/g to 10^{-14} g/g	g	Days to weeks	Destructive, useful for non-metals, minimal sample preparation	Irradiated at MITR-II, HPGe assay at U. Alabama	3
GD-MS	^{238}U, ^{235}U, ^{232}Th (top of chain)	10^{-10} g/g	mg to g	Days	Destructive, minimal matrix effects, cannot analyze ceramics and other insulators	National Research Council Canada	2
Radon Emanation	^{222}Rn	0.1 mBq	kg	1 to 3 weeks	Non-destructive, large samples, limited by size of emanation chamber	UCL $\times 2$, U. Maryland, SDSM&T $\times 2$, U. Alabama $\times 2$	175
Surface α	^{210}Pb, ^{210}Bi, ^{210}Po	120 $\alpha/(\mathrm{m}^2 \cdot$ day)	g to kg	<1 week	Non-destructive, thin samples, large surface area required	SDSM&T (Si), Brown (XIA), Boulby (XIA), U. Alabama (Si)	306

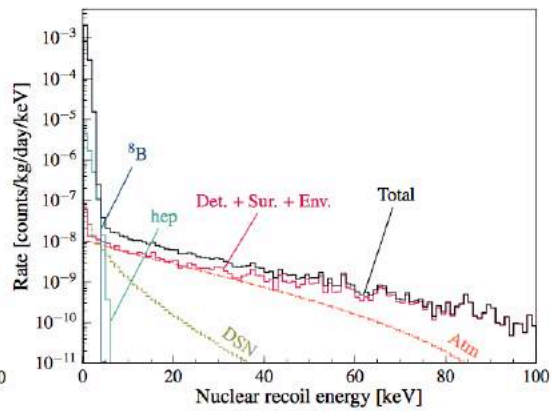
Sparing you the details!

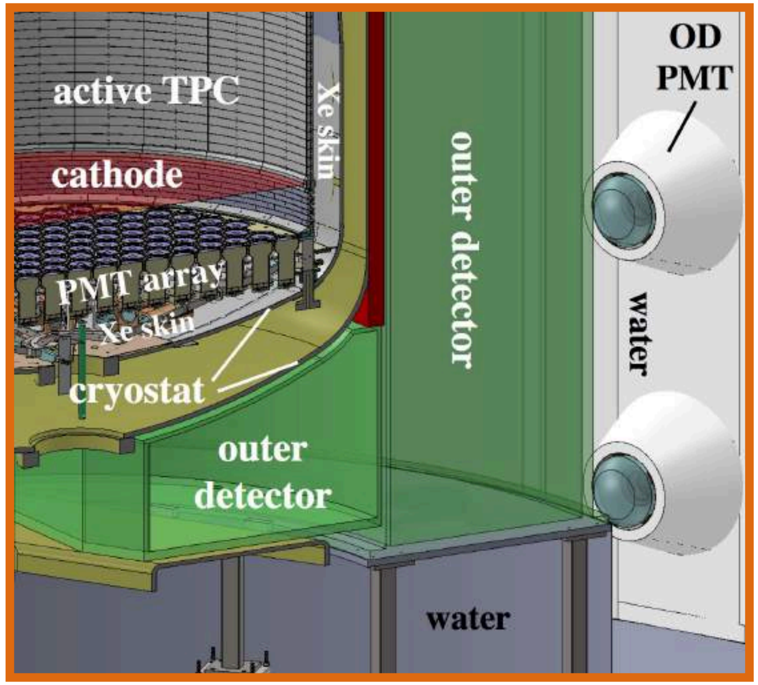
→ Complete understanding of ER and NR rates from known sources over the full relevant energy range

- Cosmics, external, internal, surfaces, β, γ, x, α, n, ν,…
- Includes f.v., LXe skin, OD, water veto
- Further details in *backup slides*









Backgrounds + Signal Model + PLR

Science Reach (Sensitivity)

What this means for WIMPs…

arXiv:1802.06039

039v1 [astro-ph.IM] 16 Feb 2018

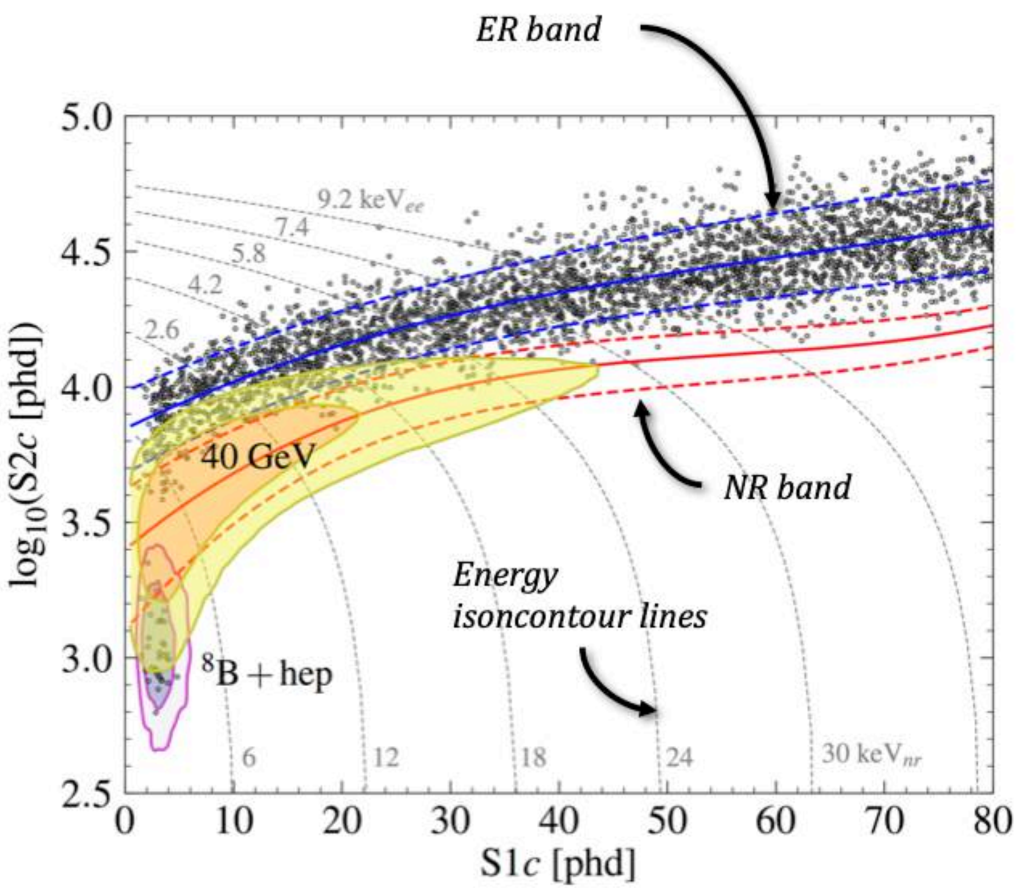
Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment

