THE LUX-ZEPLIN DARK MATTER EXPERIMENT

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On behalf of the LZ collaboration

12TH 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 $e^{\pm}$, γ).
- ✧ Low energy thresholds maximise sensitivity to WIMP-induced nuclear recoils ~ few keV.
- ✧ Low background requirements; underground operation, radio-pure detector materials etc.

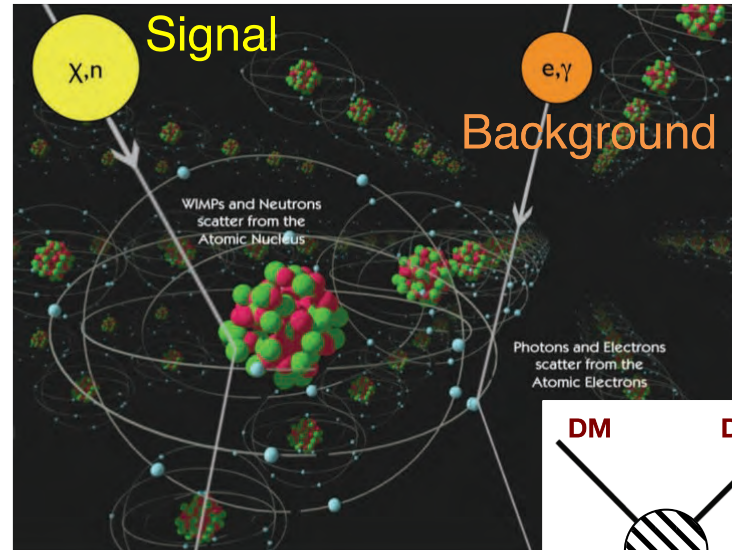
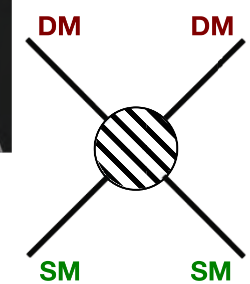
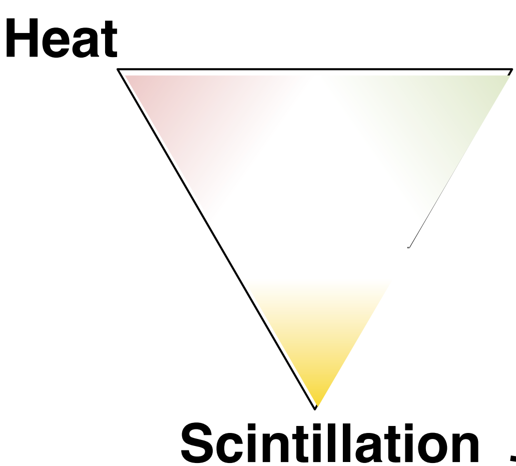


