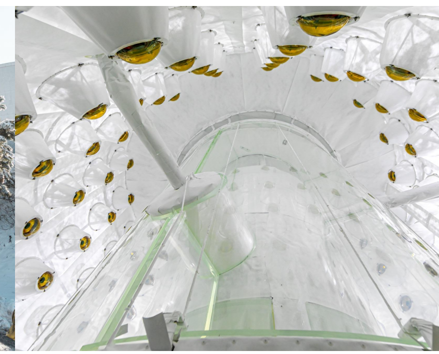
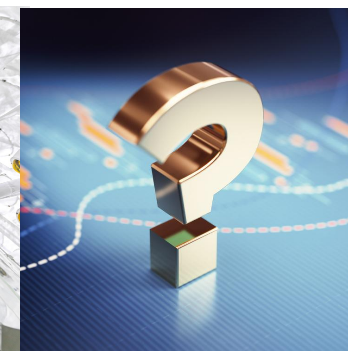
Status of the LUX-ZEPLIN Dark Matter Experiment



Blois2022

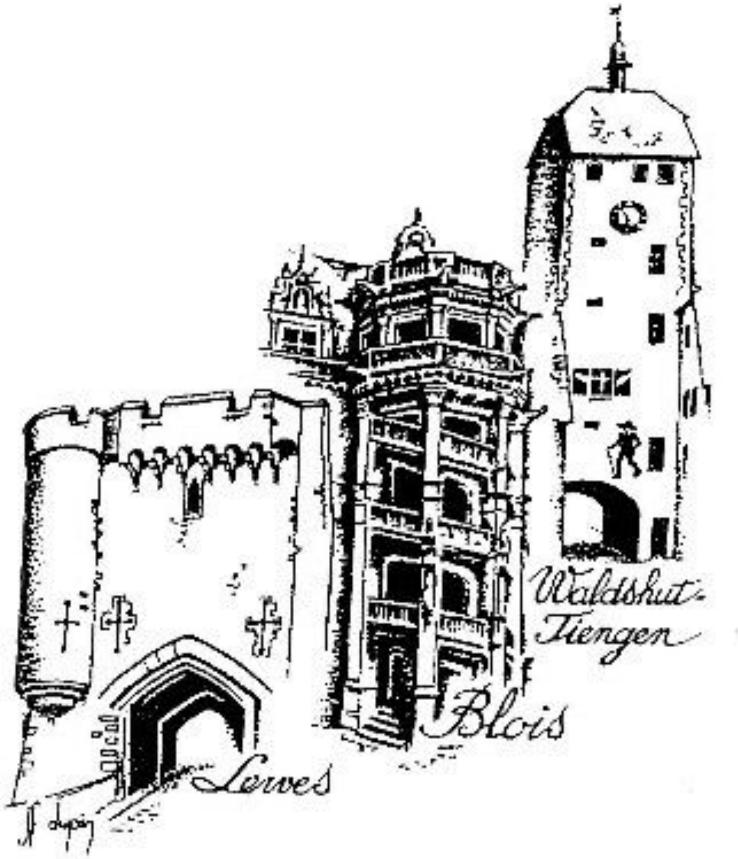
Jim Dobson* for the LZ Collaboration

* STFC Ernest Rutherford Fellow, University College London

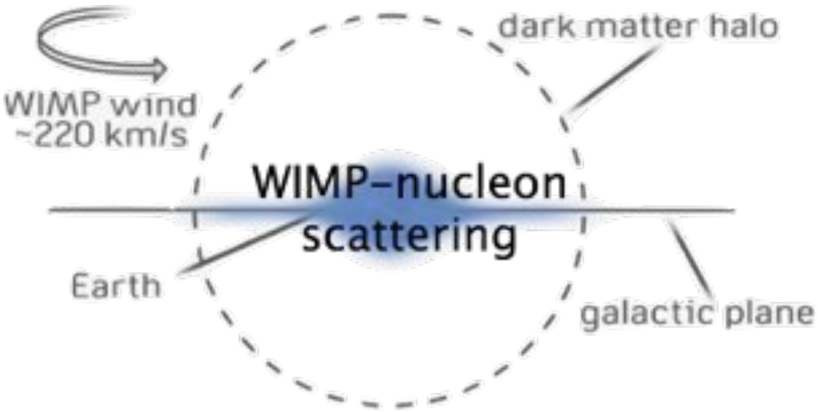
Greetings Blois, from your twin Lewes!

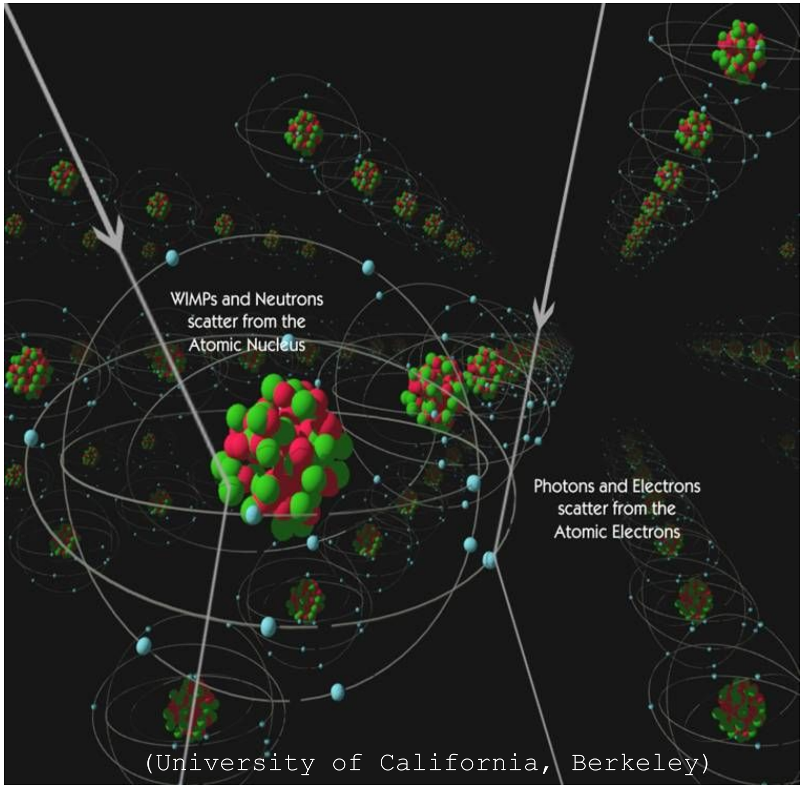
View of Lewes castle, South Coast of England

Outside my front door :-)



Direct detection of Dark Matter



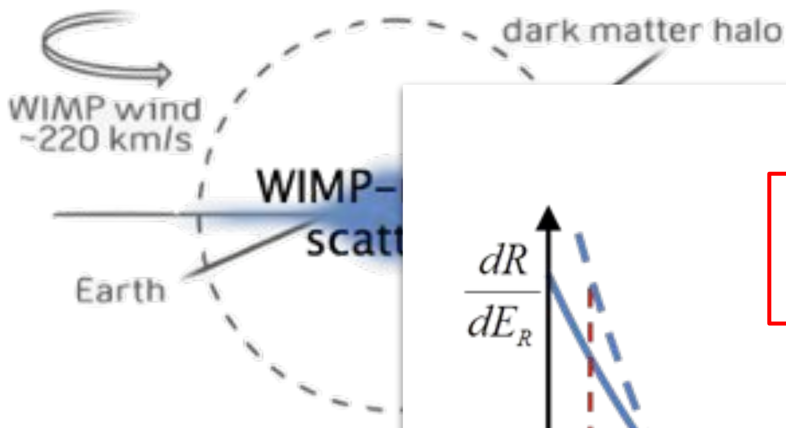


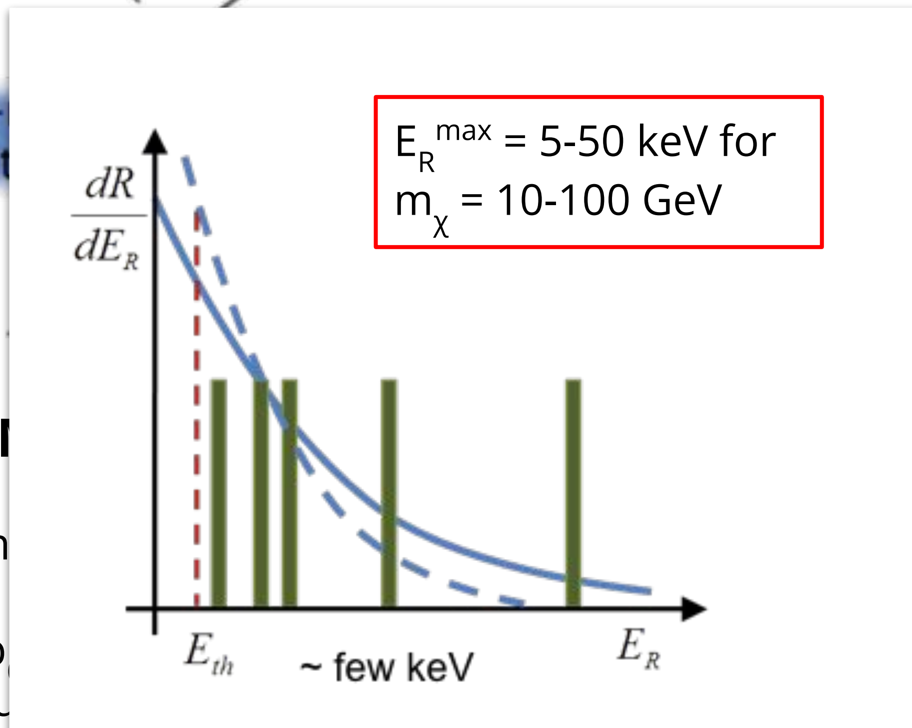
(University of California, Berkeley)

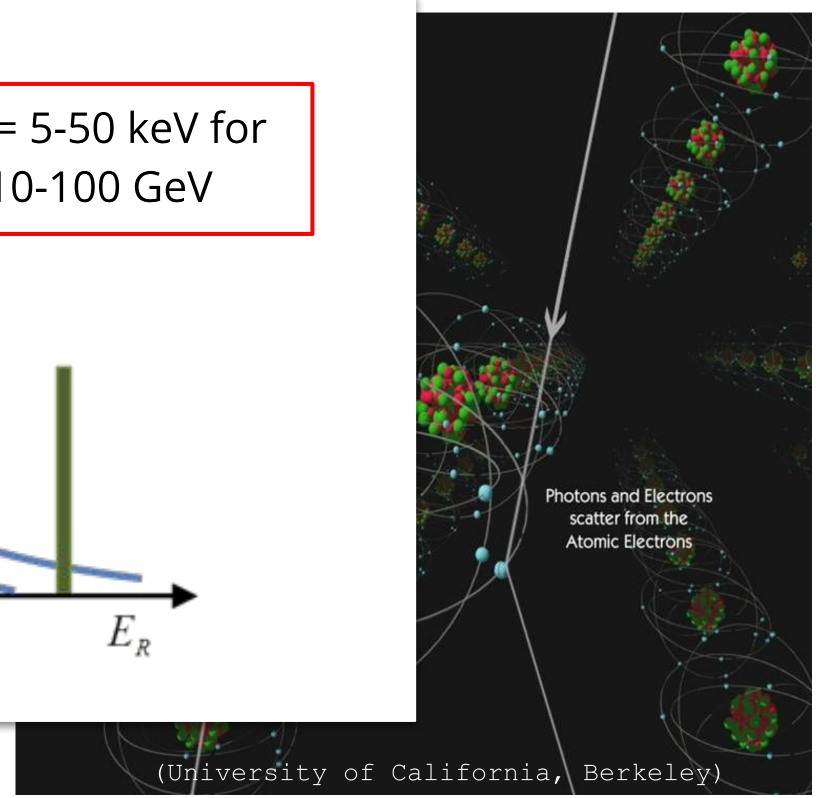
Standard Halo Model

- Isothermal sphere of DM, $\rho \propto r^{-2}$
- Local density ρ_0 ~ 0.3 GeV/cm3
- Maxwellian (truncated) velocity distribution, f(v)
- Characteristic velocity v_0=220 km/s → non-relativistic!

