



# THE LUX-ZEPLIN DARK MATTER EXPERIMENT

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*On behalf of the LZ collaboration*

**12<sup>TH</sup> INTERNATIONAL WORKSHOP DARK SIDE OF THE UNIVERSE**  
**University of Bergen, 25-29 July**

# LZ collaboration



- ✧ 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
- ✧ Shanghai Jiao Tong University, China
- ✧ 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 California, Berkley
- ✧ University of California, Davis
- ✧ University of California, Santa Barbara
- ✧ University of Edinburgh



- ✧ University of Liverpool
- ✧ University of Maryland
- ✧ University of Michigan
- ✧ University of Oxford
- ✧ University of Rochester
- ✧ University of Sheffield
- ✧ University of South Dakota
- ✧ University of Wisconsin-Madison
- ✧ Washington University in St. Louis
- ✧ Yale University

# How to catch a WIMP



- ✧ Direct detection is based on the observation of a WIMP scattering from a target nucleus.
- ✧ One of the key requirements is to distinguish nuclear recoils (signal) from electron recoils (background  $e^\pm, \gamma$ ).
- ✧ Low energy thresholds maximise sensitivity to WIMP-induced nuclear recoils  $\sim$  few keV.
- ✧ Low background requirements; underground operation, radio-pure detector materials etc.

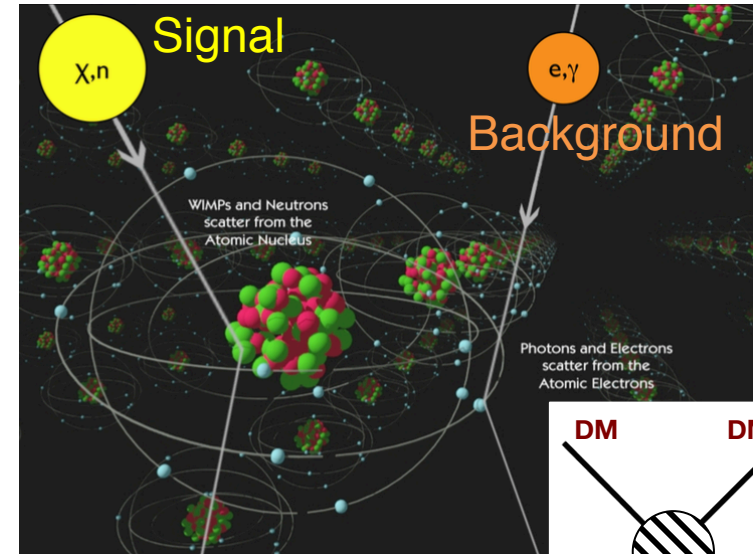
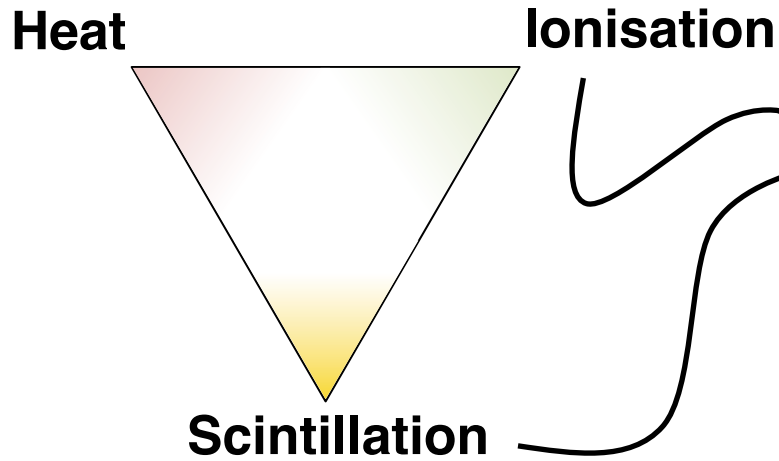
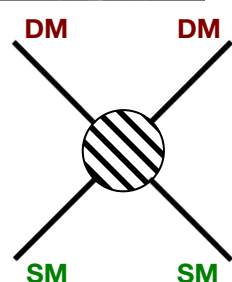


Image courtesy of M. Attisha



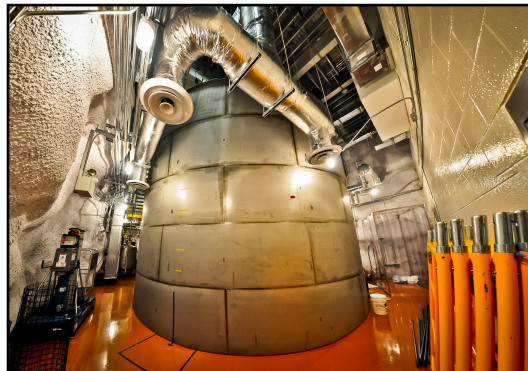
Two-phase liquid/gas noble detectors  
**LZ, LUX, ZEPLIN, XENON, Panda-X,**  
**Darkside, WARP, ArDM**

Challenge: search for events that are both rare ( $\ll 1$  event/kg/year) and involve small energy transfers ( $< 100$  keV).

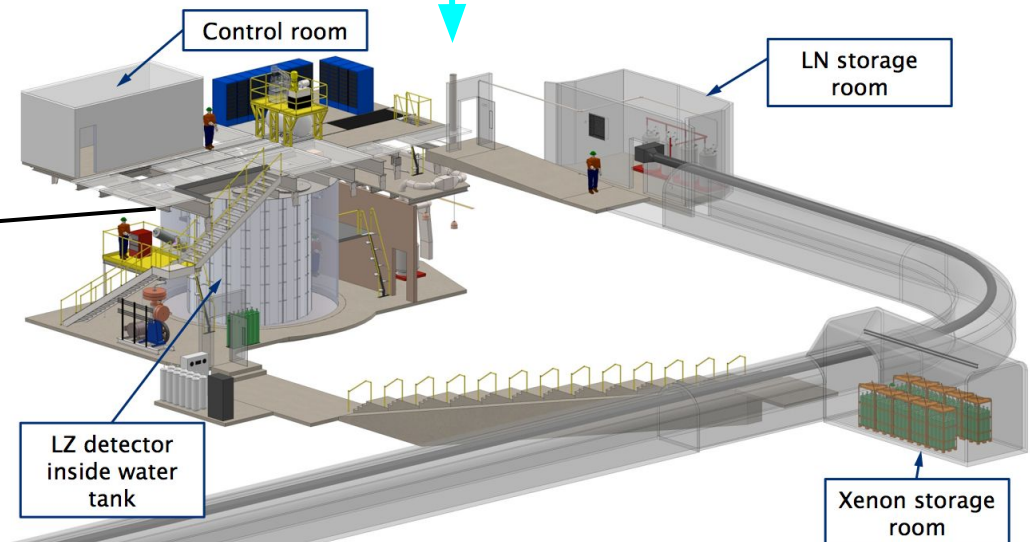
# Sanford Underground Research Facility (SURF)