D.S. Akerib,[1,2] C.W. Akerlof,[3] S.K. Alsum,[4] H.M. Araújo,[5] M. Arthurs,[3] X. Bai,[6] A.J. Bailey,[5,a] J. Balajthy,[7] S. Balashov,[8] D. Bauer,[5] J. Belle,[9] P. Beltrame,[10] T. Benson,[4] E.P. Bernard,[11,12] T.P. Biesiadzinski,[1,2] K.E. Boast,[13] B. Boxer,[14] P. Brás,[15] J.H. Buckley,[16] V.V. Bugaev,[16] S. Burdin,[14] J.K. Busenitz,[17] C. Carels,[13] D.L. Carlsmith,[4] B. Carlson,[18] M.C. Carmona-Benitez,[19] C. Chan,[20] J.J. Cherwinka,[4] A. Cole,[12] A. Cottle,[9] W.W. Craddock,[1] A. Currie,[5,b] J.E. Cutter,[21] C.E. Dahl,[22,9] L. de Viveiros,[19] A. Dobi,[12,c] J.E.Y. Dobson,[23,d] E. Druszkiewicz,[24] T.K. Edberg,[7] W.R. Edwards,[12,e] A. Fan,[1,2] S. Fayer,[5] S. Fiorucci,[12] T. Fruth,[13] R.J. Gaitskell,[20] J. Genovesi,[6] C. Ghag,[23] M.G.D. Gilchriese,[12] M.G.D.van der Grinten,[8] C.R. Hall,[7] S. Hans,[25] K. Hanzel,[12] S.J. Haselschwardt,[26] S.A. Hertel,[27] S. Hillbrand,[21] C. Hjemfelt,[6] M.D. Hoff,[12] J.Y-K. Hor,[17] D.Q. Huang,[20] C.M. Ignarra,[1,2] W. Ji,[1,2] A.C. Kaboth,[28,8] K. Kamdin,[12,11] J. Keefner,[18] D. Khaitan,[24] A. Khazov,[8] Y.D. Kim,[29] C.D. Kocher,[20] E.V. Korolkova,[30] H. Kraus,[13] H.J. Krebs,[1] L. Kreczko,[31] B. Krikler,[31] V.A. Kudryavtsev,[30] S. Kyre,[26] J. Lee,[29] B.G. Lenardo,[21] D.S. Leonard,[29] K.T. Lesko,[12] C. Levy,[32] J. Li,[29] J. Liao,[20] F.-T. Liao,[13] J. Lin,[11,12] A. Lindote,[15] R. Linehan,[1,2] W.H. Lippincott,[9] X. Liu,[10] M.I. Lopes,[15] B. López Paredes,[5] W. Lorenzon,[3] S. Luitz,[1] J.M. Lyle,[20] P. Majewski,[8] A. Manalaysay,[21] R.L. Mannino,[33] C. Maupin,[18] D.N. McKinsey,[11,12] Y. Meng,[17] E.H. Miller,[6] J. Mock,[32,12,f] M.E. Monzani,[1,2,g] J.A. Morad,[21] E. Morrison,[6] B.J. Mount,[34] A.St.J. Murphy,[10] H.N. Nelson,[26] F. Neves,[15] J. Nikoleyczik,[4] K. O'Sullivan,[12,11,h] I. Olcina,[5] M.A. Olevitch,[16] K.C. Oliver-Mallory,[12,11] K.J. Palladino,[4] S.J. Patton,[12] E.K. Pease,[12] B. Penning,[35] A. Piepke,[17] S. Powell,[14] R.M. Preece,[8] K. Pushkin,[3] B.N. Ratcliff,[1] J. Reichenbacher,[6] C.A. Rhyne,[20] A. Richards,[5] J.P. Rodrigues,[15] R. Rosero,[25] P. Rossiter,[30] J.S. Saba,[12] M. Sarychev,[9] R.W. Schnee,[6] M. Schubnell,[3] P.R. Scovell,[13] S. Shaw,[26] T.A. Shutt,[1,2] J.J. Silk,[7] C. Silva,[15] K. Skarpaas,[1] W. Skulski,[24] M. Solmaz,[26] V.N. Solovov,[15] P. Sorensen,[12] I. Stancu,[17] M.R. Stark,[6] T.M. Stiegler,[33] K. Stifter,[1,2] M. Szydagis,[32] W.C. Taylor,[20] R. Taylor,[5] D.J. Taylor,[18] D. Temples,[22] P.A. Terman,[33] K.J. Thomas,[12,i] M. Timalsina,[6] W.H. To,[1,2] A. Tomás,[5] T.E. Tope,[9] M. Tripathi,[21] C.E. Tull,[12] L. Tvrznikova,[36,11,12] U. Utku,[23] J. Va'vra,[1] A. Vacheret,[5] J.R. Verbus,[20,j] E. Voirin,[9] W.L. Waldron,[12] J.R. Watson,[11,12] R.C. Webb,[33] D.T. White,[26] T.J. Whitis,[1,37] W.J. Wisniewski,[1] M.S. Witherell,[12,11] F.L.H. Wolfs,[24] D. Woodward,[30,k] S.D. Worm,[8,l] M. Yeh,[25] J. Yin,[24] and I. Young[9]