Direct detection of Dark Matter







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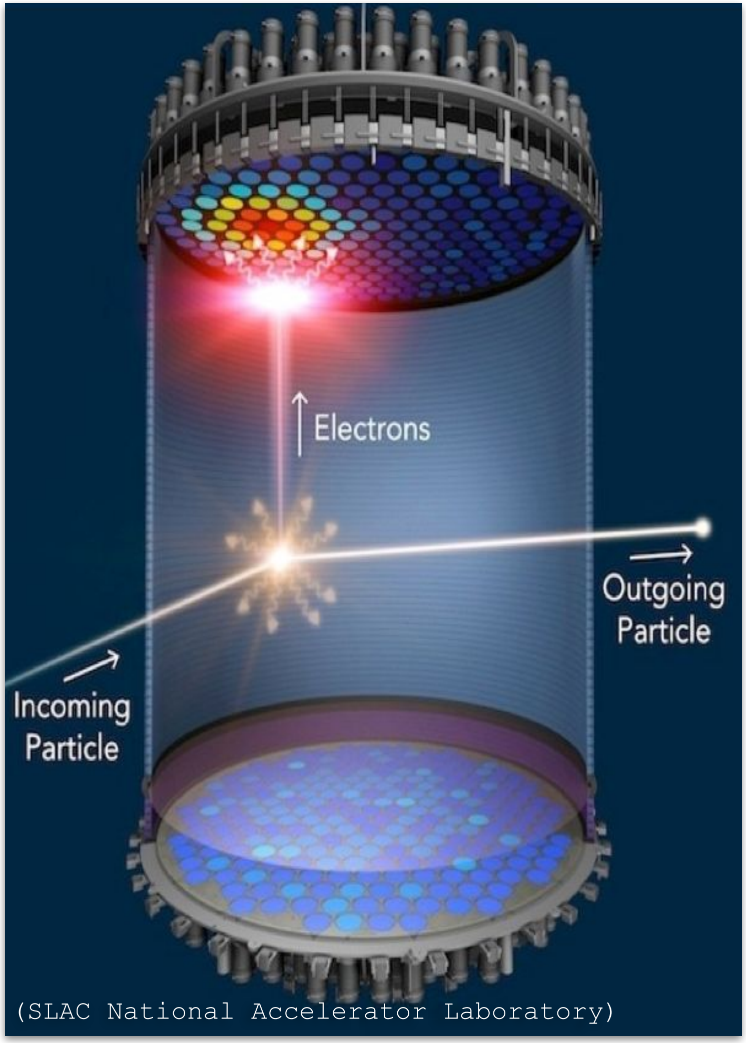
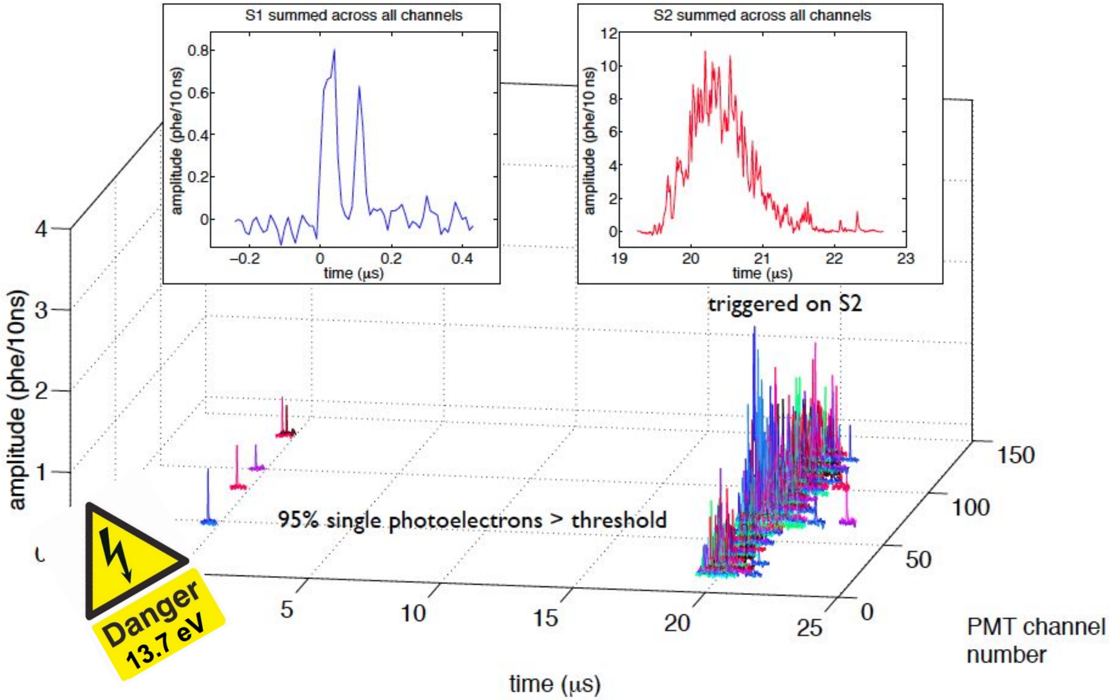
Liquid Xenon Time Projection Chambers





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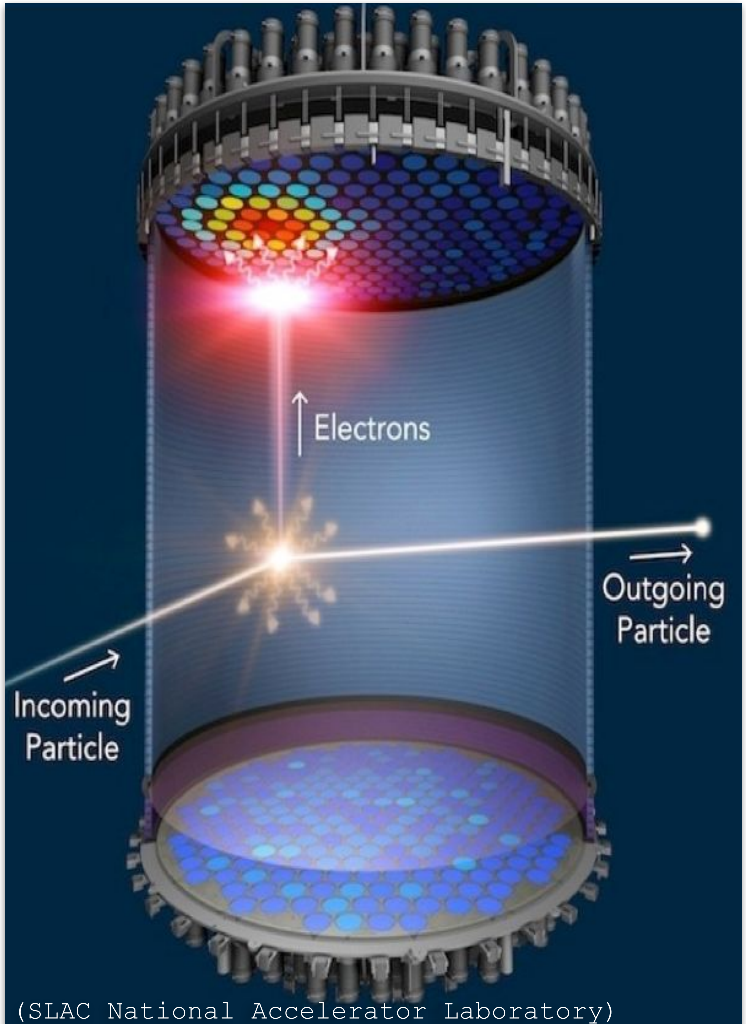
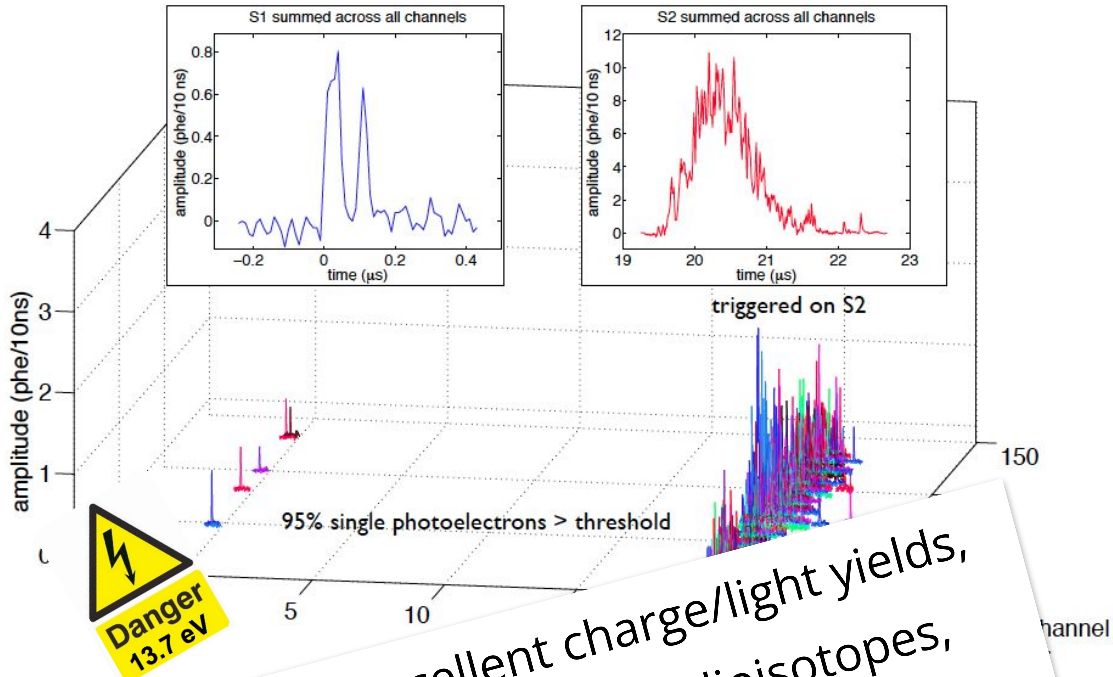


(SLAC National Accelerator Laboratory)



Key features: excellent charge/light yields, $\sigma \propto A^2$, lack of long-lived radioisotopes, fiducialisation →highly scalable.

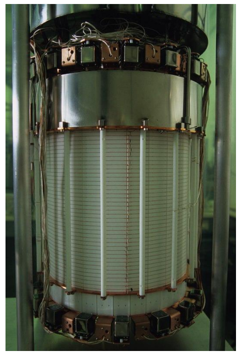
Leading technology above a ~few GeV

ZEPLIN-III

12 kg (7 kg)

2008

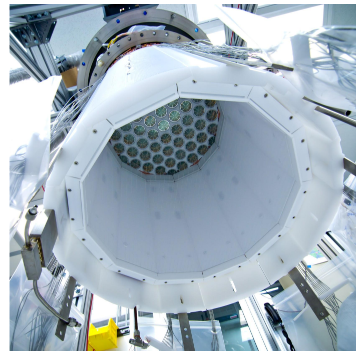
XENON100



62 kg (34 kg)

2013

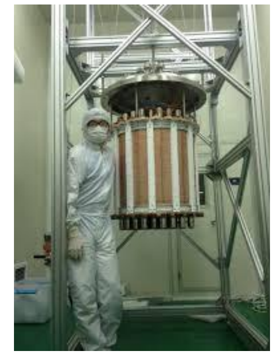
LUX



250 kg (100 kg)

2016

PANDAX-II



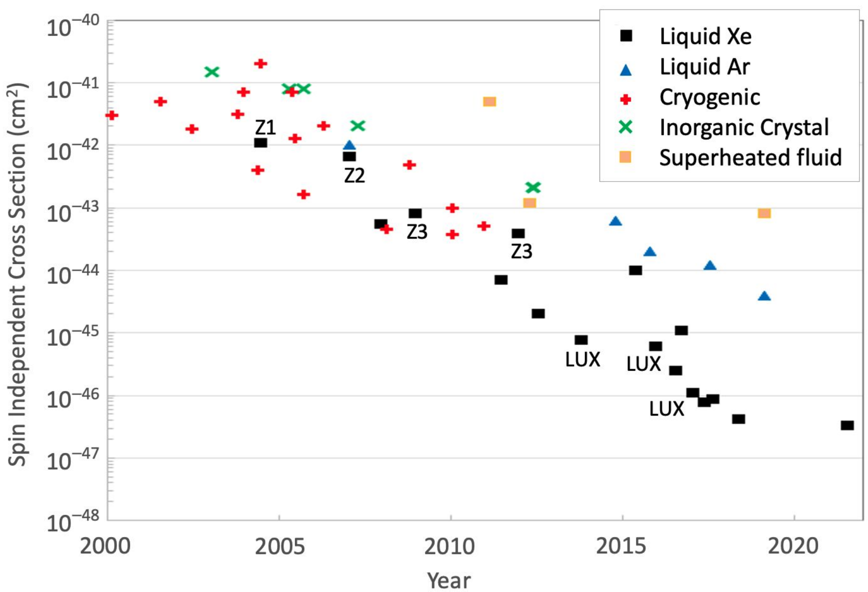
580 kg (362 kg)

2017

XENON1T

2,000 kg (1,042 kg)

2018



Jim Dobson – Blois2022

LUX-ZEPLIN

7,000 kg (5,600 kg)

2022-25

Also XENON-NT & PandaX-4T

Leading technology above a ~few GeV

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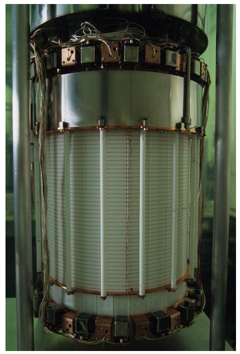

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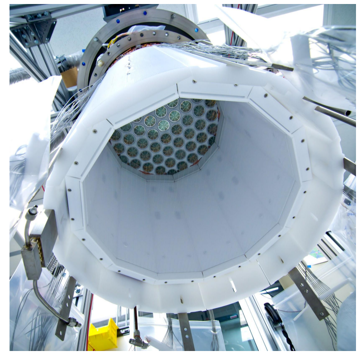