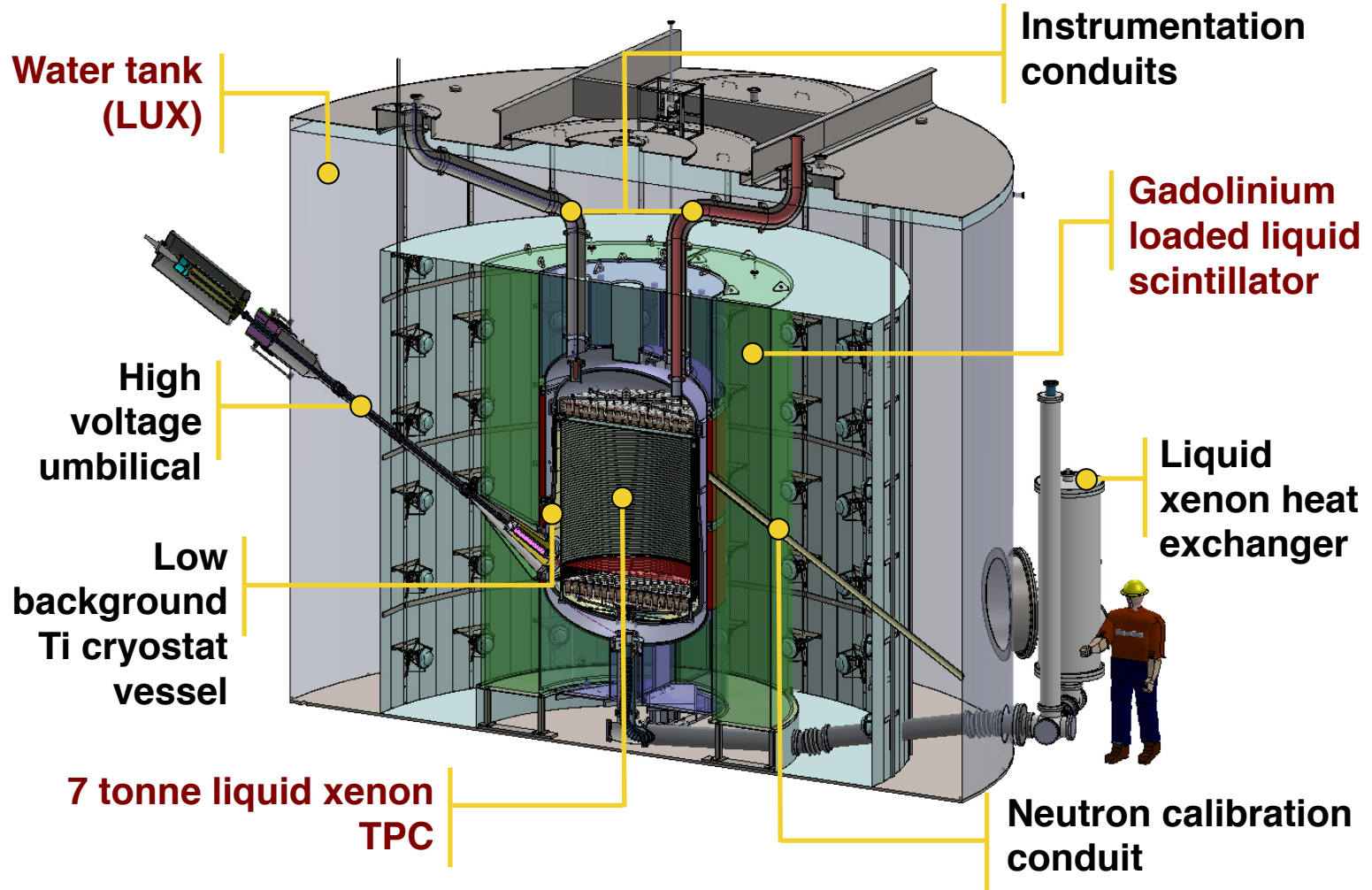
Davis Cavern 1480 m  
(4200 mwe)



Water tank currently hosting the LUX experiment at SURF to be used for LZ. Image courtesy of C. Faham.



# LZ schematic



# Two-phase xenon TPC



## S1 prompt scintillation:

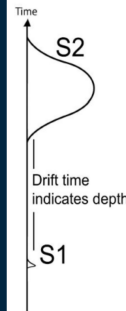
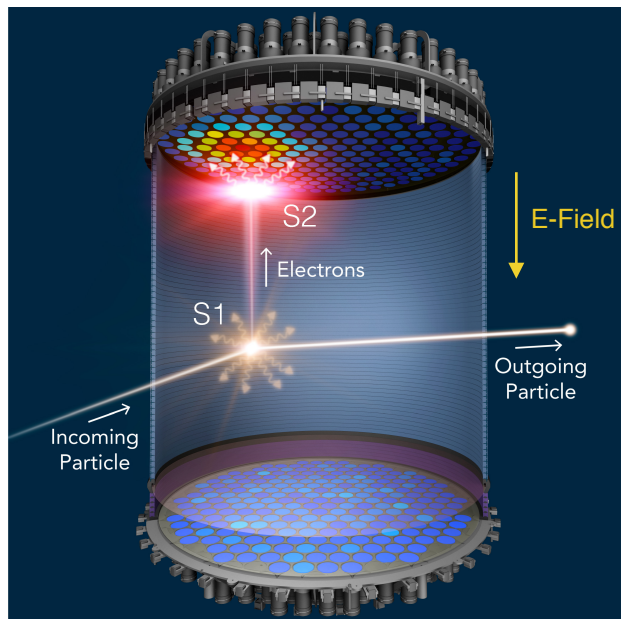
- ✧ UV photons  $\sim 175$  nm.

## S2 delayed ionisation:

- ✧ Ionisation electrons drift under E-field;
- ✧ Electroluminescence in the gas phase.