Image courtesy of M. Attisha





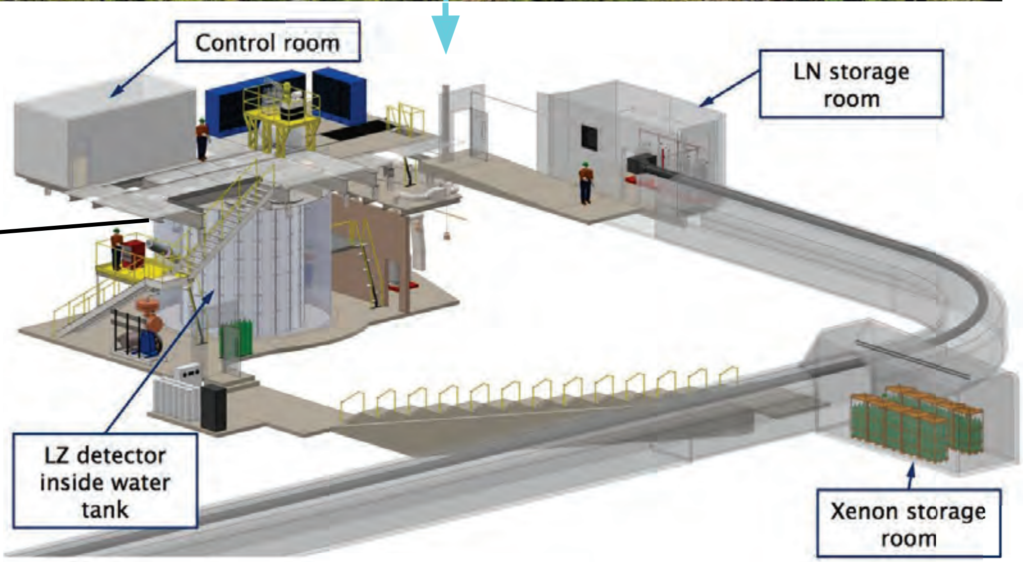
Two-phase liquid/gas noble detectors

LZ, LUX, ZEPLIN, XENON, Panda-X, Darkside, WARP, ArDM

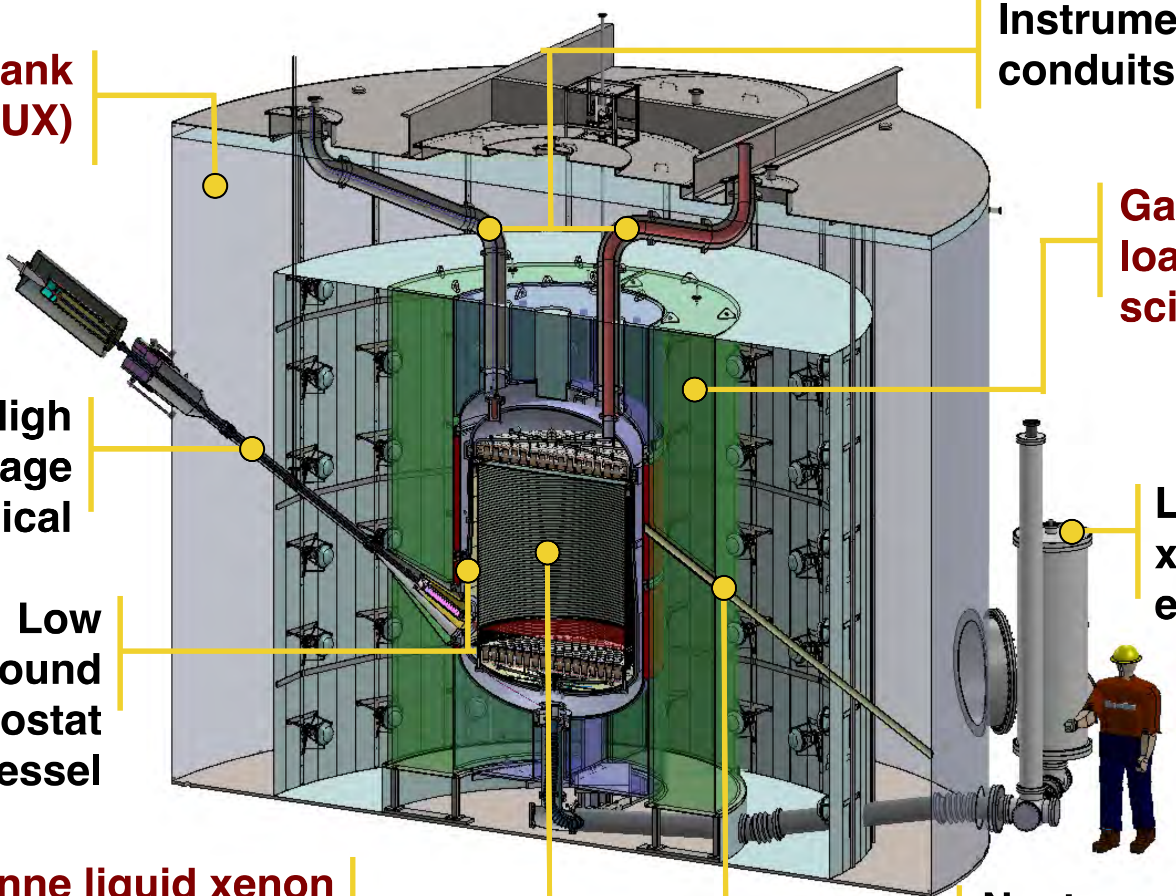
Challenge: search for events that are both rare (<< 1 event/kg/year) and involve small energy transfers (< 100 keV).

Sanford Underground Research Facility (SURF)