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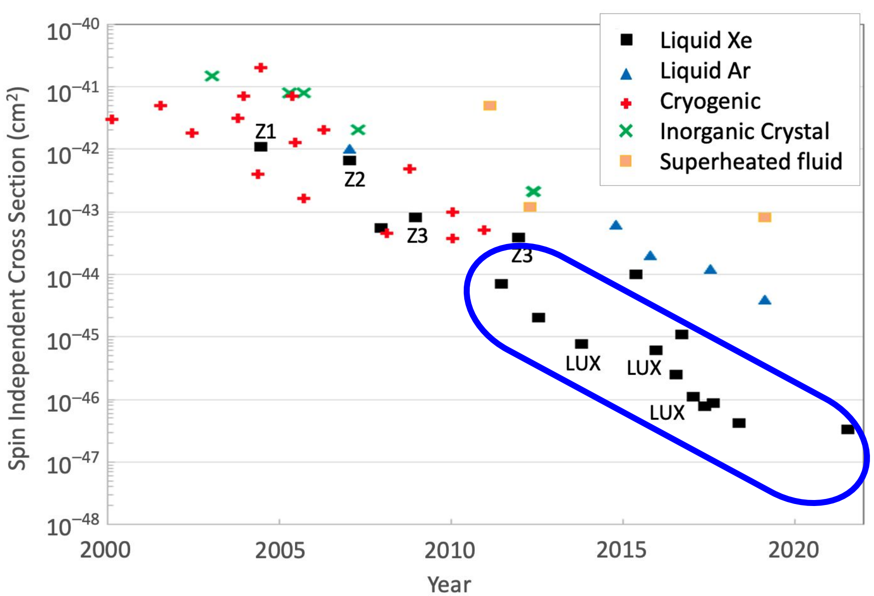


Jim Dobson – Blois2022

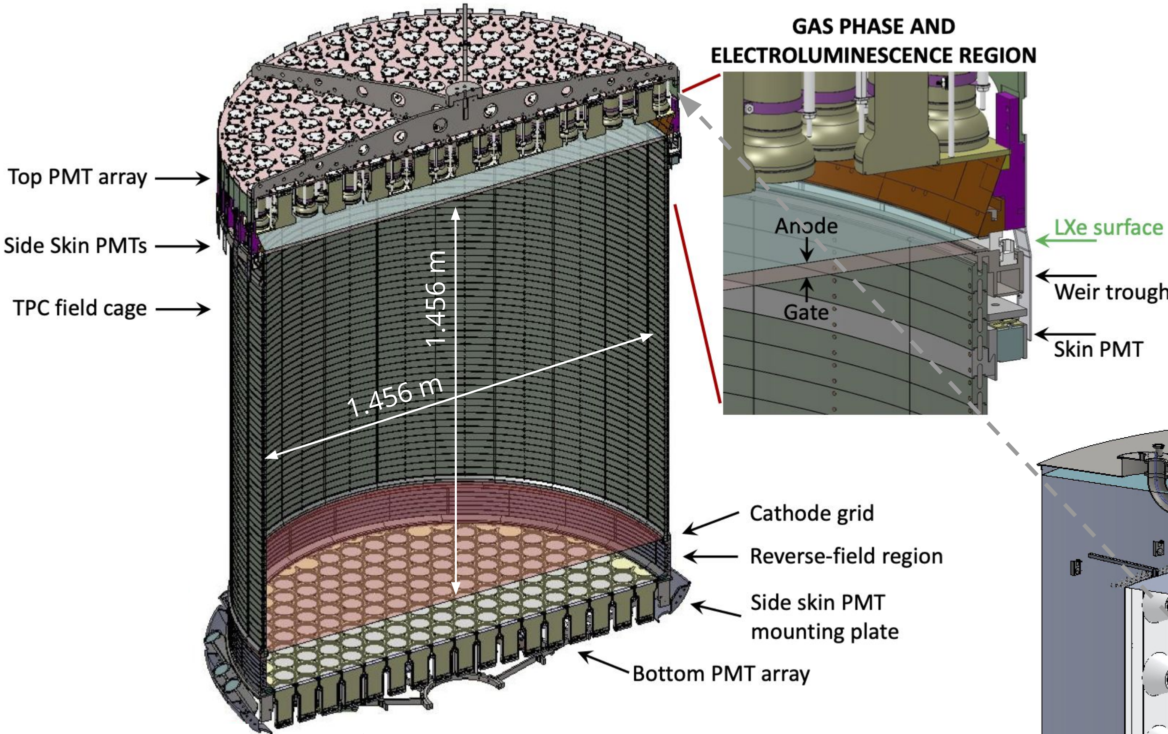
LUX-ZEPLIN

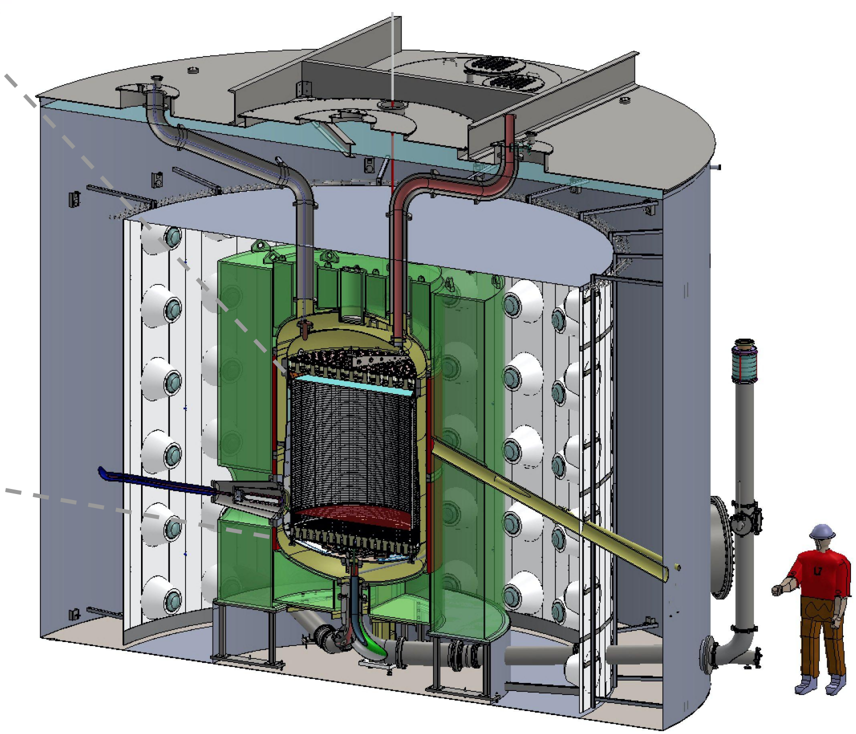
7,000 kg (5,600 kg)

2022-25

Also XENON-NT & PandaX-4T

The LUX-ZEPLIN Detector



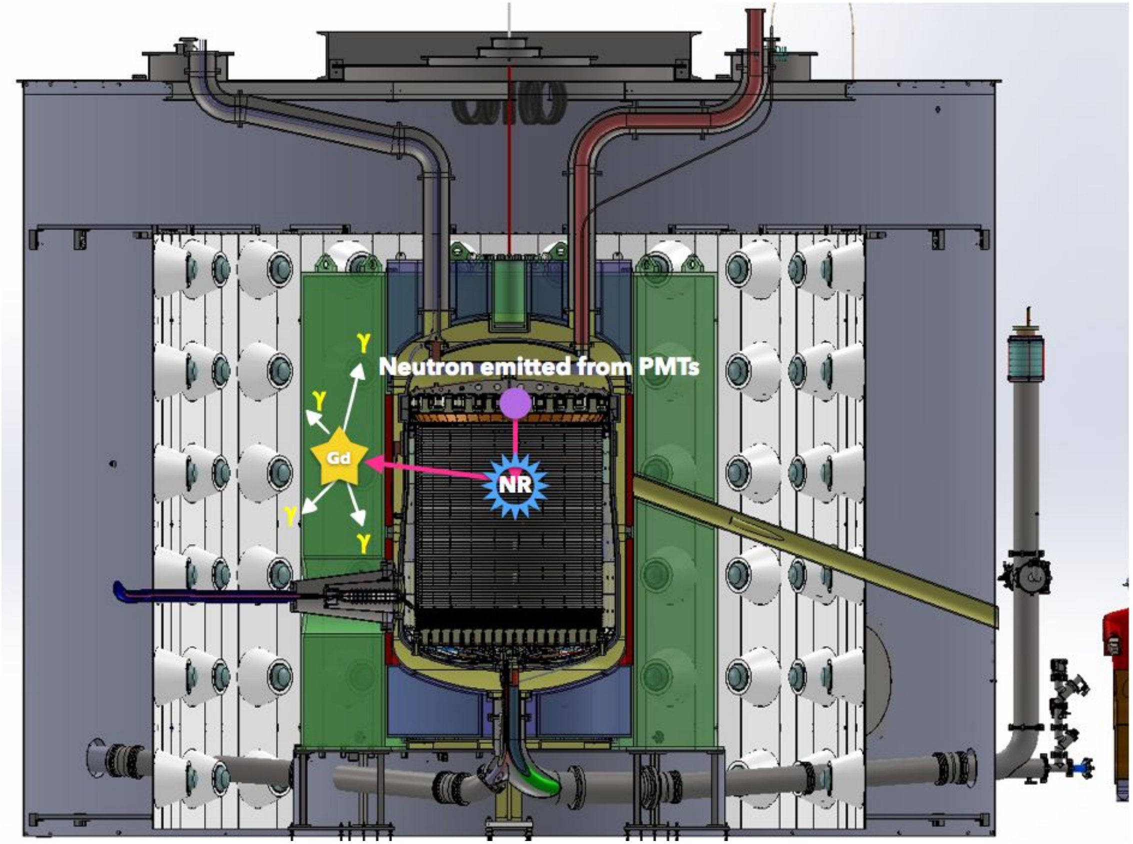


TPC key stats:

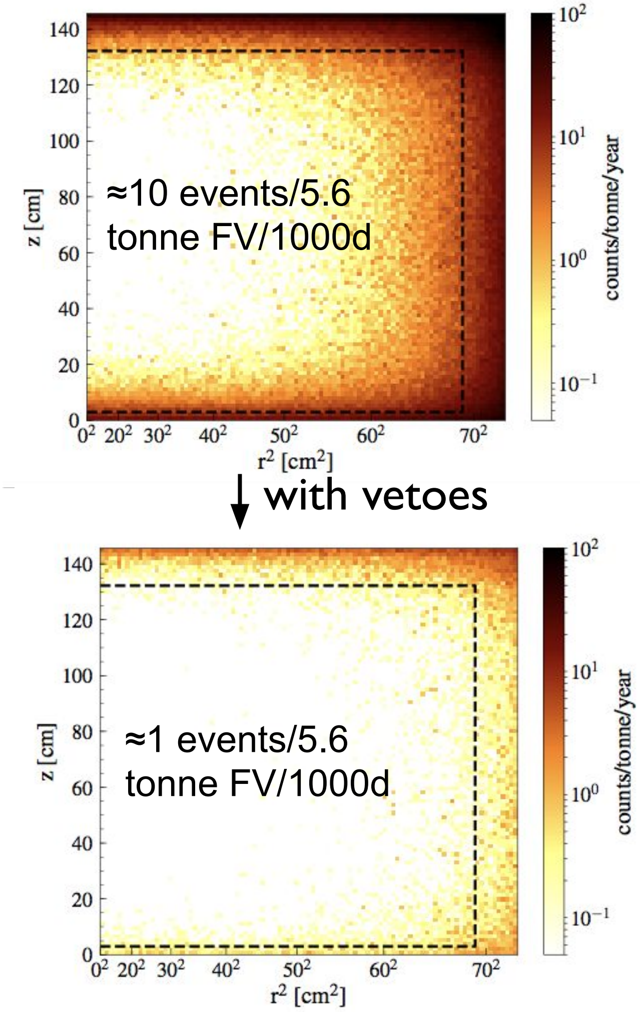
- 1.456 m between cathode and gate grid
- 7 tonne active region
- 494 Hamamatsu R11410-22 3” PMTs
- High reflectivity PTFE for light collection

Active veto system

- Optically separated Xe skin layer
- Gd-doped LS Outer Detector
- BG reduction & in-situ characterisation