## S1 + S2 event-by-event:

- ✧ 3D position reconstruction (mm vertex resolution) - identify multiple scatter events, fiducialise WIMP target;
- ✧ Identification of background electron recoils based on ratio of light/charge ( $> 99.5\%$  discrimination, 50% nuclear recoil acceptance).

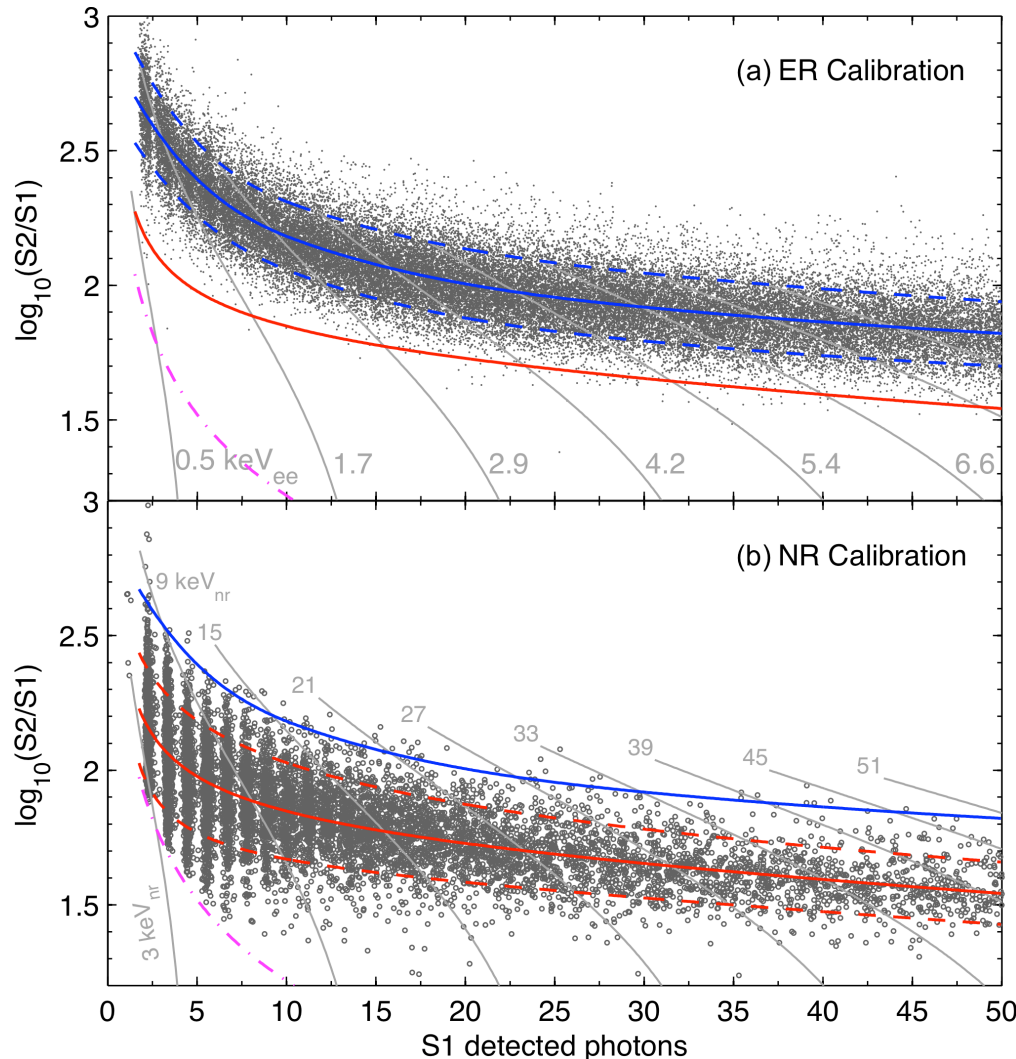


**253 + 241 low background PMTs (top + bottom)**

**Total xenon mass – 10 tonnes**  
**Active xenon mass – 7 tonnes**  
**Fiducial xenon mass – 5.6 tonnes**



# Combined S1 + S2 signals



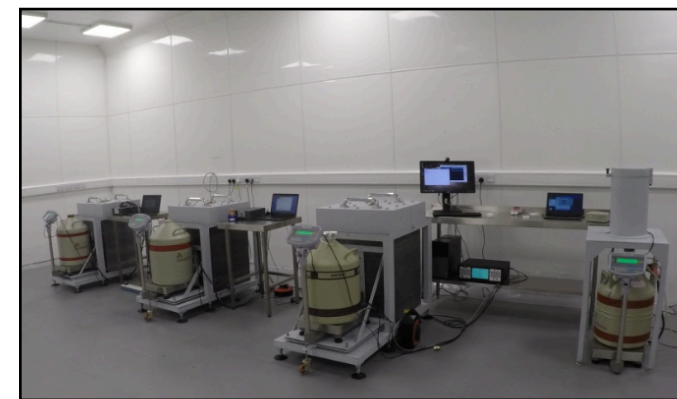
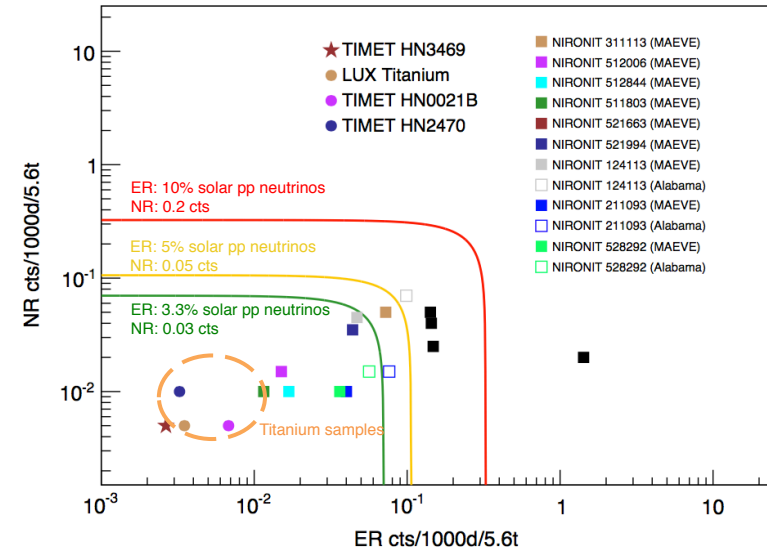
LUX calibration data – plotting S1 vs  $\log_{10}(S2/S1)$  gives visual separation. Blue line indicates median of the ER band and red line indicates median of the NR band. The dashed lines indicate 80% population contours.