(The LUX-ZEPLIN Collaboration)

[1] *SLAC National Accelerator Laboratory, Menlo Park, CA 94025-7015, USA*
[2] *Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Stanford, CA 94305-4085 USA*
[3] *University of Michigan, Randall Laboratory of Physics, Ann Arbor, MI 48109-1040, USA*
[4] *University of Wisconsin-Madison, Department of Physics, Madison, WI 53706-1390, USA*
[5] *Imperial College London, Physics Department, Blackett Laboratory, London SW7 2AZ, UK*
[6] *South Dakota School of Mines and Technology, Rapid City, SD 57701-3901, USA*
[7] *University of Maryland, Department of Physics, College Park, MD 20742-4111, USA*

Full simulation of event rates



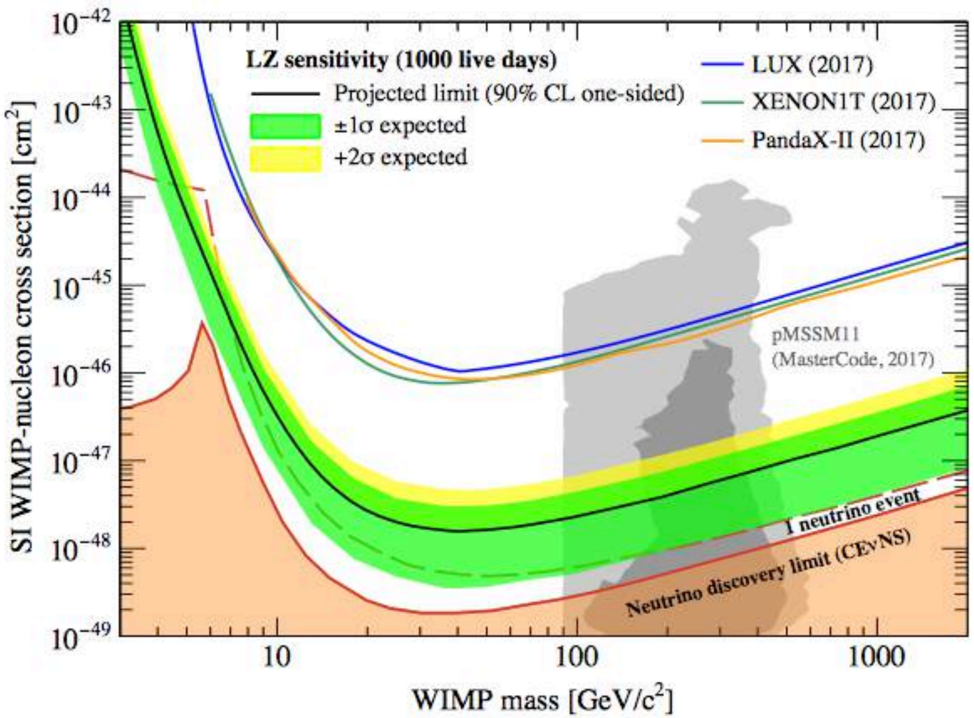
Simulated dataset inside the fiducial volume for the full LZ exposure (1000 days × 5600 kg)