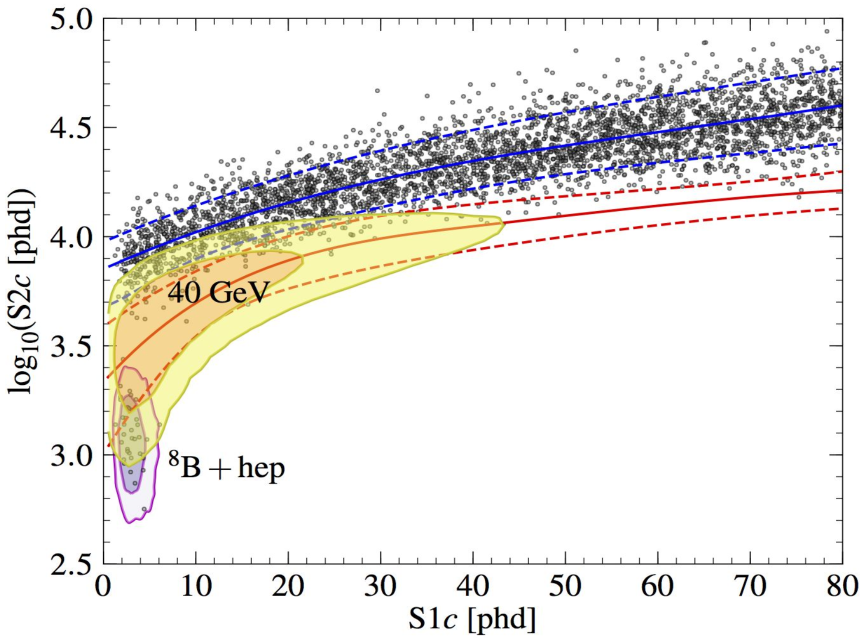


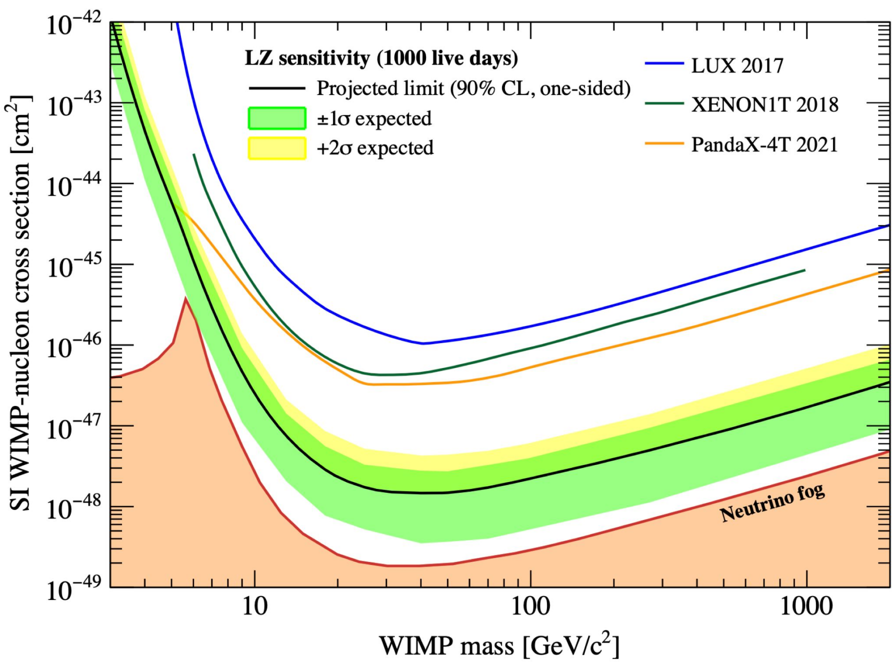
6-30 keV nuclear recoils



WIMP Sensitivity full exposure

1000 live-days with 5.6 tonne fiducial volume





PhysRevD.101.052002

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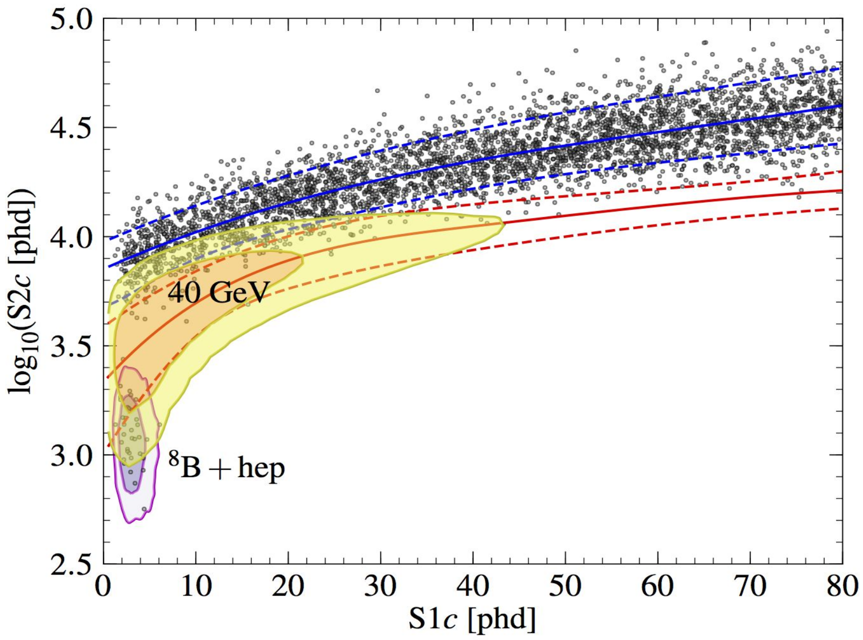
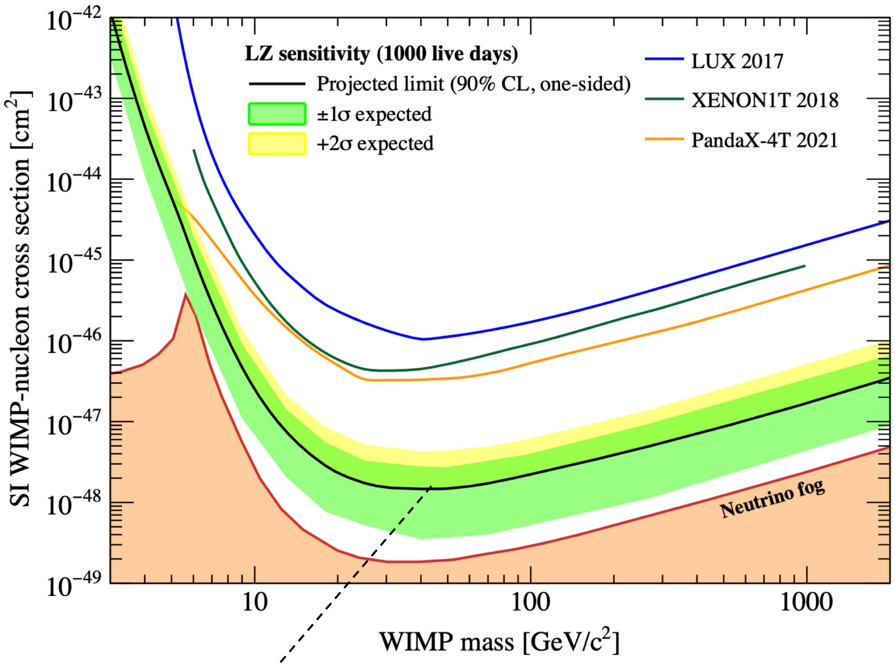


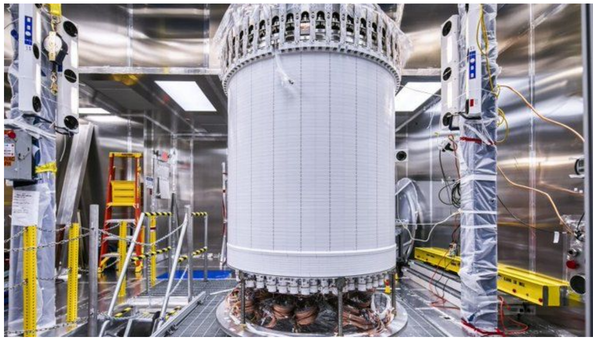


PhysRevD.101.052002

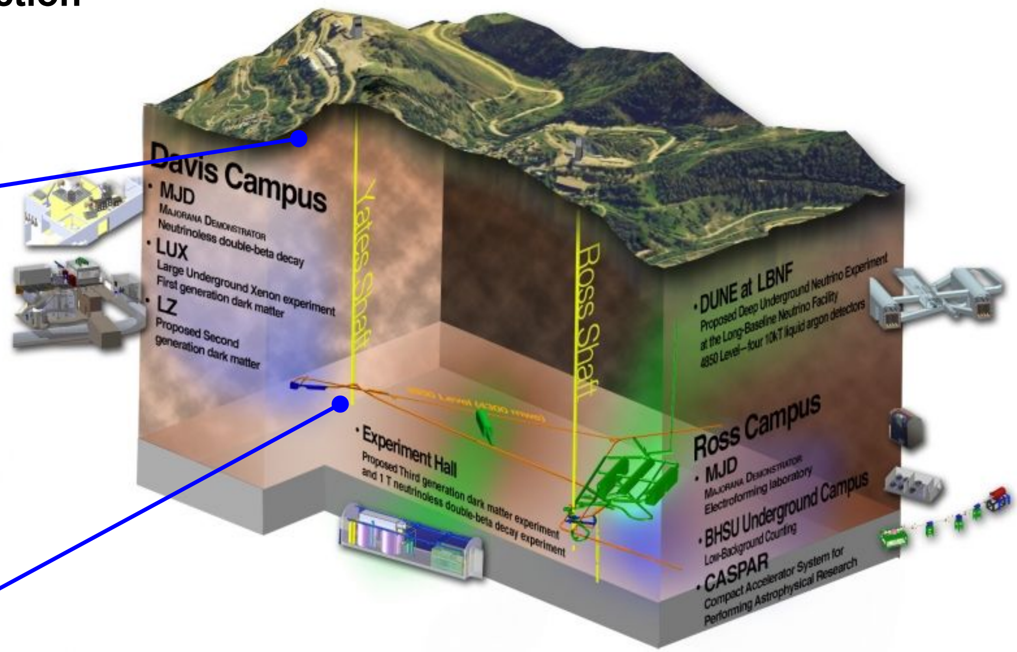
Median UL 90% CL: 1.4×10^{-48} cm^2 @ 40 GeV

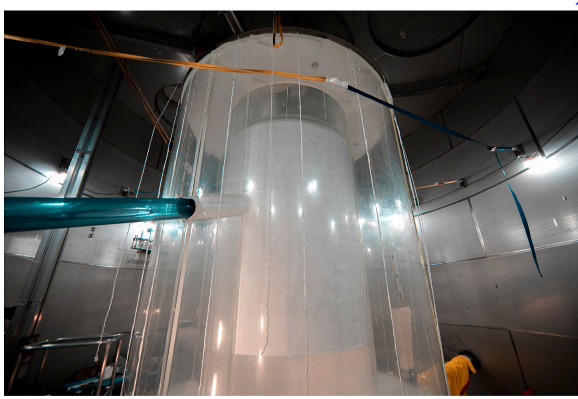
Backgrounds, backgrounds, backgrounds

1) Ultra-radio pure materials and construction



2) Take 1 mile underground





3) Run until background limited

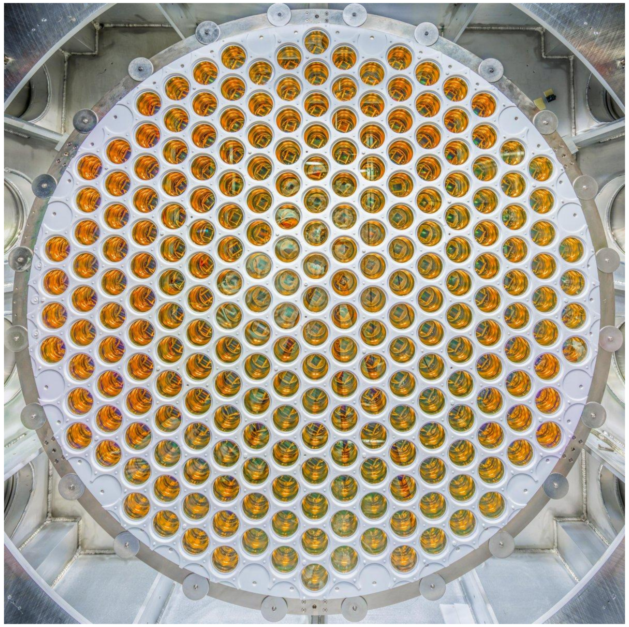
Radiopurity is key:

- ➔ Xe purification with chromatography
- ➔ Extensive radioassay campaign > 1000 assays
- ➔ Strict cleanliness controls

See Eur.Phys.J.C 80 (2020) 11

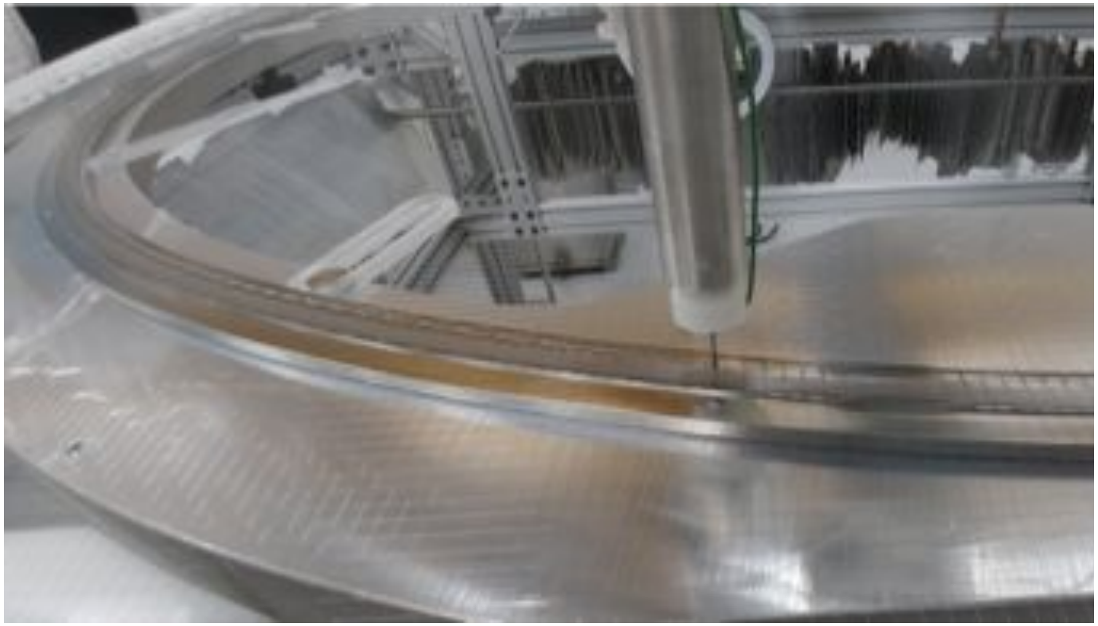
LUX-ZEPLIN Construction - a few highlights