# Background control strategy



- ✧ Underground operation within an instrumented water tank to mitigate cosmic backgrounds;
- ✧ Self-shielding in high-density target material;
- ✧ Material-screening to select low radioactivity components (table below);
- ✧ Purification of liquid xenon; removal of radioactive noble gases (Kr, Ar, Rn) and electronegative contaminants.

Technique	Isotopes	Sensitivity
HPGe	$^{238}\text{U}$ , $^{235}\text{U}$ , $^{232}\text{Th}$ chains, $^{40}\text{K}$ , $^{60}\text{Co}$ , $^{137}\text{Cs}$ , any $\gamma$ -emitter	50 ppt U, 100 ppt Th
ICP-MS	$^{238}\text{U}$ , $^{235}\text{U}$ , $^{232}\text{Th}$ (top of chain)	$10^{-12}$ g/g
NAA	$^{238}\text{U}$ , $^{235}\text{U}$ , $^{232}\text{Th}$ (top of chain), K	$10^{-12}$ g/g to $10^{-14}$ g/g
Radon Emanation	$^{222}\text{Rn}$ , $^{220}\text{Rn}$	0.1 mBq



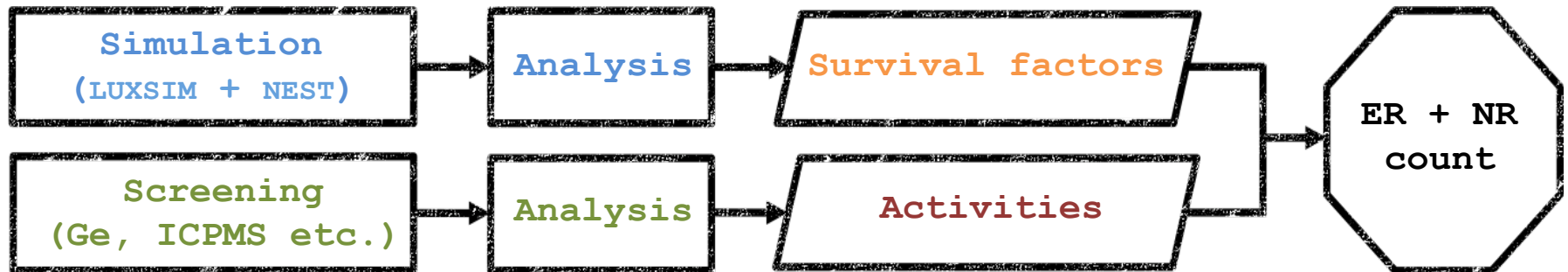
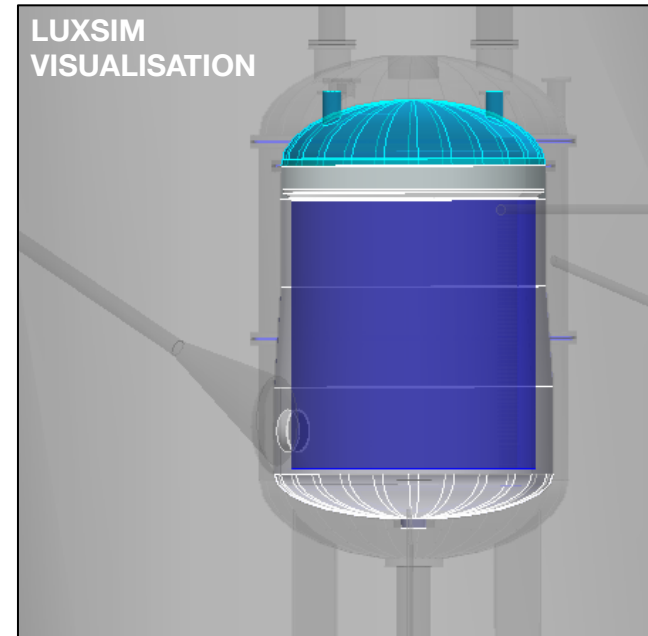
*Boulby Underground Germanium Suite (BUGS) in the low background counting facility of the new Boulby Underground Laboratory*



# Background simulations



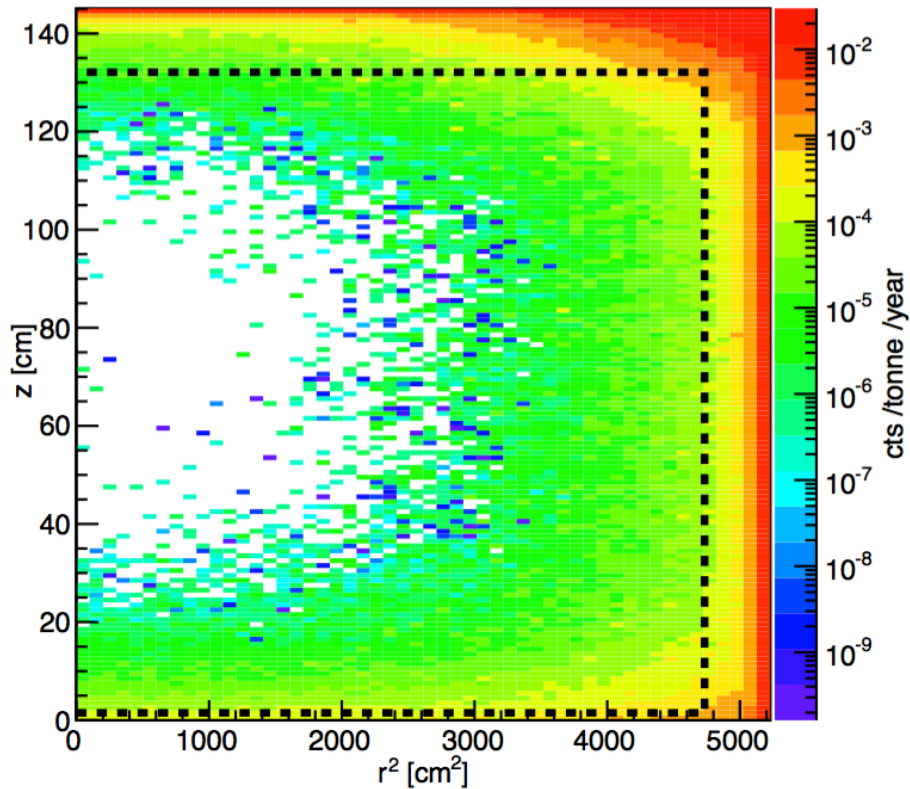
- ❖ GEANT4-based simulation package **LUXSIM** [arXiv: 1111.2074] is used to simulate radiogenic, cosmogenic and laboratory backgrounds.
- ❖ Detector response (S1 and S2 signals) simulated using **NEST** [arXiv:1307.6601].
- ❖ Accurate implementation of LZ geometry according to engineering designs.
- ❖ Event generators used as inputs; gammas from GEANT4 libraries, neutron spectra from SOURCES4A code, muons according to spectra obtained with **MUSIC** and **MUSUN** codes [arXiv:0810.4635].