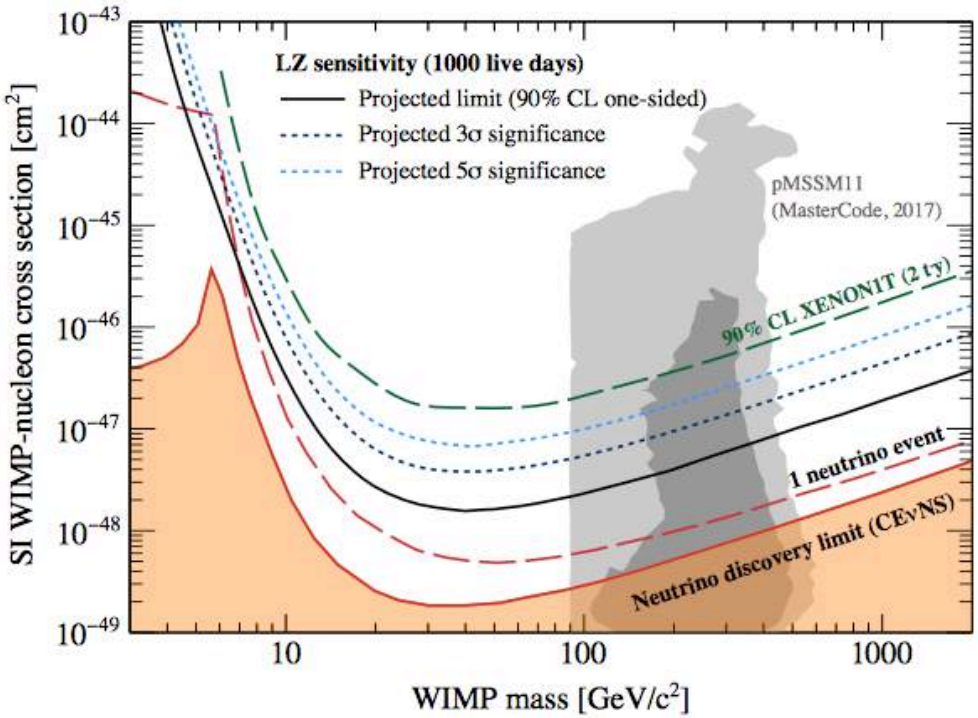
ER: electron recoil
NR: neutron recoil

- ER and NR events discriminated from their different S2/S1 proportion
- ER and NR bands obtained through calibration
- Many γ and n events occur close to the TPC wall
  - ➢ Veto them: Xe skin and OD
  - ➢ Define a fiducial region: 5.6 t for the WIMP search
- ○ PLR analysis
- ○ Blinding via salt