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



LZ schematic

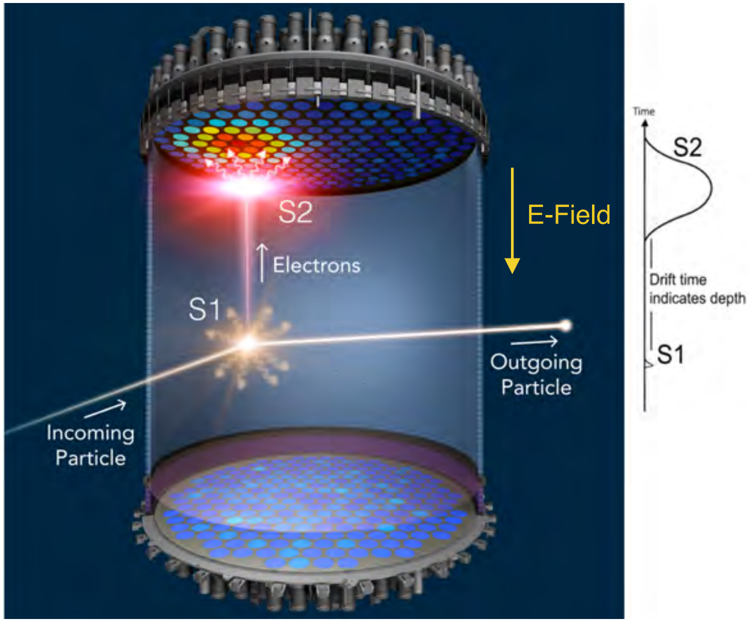


Two-phase xenon TPC

S1 prompt scintillation:
- ✧ UV photons ~ 175 nm.

S2 delayed ionisation:
- ✧ Ionisation electrons drift under E-field;
- ✧ Electroluminesce 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).

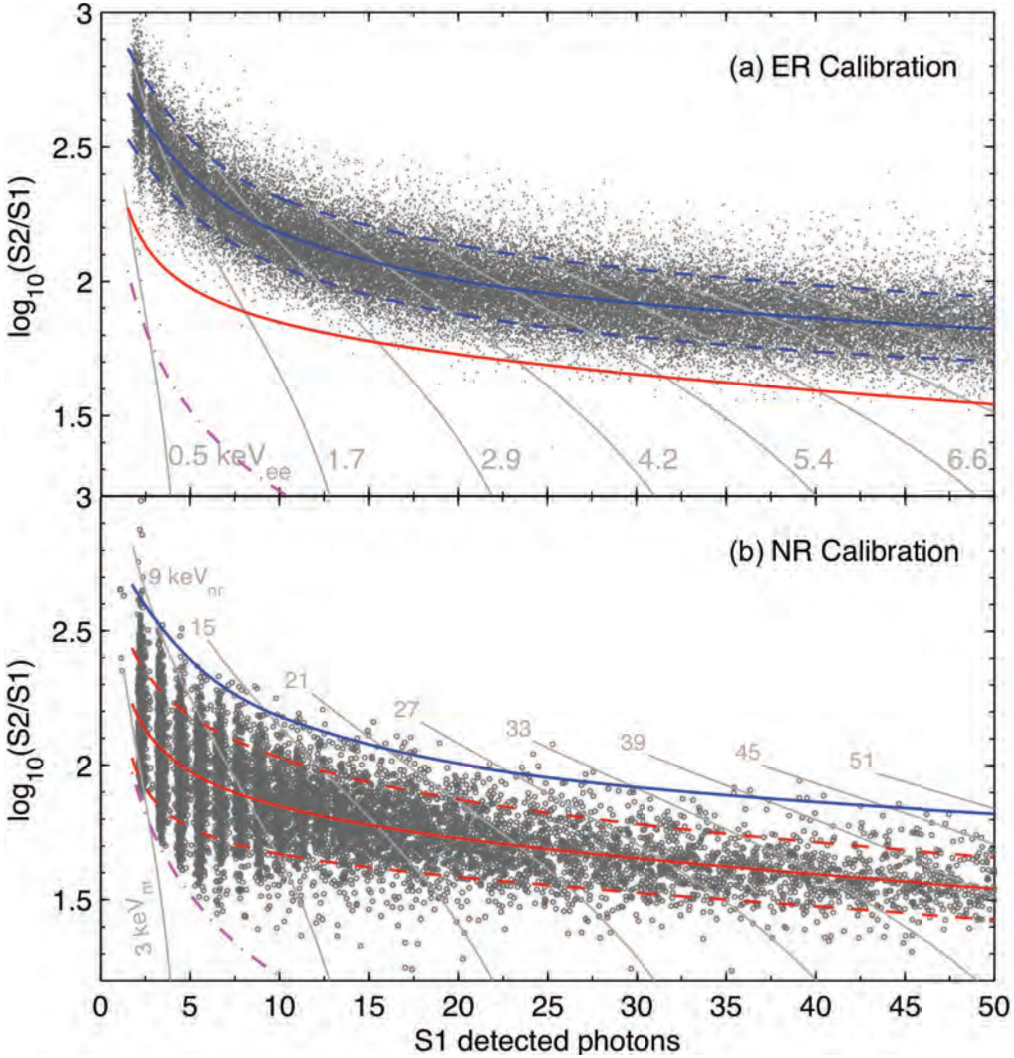


253 + 241 low background PMTs (top + bottom)