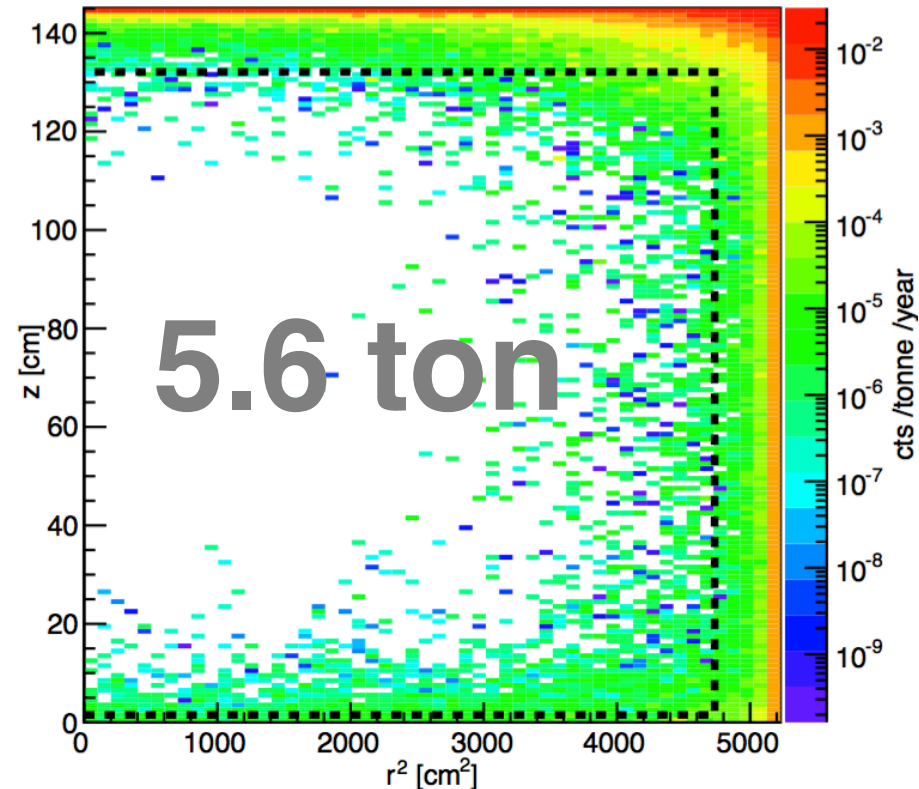
# Fiducialisation



ROI + Single scatter



ROI + Single scatter + vetoes

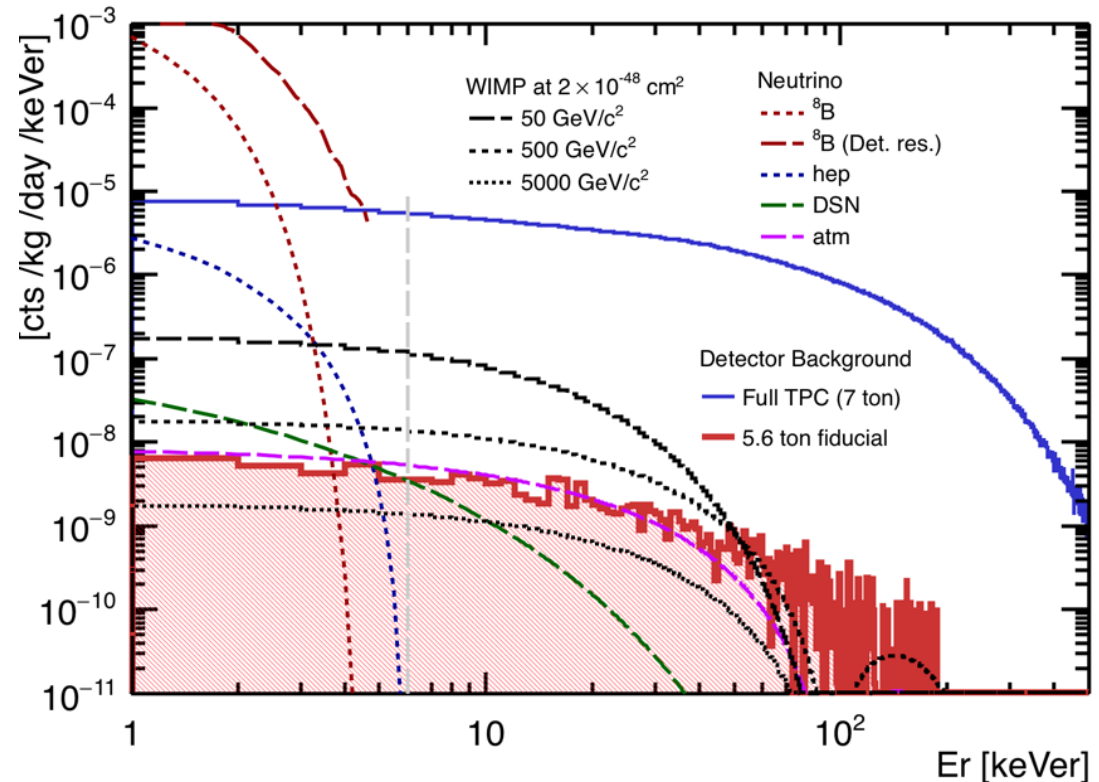


# Other backgrounds



- ✧ **ER:** Neutrino-electron scattering from solar pp neutrinos,  $2\nu bb$  from  $^{136}\text{Xe}$ .
- ✧ **NR:** Coherent-neutrino scattering from  $^8\text{B}$  solar neutrinos, atmospheric and diffuse supernova neutrinos.