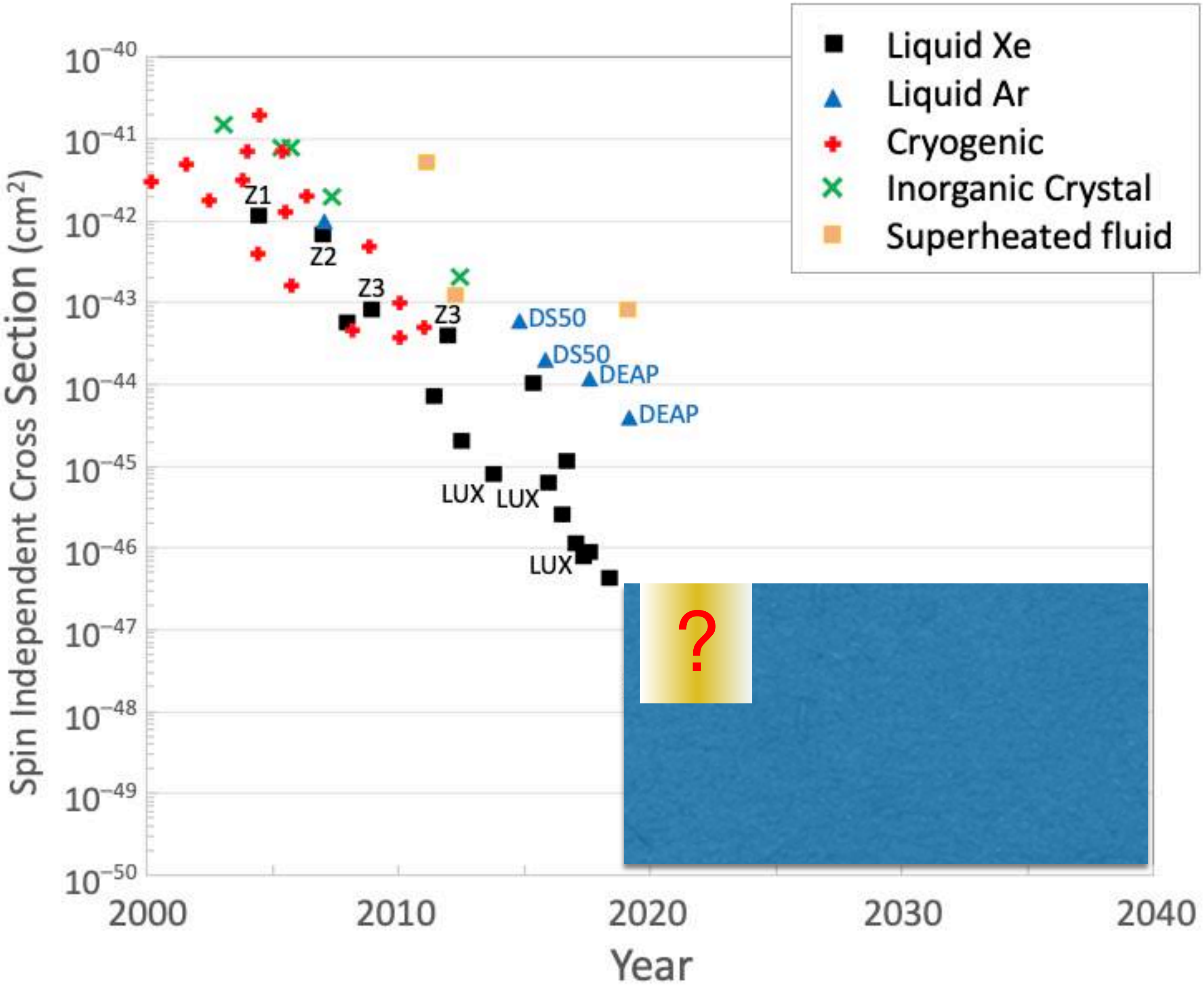
WIMP SI Sensitivity

https://arxiv.org/pdf/1802.06039.pdf

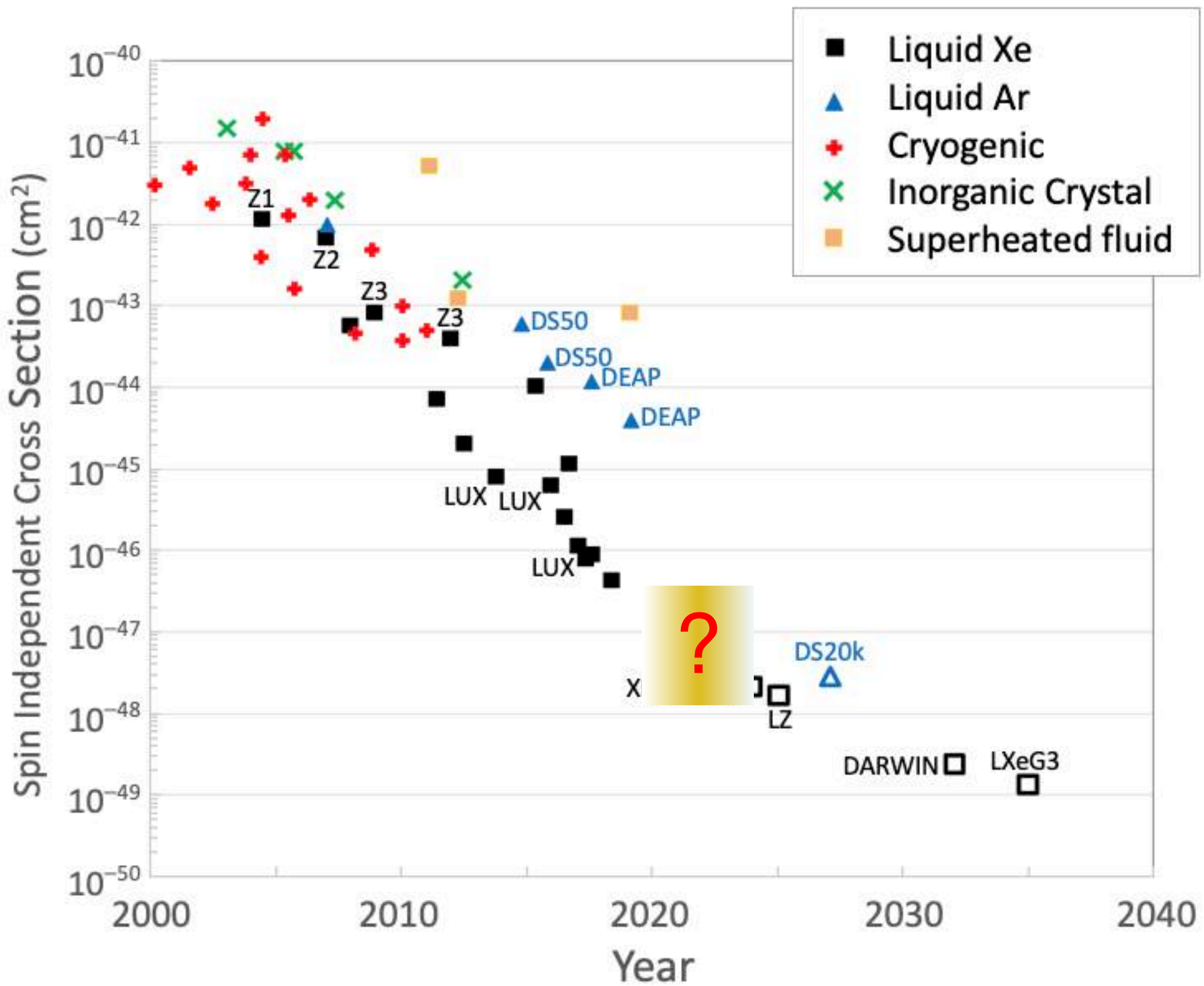




- Expected limits on spin-independent cross-sections for 1000 days of live time (left) and discovery potential (right).



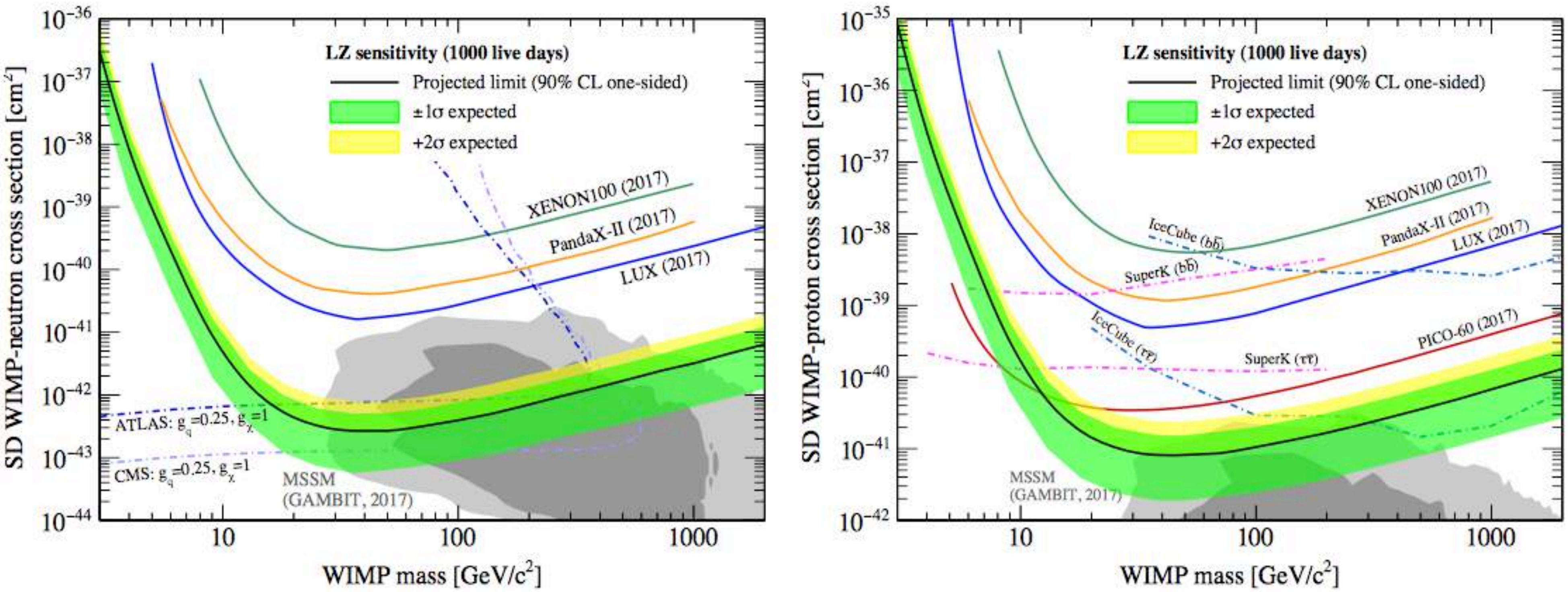
Liquid Xe
Liquid Ar
Cryogenic
Inorganic Crystal
Superheated fluid
Spin Independent Cross Section (cm²)
10⁻⁴⁰
10⁻⁴¹
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10⁻⁴⁵
10⁻⁴⁶
10⁻⁴⁷
10⁻⁴⁸
10⁻⁴⁹
10⁻⁵⁰
Z1
Z2
Z3
Z3
DS50
DS50
DEAP
DEAP
LUX
LUX
LUX
?
2000
2010
2020
2030
2040
Year