2018



Bottom PMT array after assembly at Brown University

2019



HV grids production at SLAC, see Nucl.Instrum.Meth.A 1031 (2022) 165955

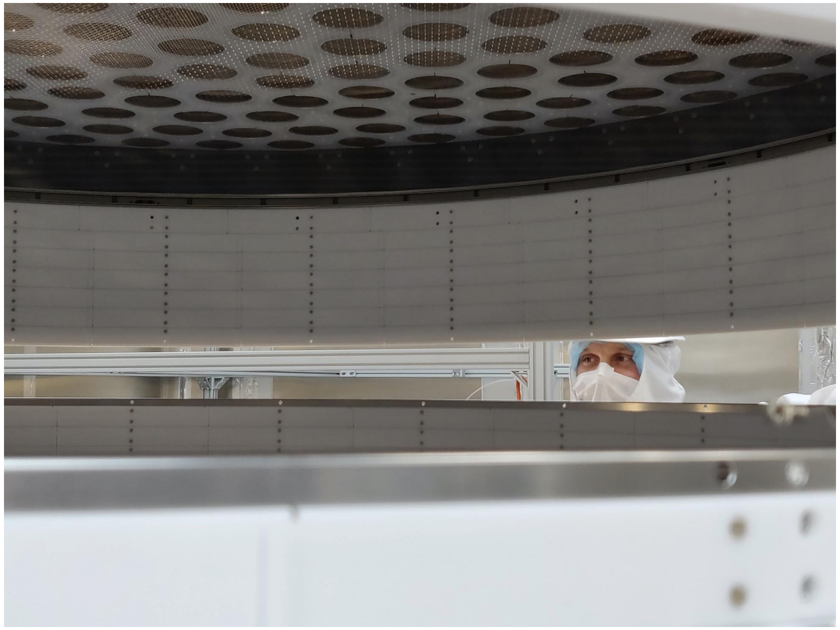
LUX-ZEPLIN Construction - a few highlights

Completed outer detector tank at Reynolds Polymer Technology - USCB

Offsite Kr removal of 10 tonnes of LXe at SLAC

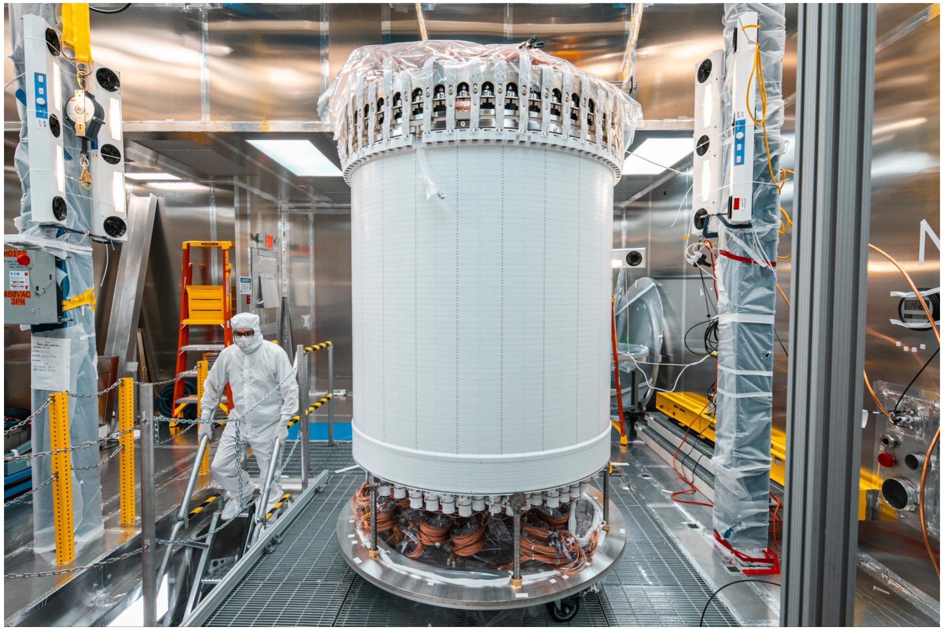
TPC Assembly at SURF surface laboratory

2019



Mating of the extraction region to central TPC

2019



Fully assembled TPC at SURF surface lab

Dust and Rn exposure control critical → assembly in Rn-reduced surface lab cleanroom

Moving to the Davis Campus

2021

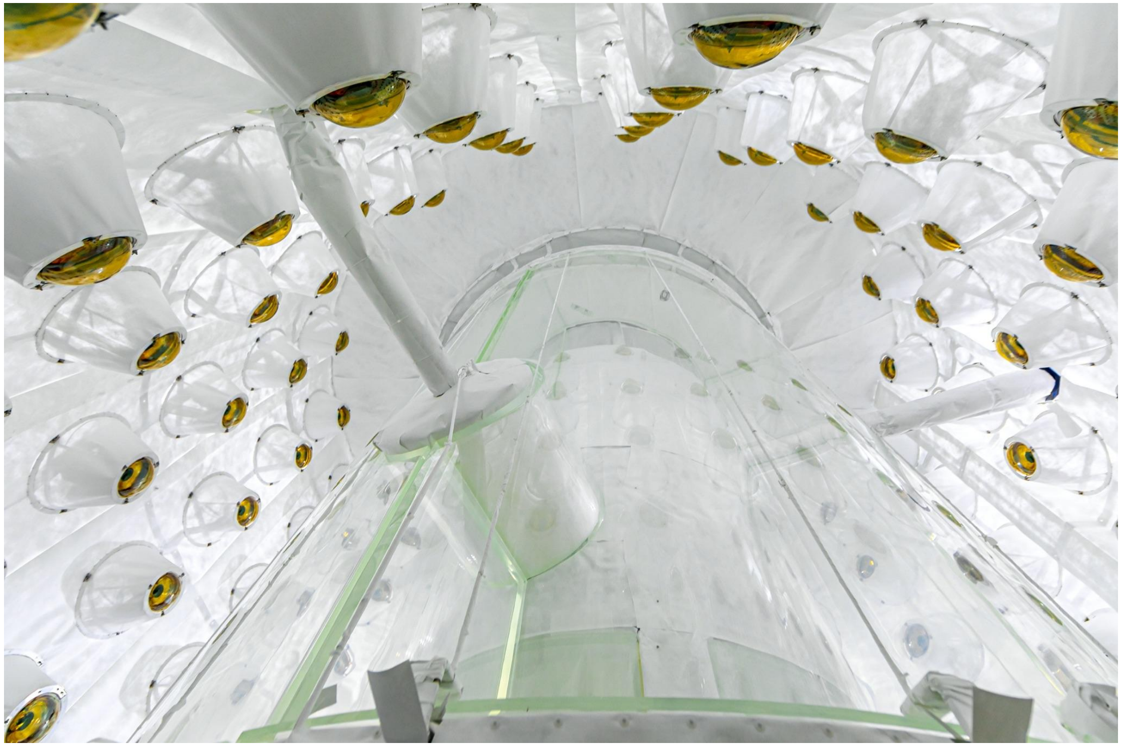
TPC inside inner cryostat vessel (ICV) being transported underground

2021

ICV being lowered into the outer vessel inside the water tank

Fully assembled 1 mile UG in Davis Campus

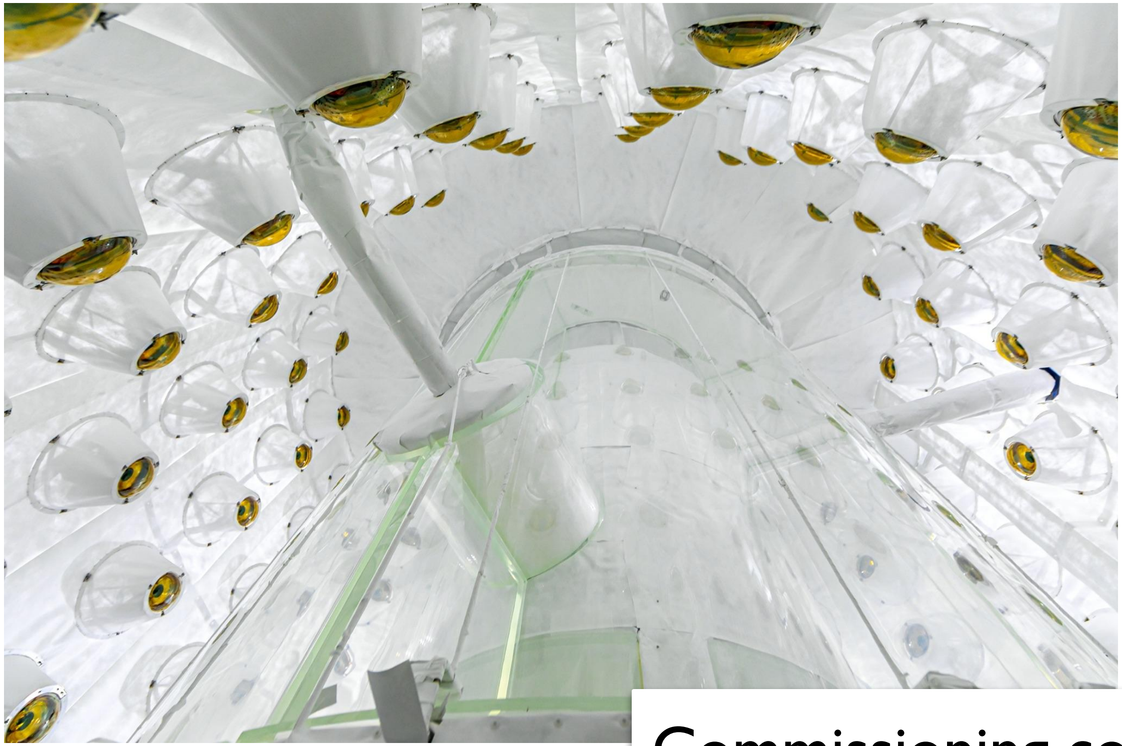
2021



Fully assembled outer detector - ready for water fill and operations

Fully assembled 1 mile UG in Davis Campus

2021



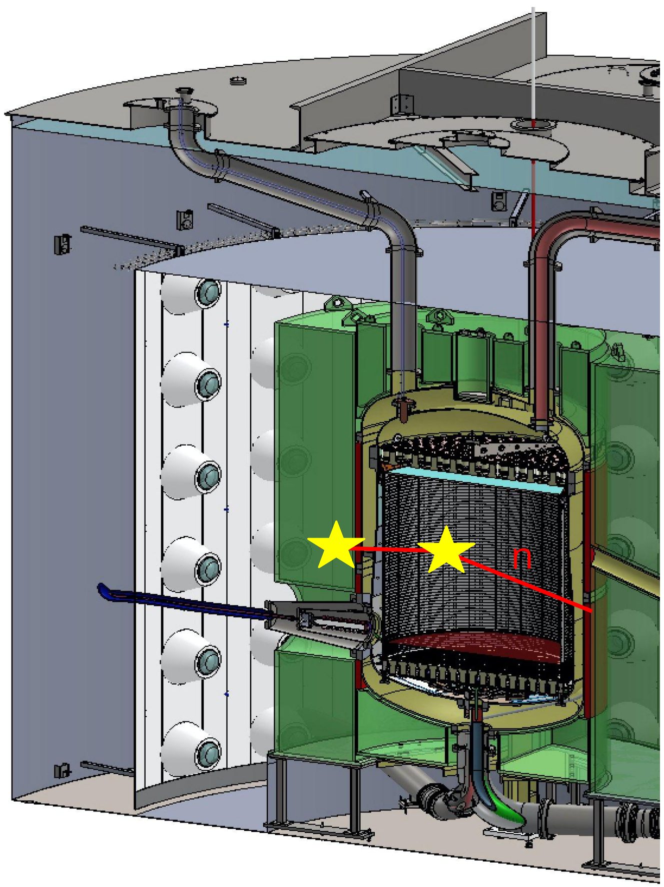
Fully assembled outer detector - ready fo