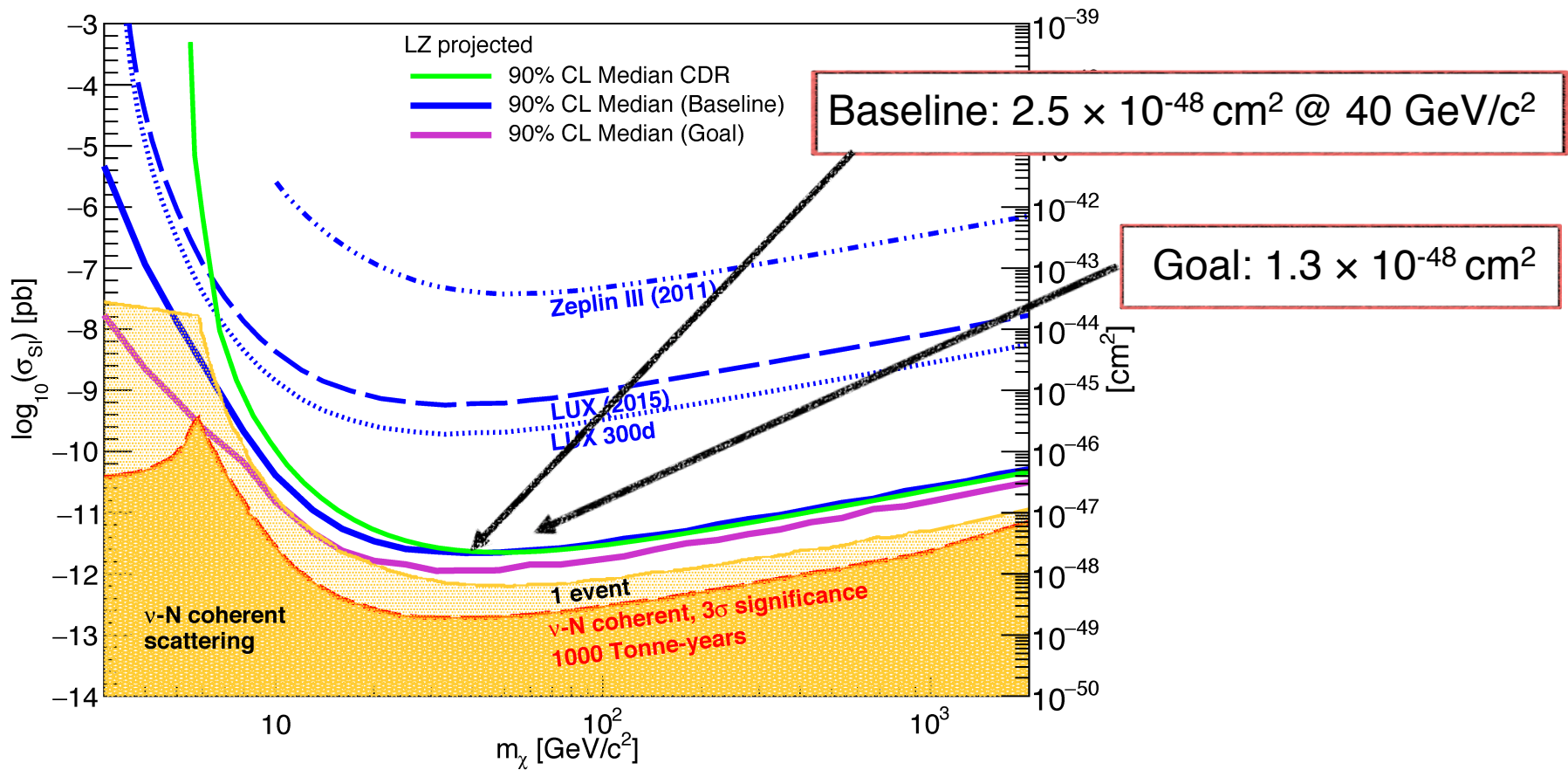
Source	ER	NR
Detector Components	10.20	0.08
Dispersed radionuclides	869	-
Lab and Cosmogenics	33.0	0.12
Fixed surface contamination	0.19	0.37
$^{136}\text{Xe}$ $2\nu bb$	67.0	-
Neutrinos	255	0.72
Total events	1230	1.29
WIMP background events (99.5 % discrimination, 50% acceptance)	6.17	0.65
<b>Total ER + NR</b>	<b>6.82</b>	