Spin Independent Cross Section (cm²)
Year
Liquid Xe
Liquid Ar
Cryogenic
Inorganic Crystal
Superheated fluid
Z1
Z2
Z3
Z3
DS50
DS50
DEAP
DEAP
LUX
LUX
LUX
X
?
LZ
DS20k
DARWIN
LXeG3

More Science

SD interactions, axions, axion-like particles (ALPs), sub-GeV dark matter, leptophillic axial vector DM, astrophysical neutrinos, $0\nu\beta\beta$'s, EFT analyses...



SD WIMP-neutron (left) and WIMP-proton (right) scattering for a 1000 live day run with a 5.6 tonne fiducial mass.

https://arxiv.org/pdf/1802.06039.pdf

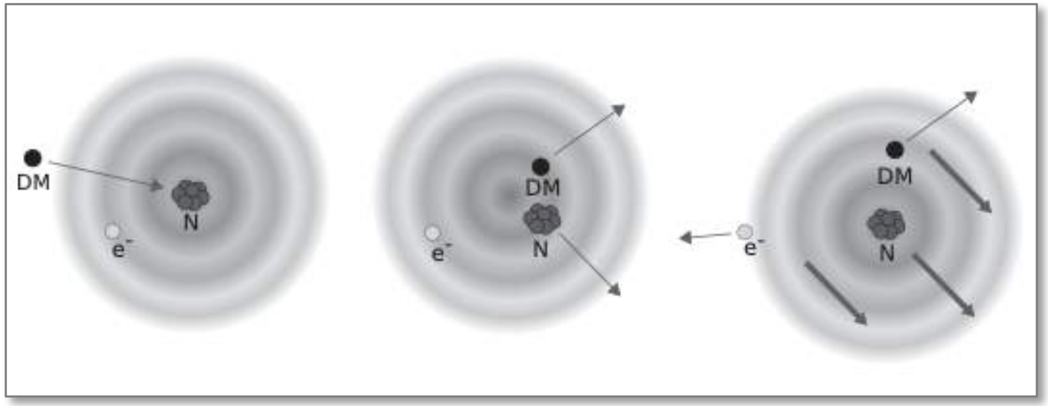
More Science

SD interactions, axions, axion-like particles (ALPs), **sub-GeV dark matter**, leptophillic axial vector DM, astrophysical neutrinos, $0\nu\beta\beta$'s, EFT analyses...

Migdal effect

Matthew J. Dolan, Felix Kahlhoefer, and Christopher McCabe
Phys. Rev. Lett. **121**, 101801

- χ-n scatter leads to *additional* ER signal
- ER quenching is << NR quenching
- Even if NR signal is below threshold, ER may still be visible
- Extends low mass sensitivity
- *Note: The reality of the Migdal effect is yet to be confirmed!*