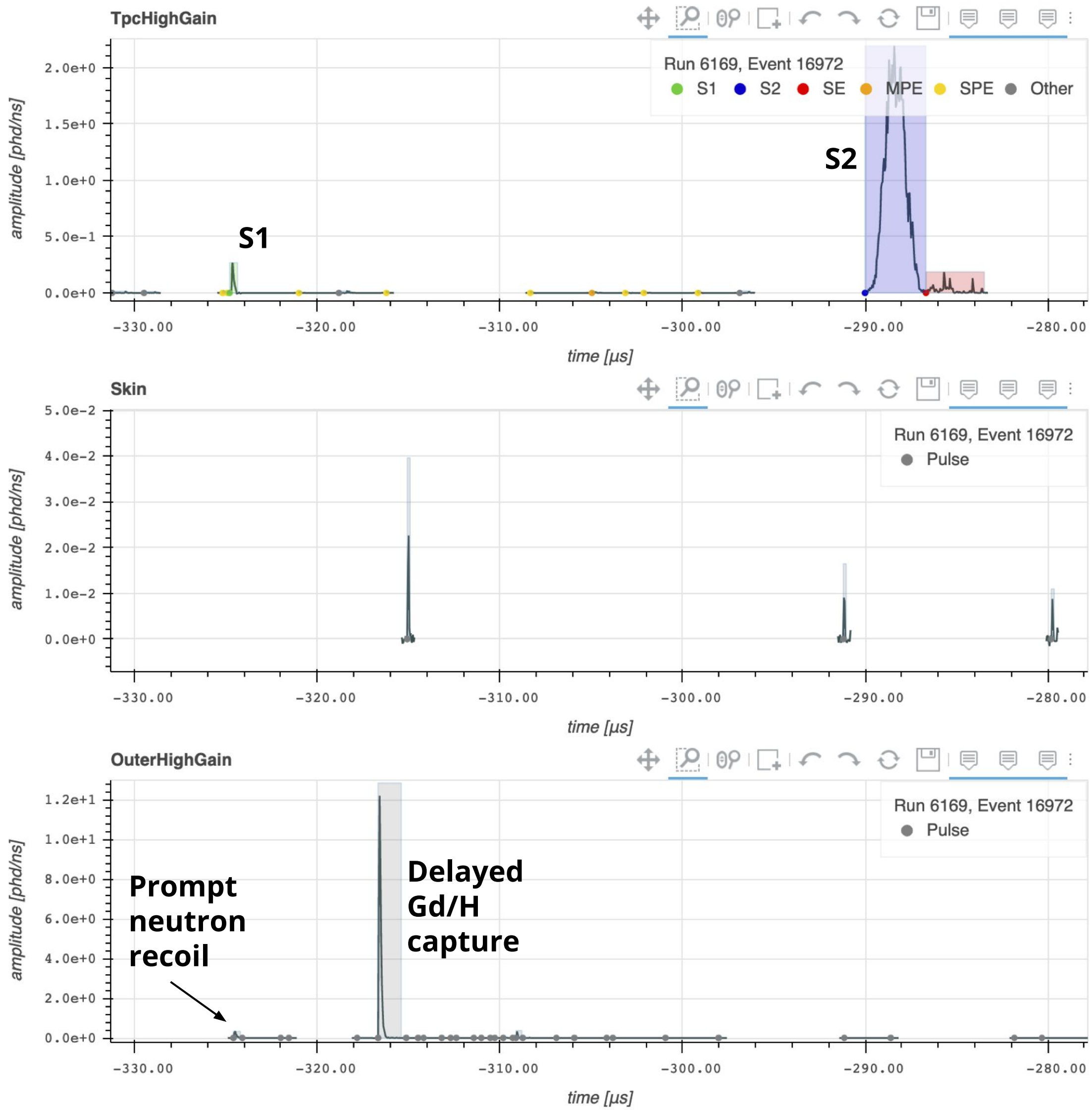
Commissioning complete -

how is the detector performing?

All detector systems operational

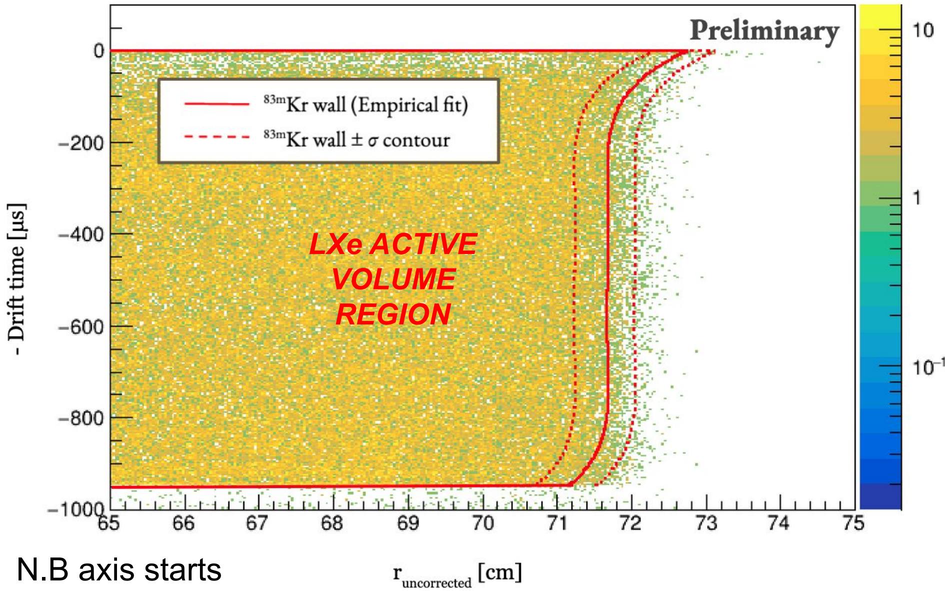
AmLi calibration neutron event in TPC O(10 keV) and Outer Detector:





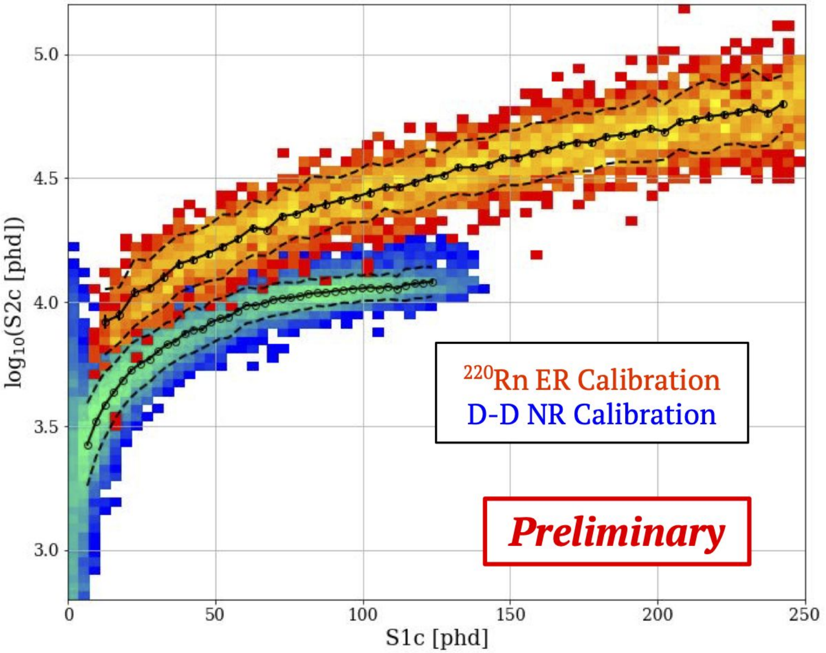
Mapping TPC response with calibrations

Reconstructing the TPC wall using injected ^{83m}Kr source:



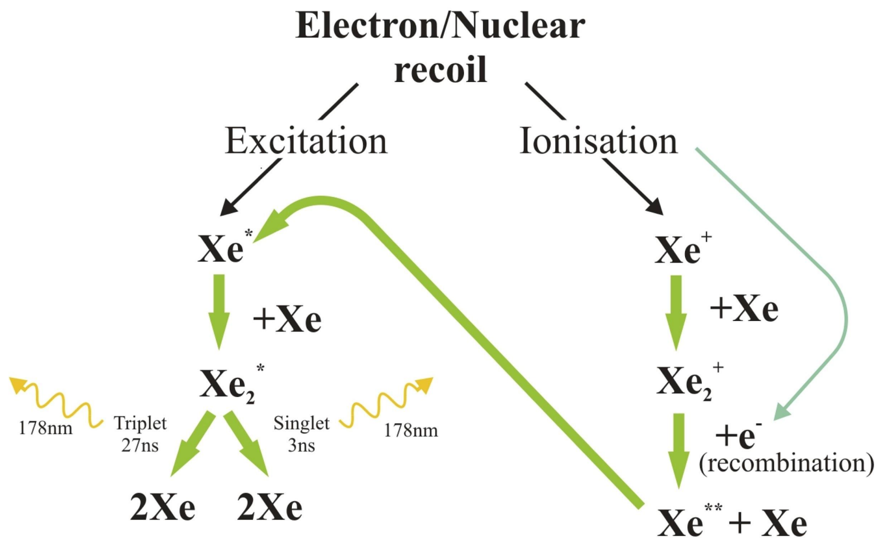
N.B axis starts at 65 cm

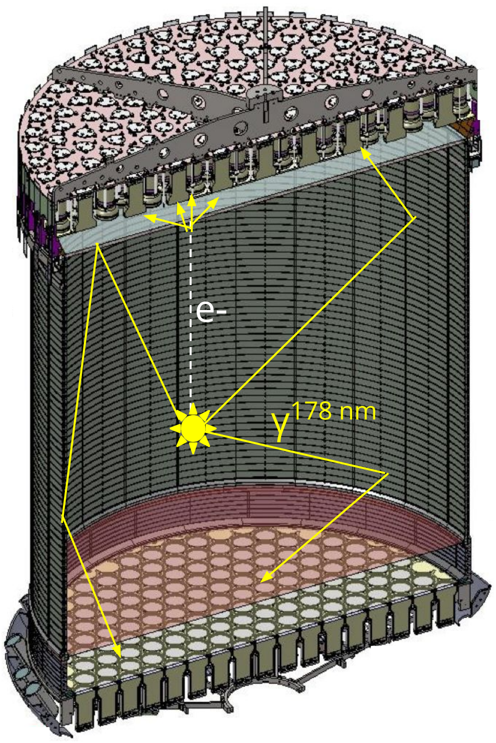
Detector response to Deuterium-deuterium neutrons and injection ^{220}Rn electron recoils:



Uniform well-behaved drift field: average ~190 V/cm

Light and Charge collection





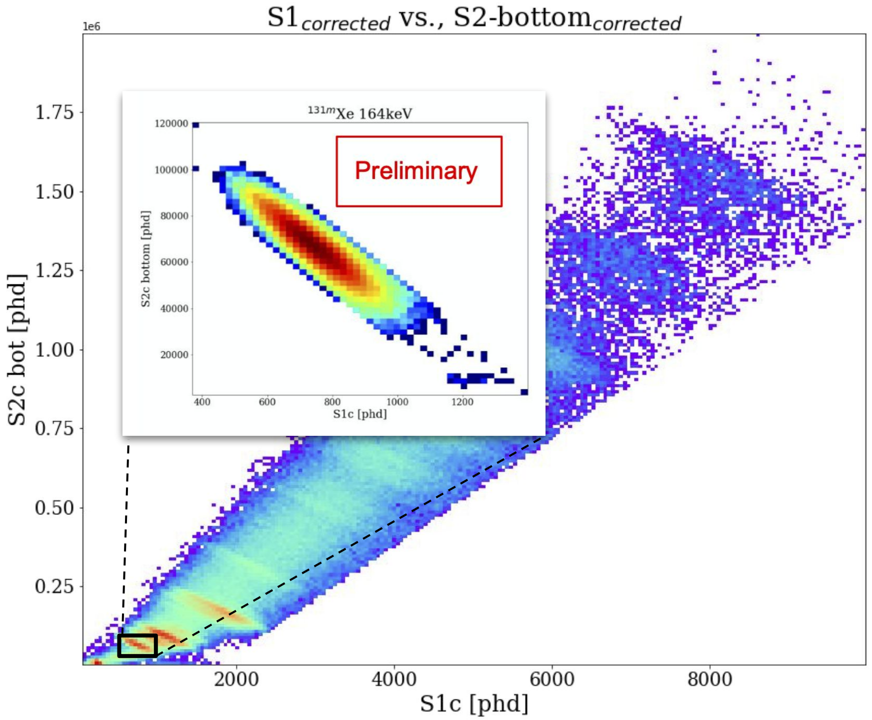
Xe microphysics → light and charge signals are anti-correlated:

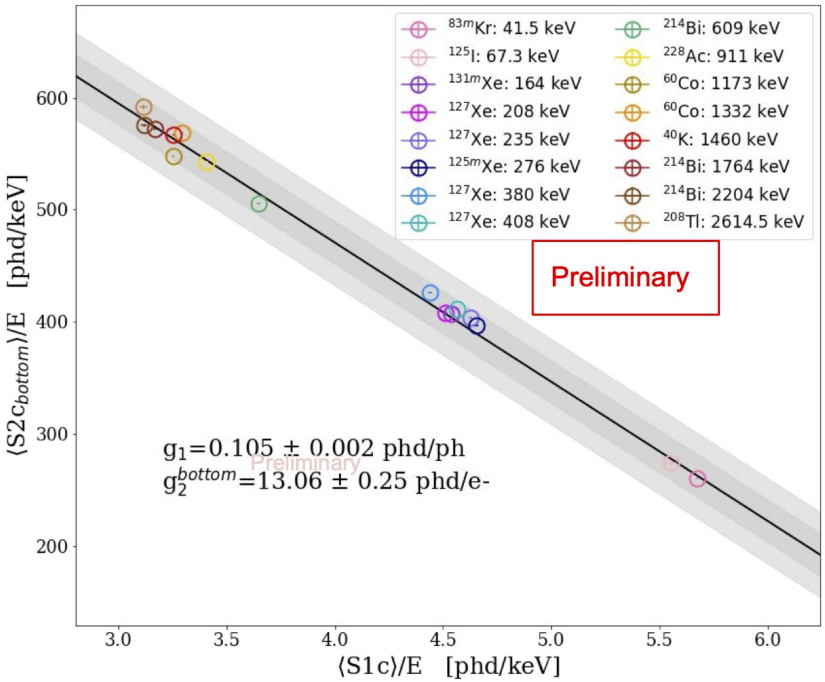
$$E = W \cdot (\frac{S1_c}{g1} + \frac{S2_c}{g2})$$

Where:
g1 = photon detection efficiency
g2 = electron gain phd/e-
W = work function = 13.5 eV/quanta

Light and Charge collection

Mono-energetic sources: source tubes + injected + activation products.