# Projected sensitivity



## WIMP-nucleon SI scattering



# LZ Timeline



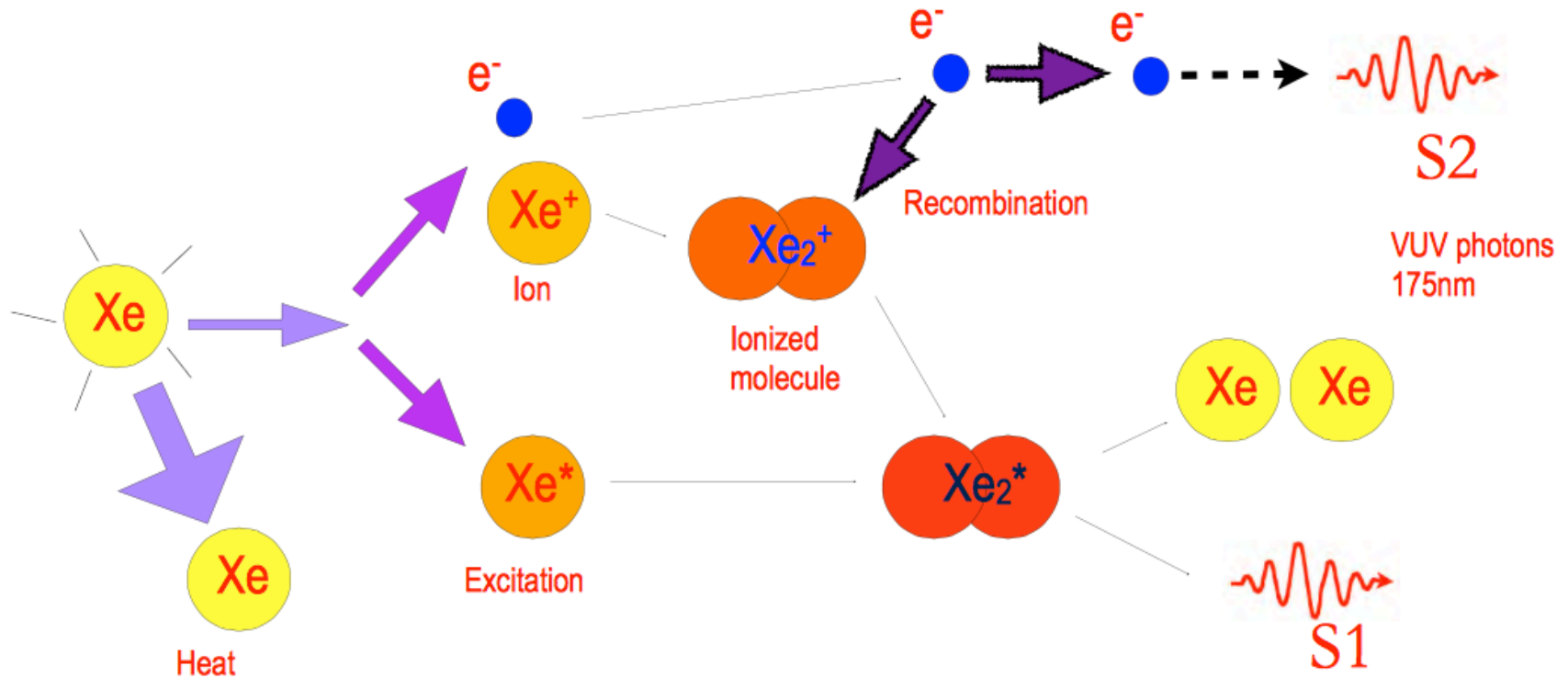
<b>Year</b>	<b>Month</b>	<b>Activity</b>
2012	March	LZ (LUX-ZEPLIN) collaboration formed
	September	DOE CD-0 for G2 dark matter experiments
2013	November	LZ R&D report submitted
2014	July	LZ Project selected in US and UK
2015	April	DOE CD-1/3a approval, similar in UK Begin long-lead procurements(Xe, PMT, cryostat)
2016	August	DOE CD-2/3b approval expected
2017	March	LUX removed from underground
	August	Beneficial occupancy surface assembly building
2018	June	Beneficial occupancy for underground installation
2019		Underground installation
2020	April	Start operations
2025+		Planning on 5+ years of operations

Backup slides

# Nuclear recoils in xenon



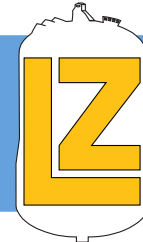
## Xenon, nuclear recoil



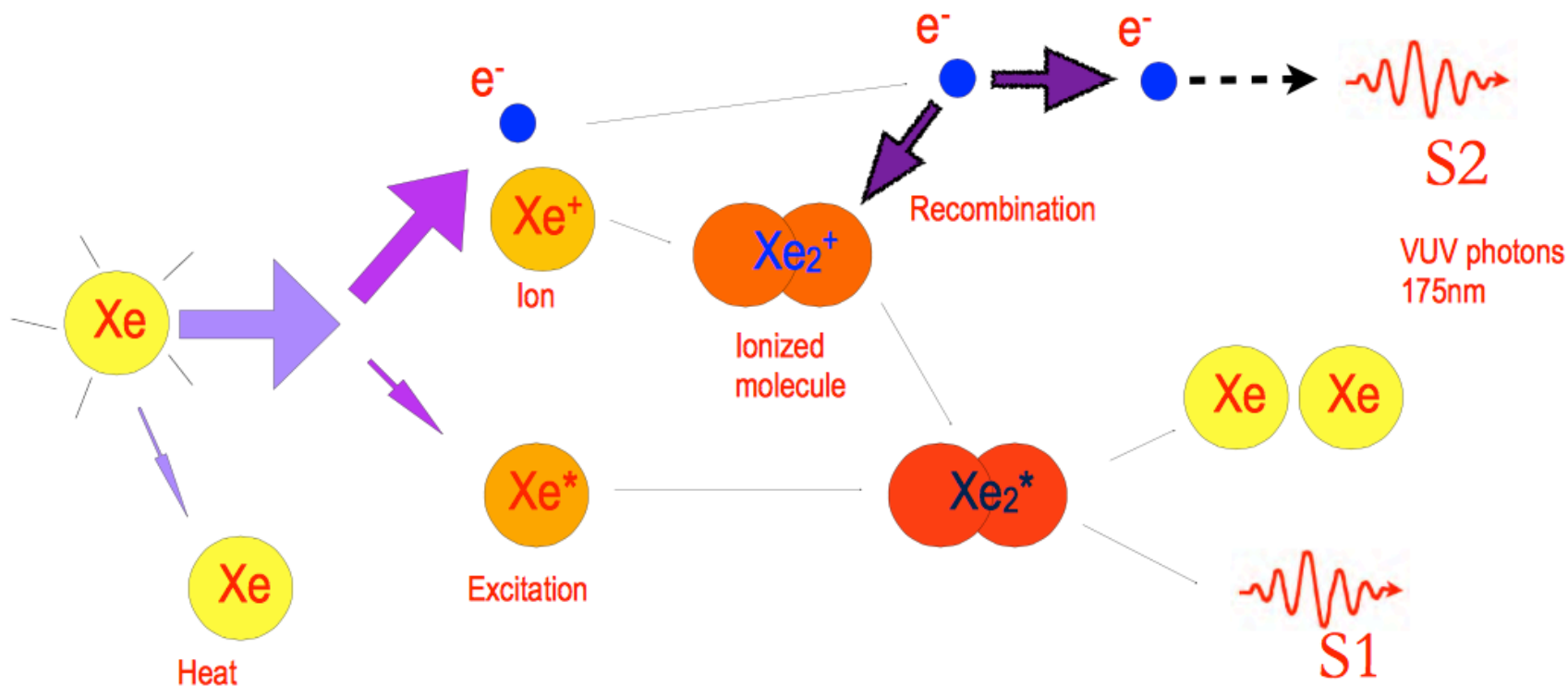
Branching (  $\rightarrow$  ) sketched for **nuclear recoils**