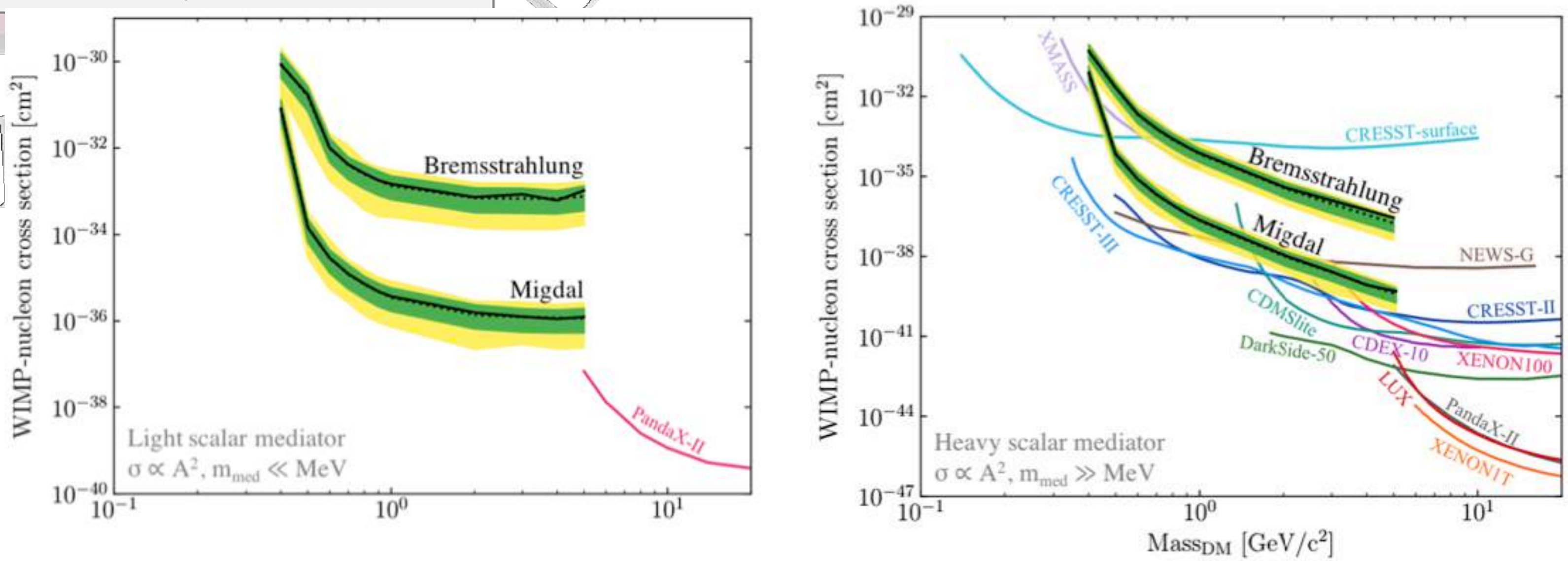


More Science

SD interactions, axions, axion-like particles (ALPs), **sub-GeV dark matter**, leptophillic axial vector DM, astrophysical neutrinos, $0\nu\beta\beta$'s, EFT analyses...

Migdal effect

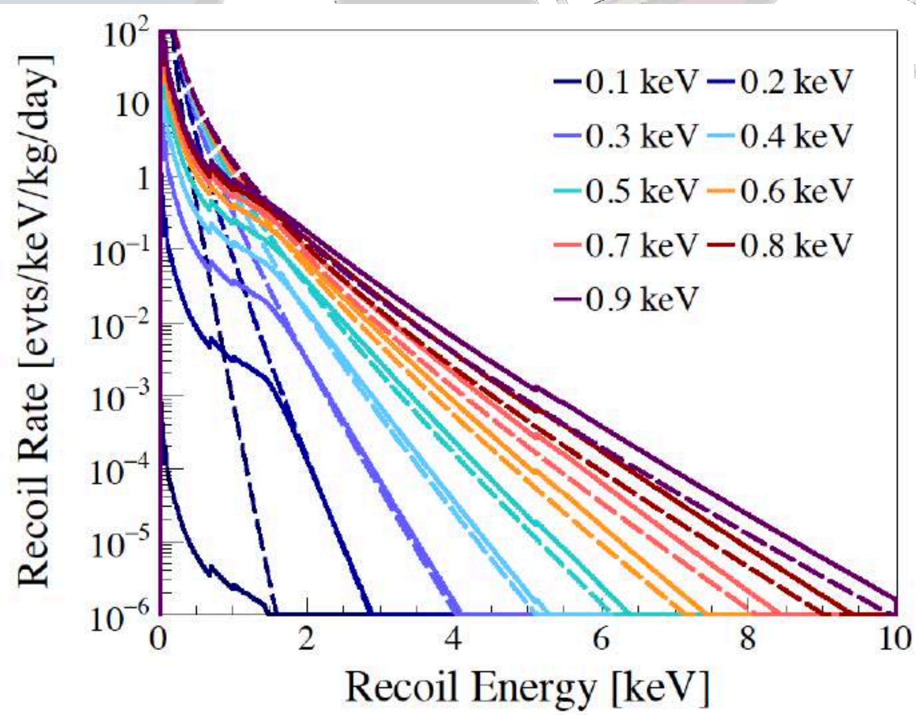
D. S. Akerib *et al.* (LUX Collaboration) Phys. Rev. Lett. **122**, 131301

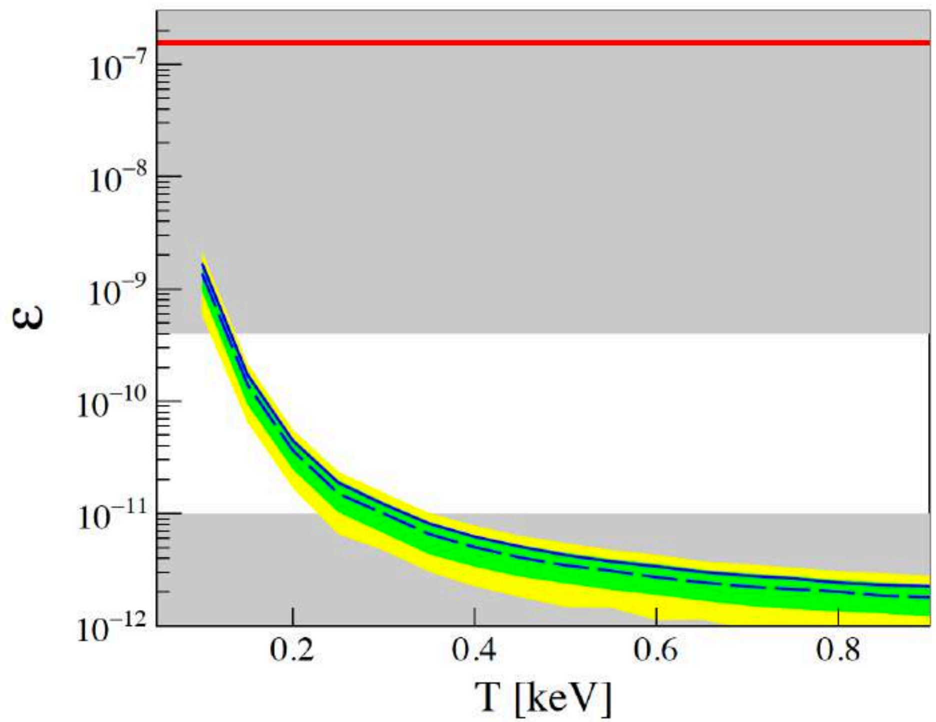


More Science

SD interactions, axions, axion-like particles (ALPs), sub-GeV dark matter, **Mirror dark matter**