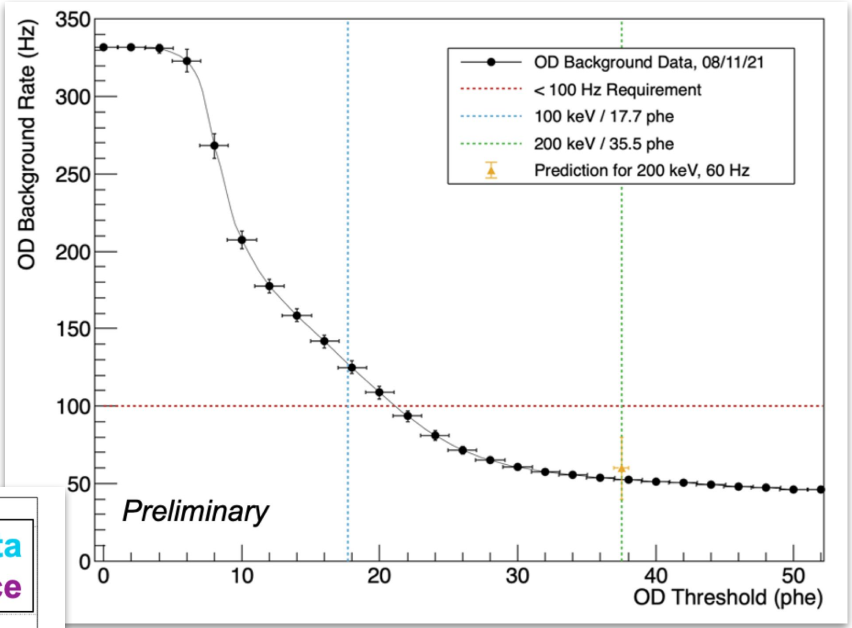


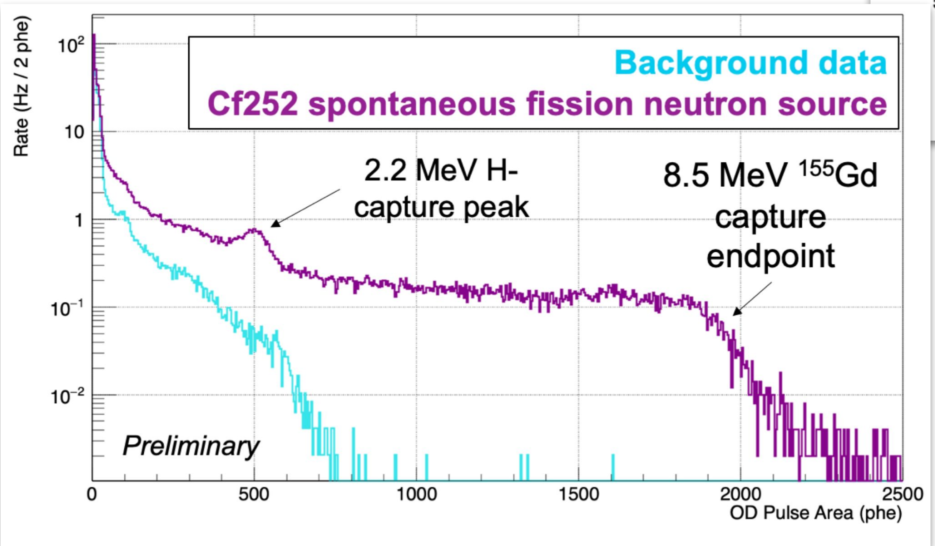
Preliminary*: g_1 = 10.5% and g_2^{bottom} = 13 phd/e

** Likely to change with full treatment of systematics/improved calibrations*

Outer detector performance

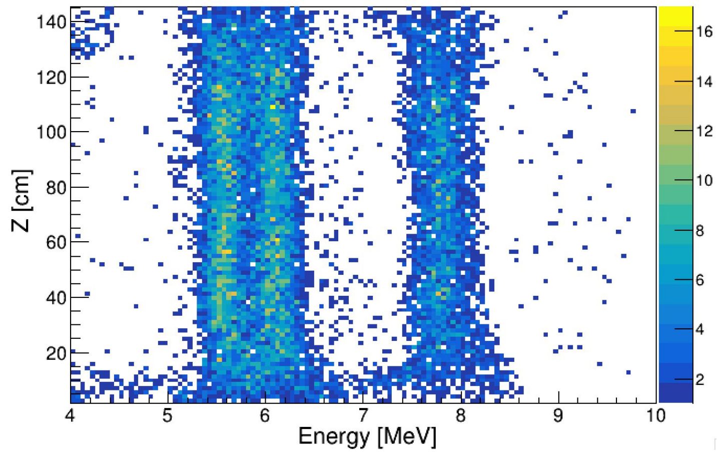
- First look at background and calibration data
- Background rate slightly lower
- Allows for < 200 keV design threshold

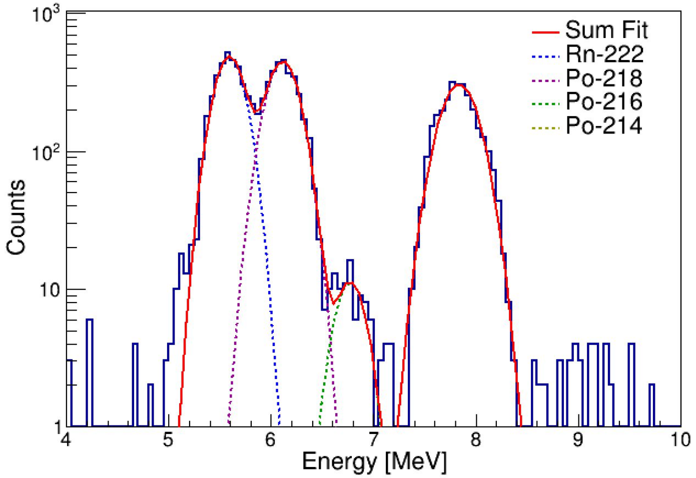




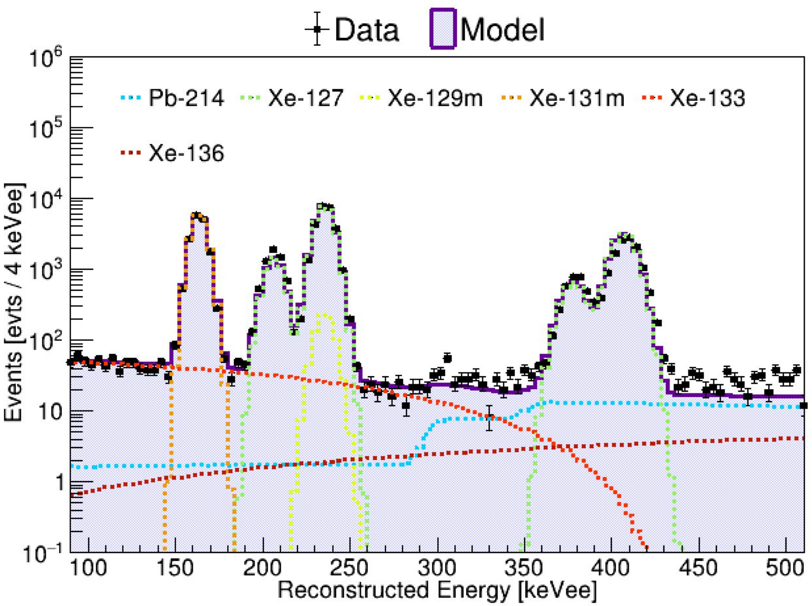
Background studies underway

^{222}Rn measurements from alpha-counting





Gamma spectroscopy - in this case fitting inner region of detector above WIMP ROI



In-situ measurements will constrain backgrounds in WIMP region of interest

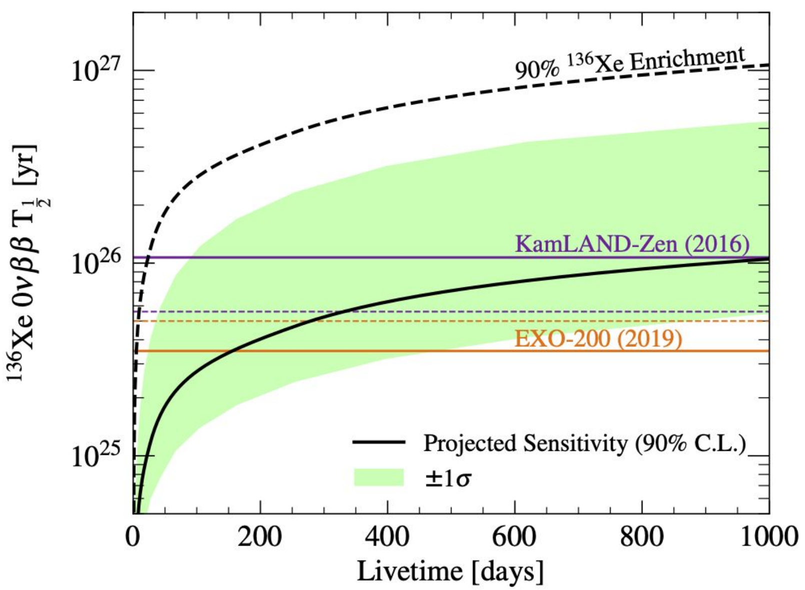
Not just WIMP physics

Non-WIMP DM candidates: Mirror dark matter, ALPs, hidden photons

Astrophysical neutrinos: solar-pp, supernova, ^{8}B CEvNS

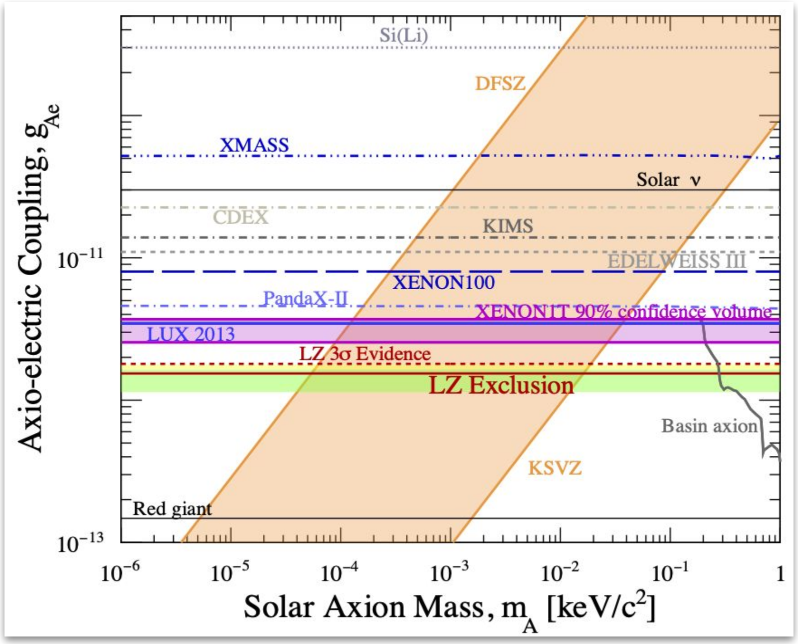
Rare decays: 0ν$\beta\beta$ of ^{124}Xe and 2νECEC on ^{124}Xe

Sensitivity to 0νββ decay of 136Xe



Phys.Rev.C 102 (2020) 1, 014602

Solar axions



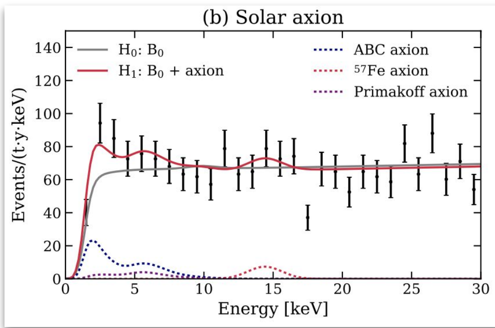
Phys.Rev.D 104 (2021) 9, 092009

Not just WIMP physics

Non-WIMP DM candidates: Mirror dark matter, ALPs, hidden photons

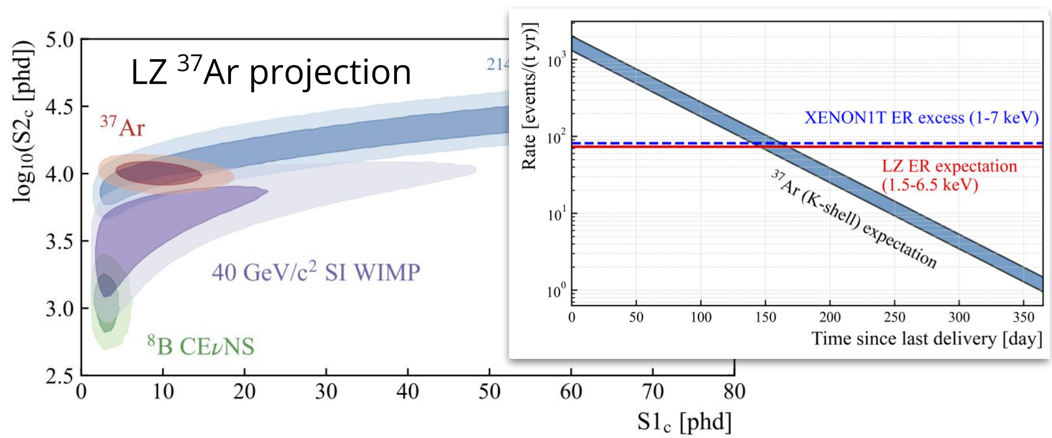
Astrophysical neutrinos: solar-pp, supernova, ^{8}B CEvNS

XENON1T excess: new physics?