Diagram by T Shutt

# Electron recoils in xenon



## Xenon, electron recoil



Branching (  $\rightarrow$  ) sketched for **electron recoils**

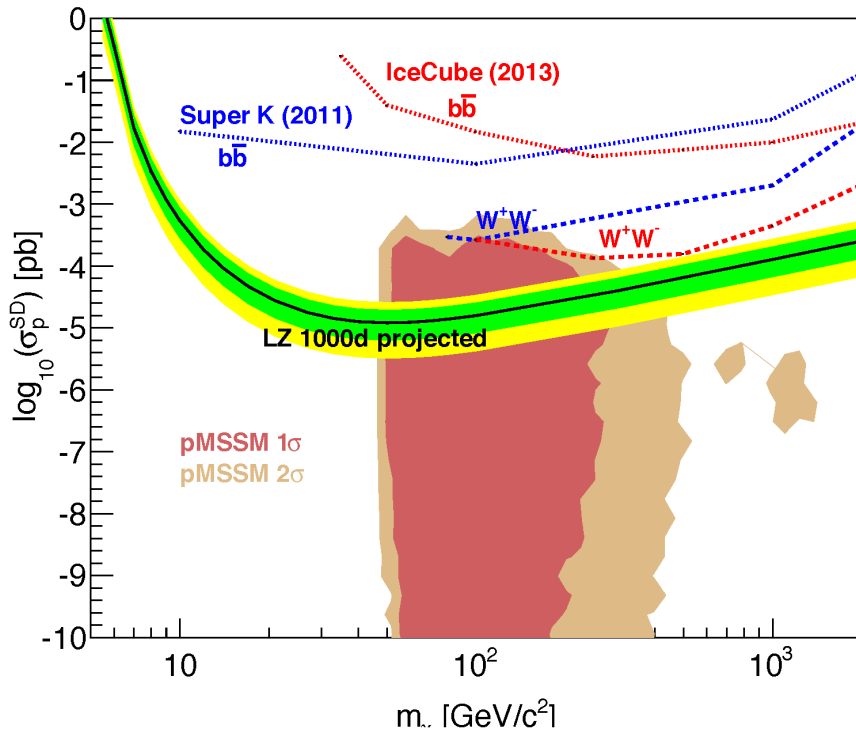
Diagram by T Shutt



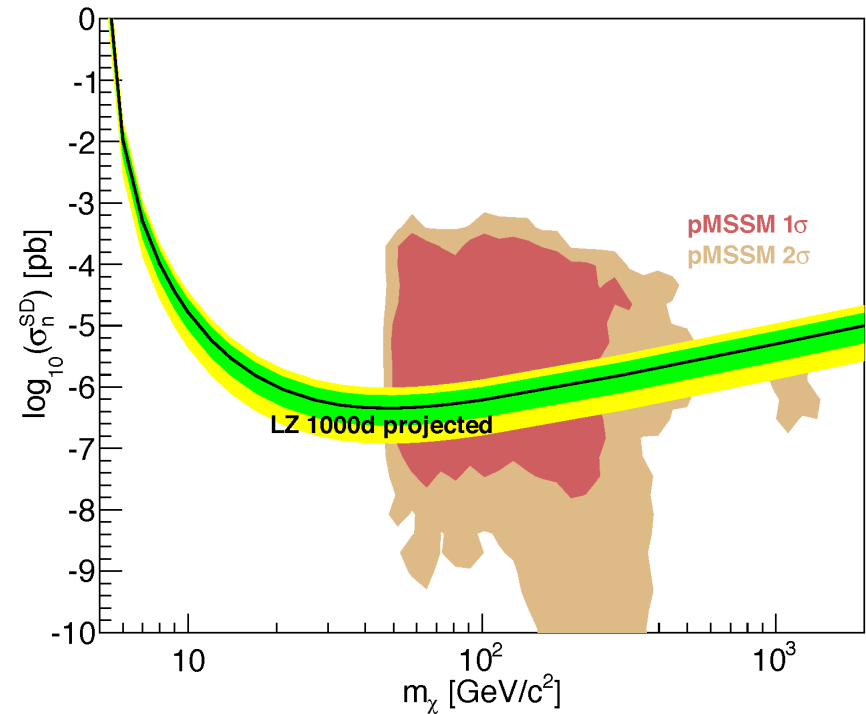
# Spin-dependent sensitivity



## WIMP-proton SD scattering



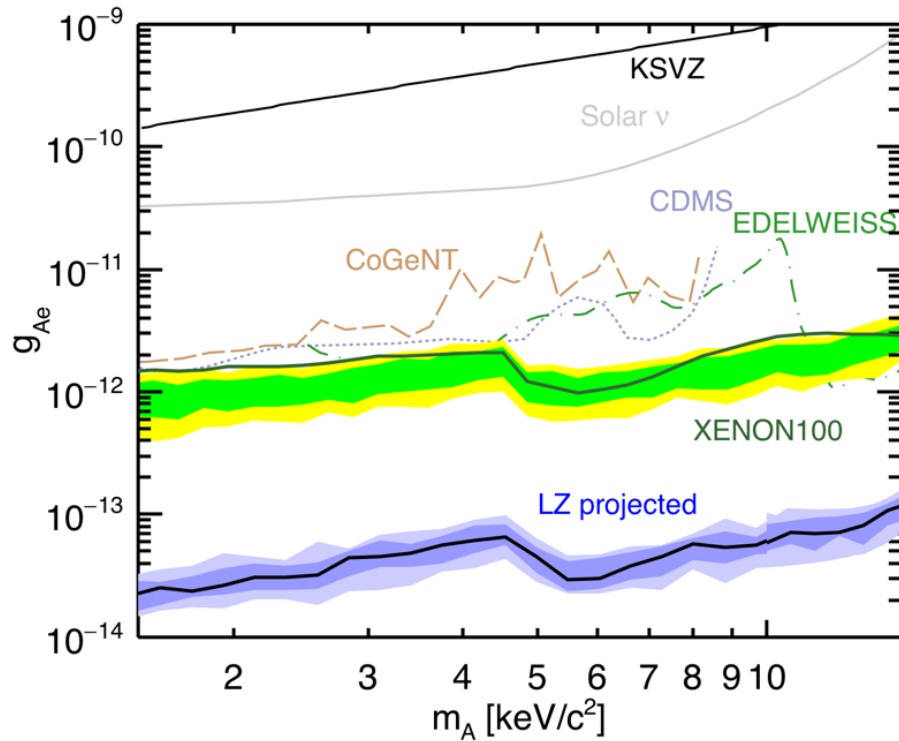
## WIMP-neutron SD scattering



# Axion sensitivity



## Dark matter axion



## Solar axion