- Submitted PRD -

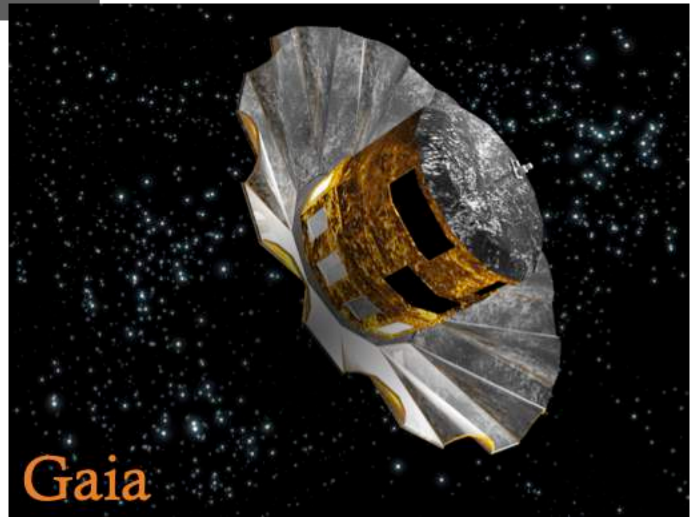


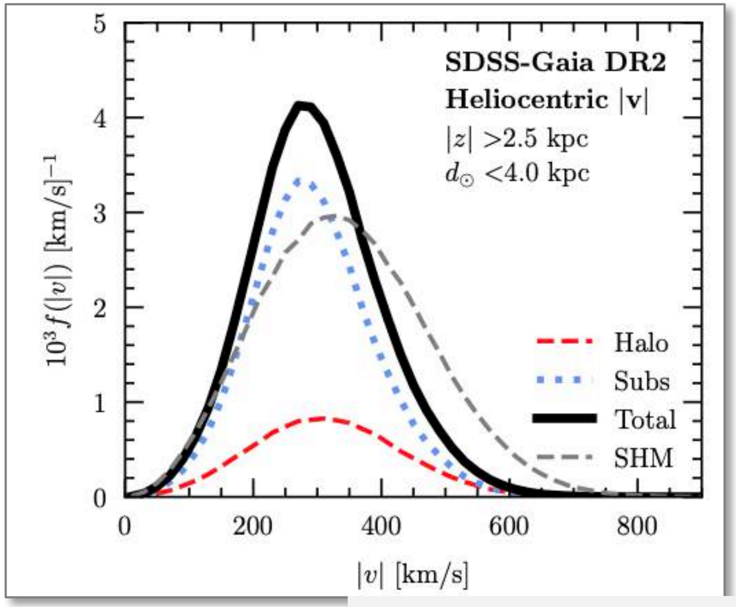


In the context of this meeting…

Updating the SHM

What is the impact on direct detection (with LZ)?





Necib et al. ApJ 874 (2019)

Looking ***beyond*** LZ…

XENON FUTURES:

R&D FOR A GLOBAL RARE EVENT OBSERVATORY

“Generation 3” dark matter

A ~50 ton LXe rare event observatory

- Expect to be operating by ~2030
- Broad science remit

Requires R&D ***now.*** UK Objectives:

- Direct observation of Migdal effect
- Enhanced liquid xenon technology & readout
- Cryogenic low background electronics
- Advanced radiopurity control techniques
- Design studies for a G3 experiment

‘Phase 1’ (18mo) just approved by STFC
‘Phase 2’ (24 mo) under evaluation.

In parallel…

STFC Opportunities Call 2019

Lead: Tim Sumner, Imperial College

Feasibility Study for Developing the Boulby Underground Laboratory into a Facility for Future Major International Projects

- Typical experiment requirements and expectations of facility support
- Use cases for 50-500 tonnes liquid targets for Dark Matter and 1000kg solid targets for 0vBB derived from existing experiments/proposals
- Consultation with wider community
- Recommendation for future developments with timescales and costs

To summarise…

Great Progress

To summarise…

Great Progress
Still lots to do

To summarise…

Great Progress
Still lots to do
Roll on 2020!

The LUX-ZEPLIN Collaboration

- Black Hills State University
- Brandeis University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics, Korea
- Fermi National Accelerator Laboratory
- Imperial College London
- LIP Coimbra, Portugal
- Lawrence Berkley National Laboratory
- Lawrence Livermore National Laboratory
- MEPhI-Moscow, Russia
- Northwestern University
- Pennsylvania State University
- Royal Holloway, University of London
- SLAC National Accelerator Laboratory
- South Dakota School of Mines and Technology
- South Dakota Science and Technology Authority
- STFC Rutherford Appleton Laboratory
- Texas A&M University
- University at Albany, SUNY
- University College London
- University of Alabama
- University of Bristol
- University of California, Berkeley
- University of California, Davis

- University of California, Santa Barbara
- University of Edinburgh
- University of Liverpool
- University of Maryland
- University of Michigan
- University of Massachusetts
- University of Oxford
- University of Rochester
- University of Sheffield
- University of South Dakota
- University of Wisconsin – Madison
- Washington University in St. Louis
- Yale University