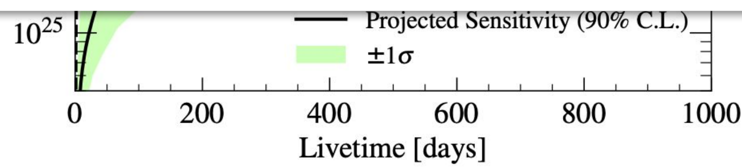


Phys.Rev.D 102 (2020) 7, 072004

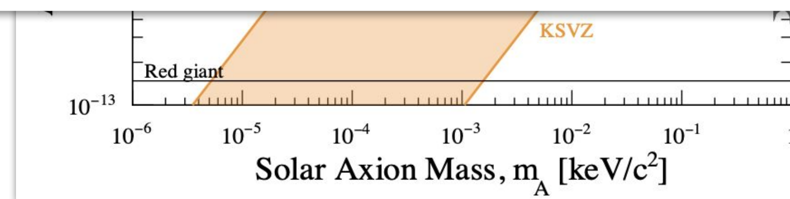
Or low-energy BG, for example Tritium, ^{37}Ar.



Phys.Rev.D 105 (2022) 8, 082004



Phys.Rev.C 102 (2020) 1, 014602



Phys.Rev.D 104 (2021) 9, 092009

In summary:

- LZ construction complete
- TPC, Skin and Outer Detector systems online
- Detector performing well
- Physics data taking now
- **Watch this space!**

LZ: 35 Institutions, 250 scientists, engineers, and technical staff

Thanks to our sponsors and 35 participating institutions!

U.S. Department of Energy
Office of Science

UKRI Science and Technology Facilities Council

Sanford Underground Research Facility
South Dakota Science and Technology Authority

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

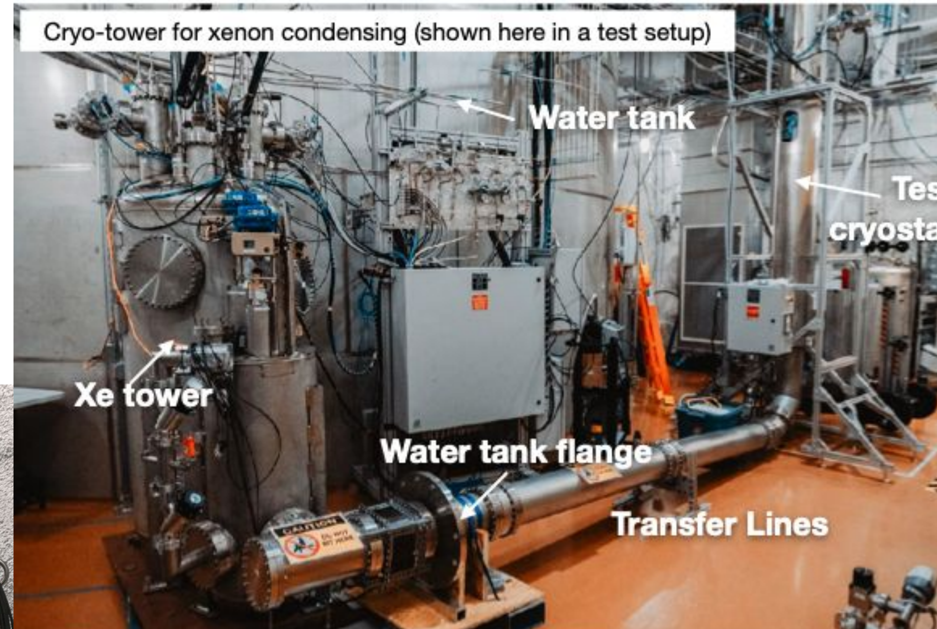
ibs Institute for Basic Science

Backups

Xenon circulation system

Circulation @ 500 slpm
→ 1 turnover/2.4d

Purification using hot zirconium getter
→ electronegative species < 0.1 ppb



Upto 600 slpm during commissioning tests

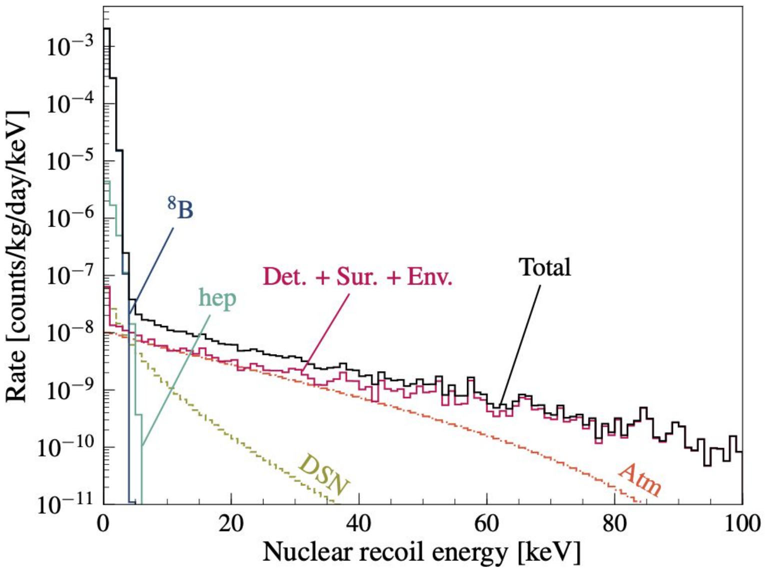
Background expectations

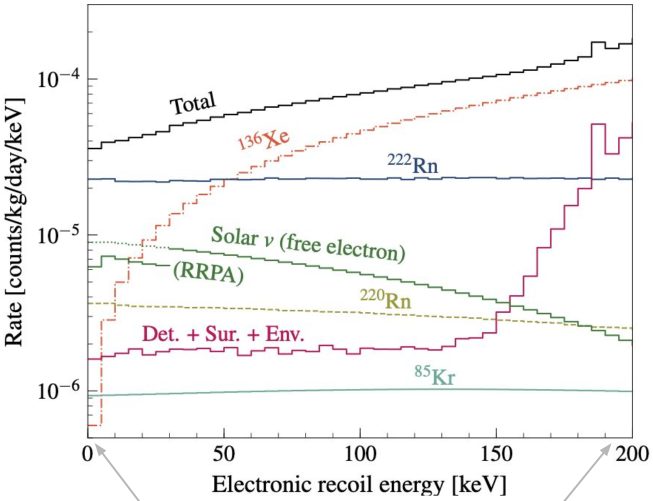
5.6 ton fiducial, 1000 live-days
~1.5 - 6.5 keV, single scatters, no coincident veto

Background Source	ERs	NRs
Detector Components	9	0.07
Dispersed Radionuclides — Rn, Kr, Ar	819	—
Laboratory and Cosmogenics	5	0.06
Surface Contamination and Dust	40	0.39
Physics Backgrounds — 2β decay, neutrinos*	322	0.51
Total (after 99.5% discrimination and 50% NR efficiency)	**6.49**	

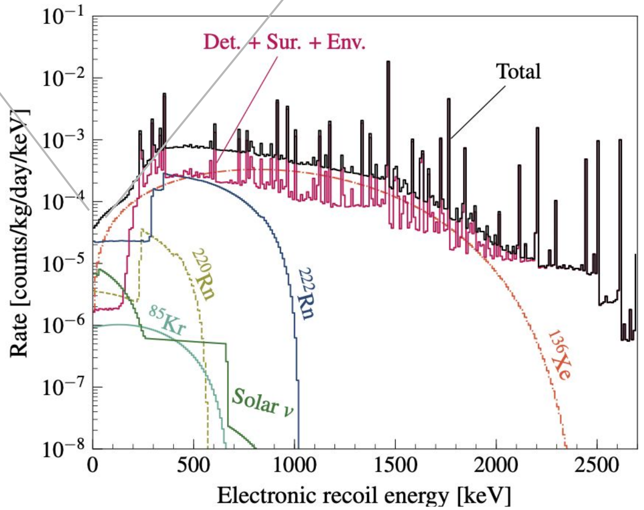
Background expectations

Nuclear recoils

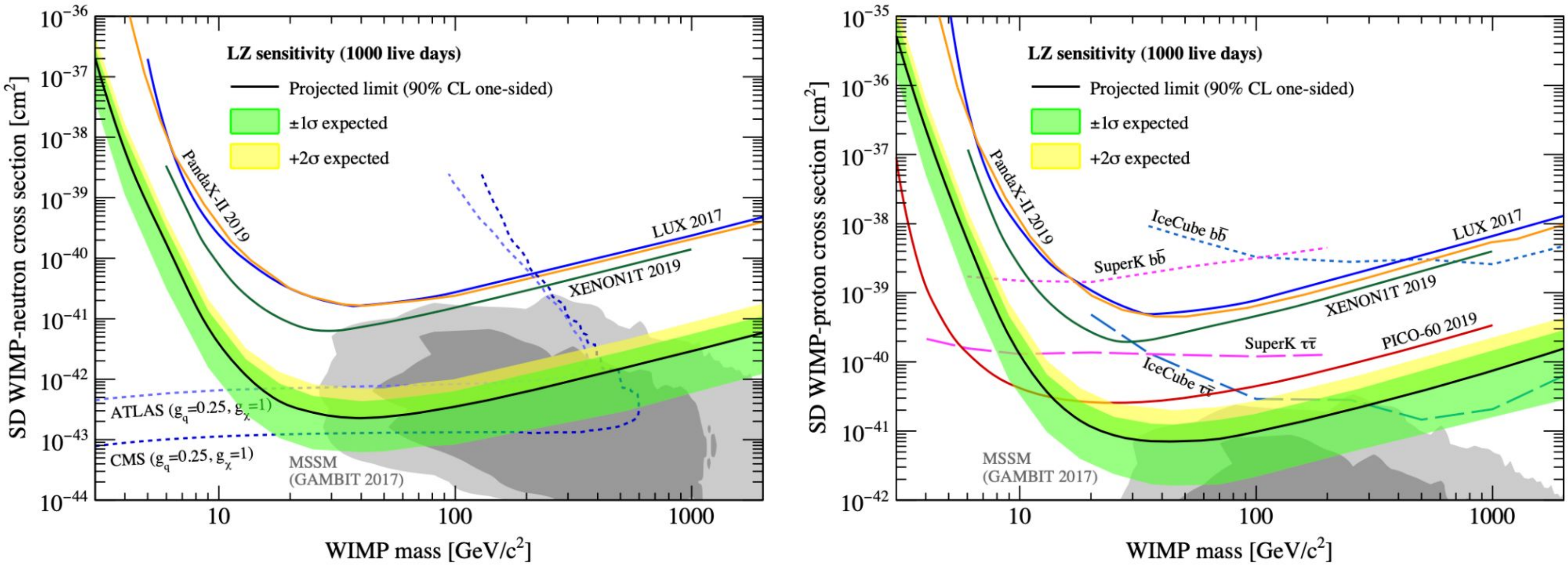




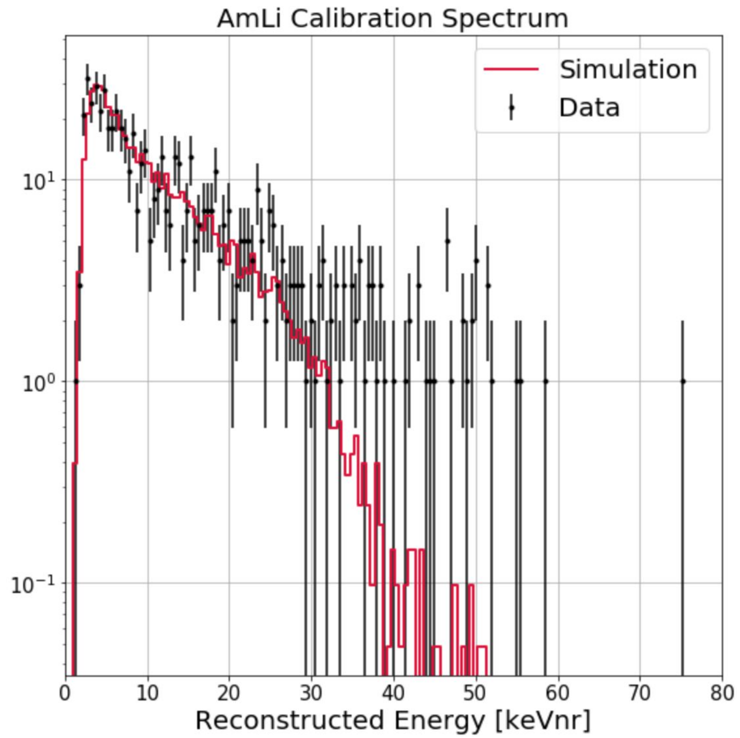
Electron recoils



Spin-dependent WIMP sensitivity



AmLi sims/data calibration spectrum



Nuclear recoil - sims vs data