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

Scale-up ~ 50 LUX fiducial mass

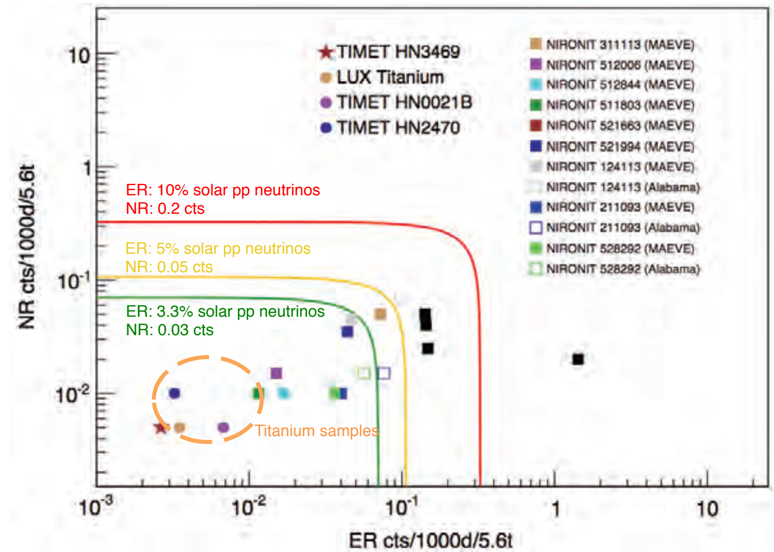
Combined S1 + S2 signals



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.

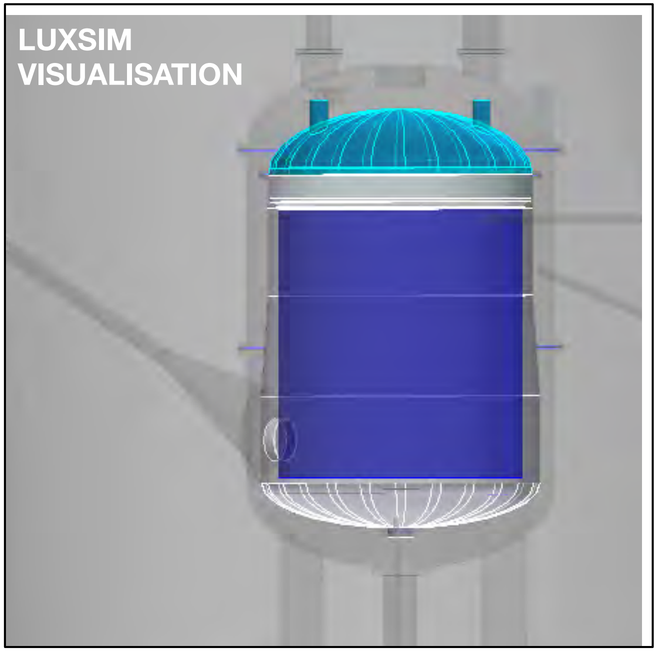


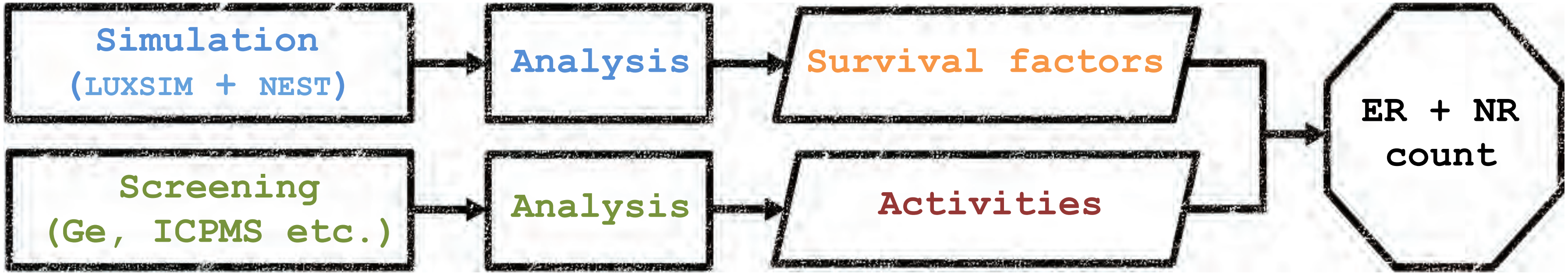
Technique	Isotopes	Sensitivity
HPGe	^{238}U, ^{235}U, ^{232}Th chains, ^{40}K, ^{60}Co, ^{137}Cs, any γ-emitter	50 ppt U, 100 ppt Th
ICP-MS	^{238}U, ^{235}U, ^{232}Th (top of chain)	10^{-12} g/g
NAA	^{238}U, ^{235}U, ^{232}Th (top of chain), K	10^{-12} g/g to 10^{-14} g/g
Radon Emanation	^{222}Rn, ^{220}Rn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

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

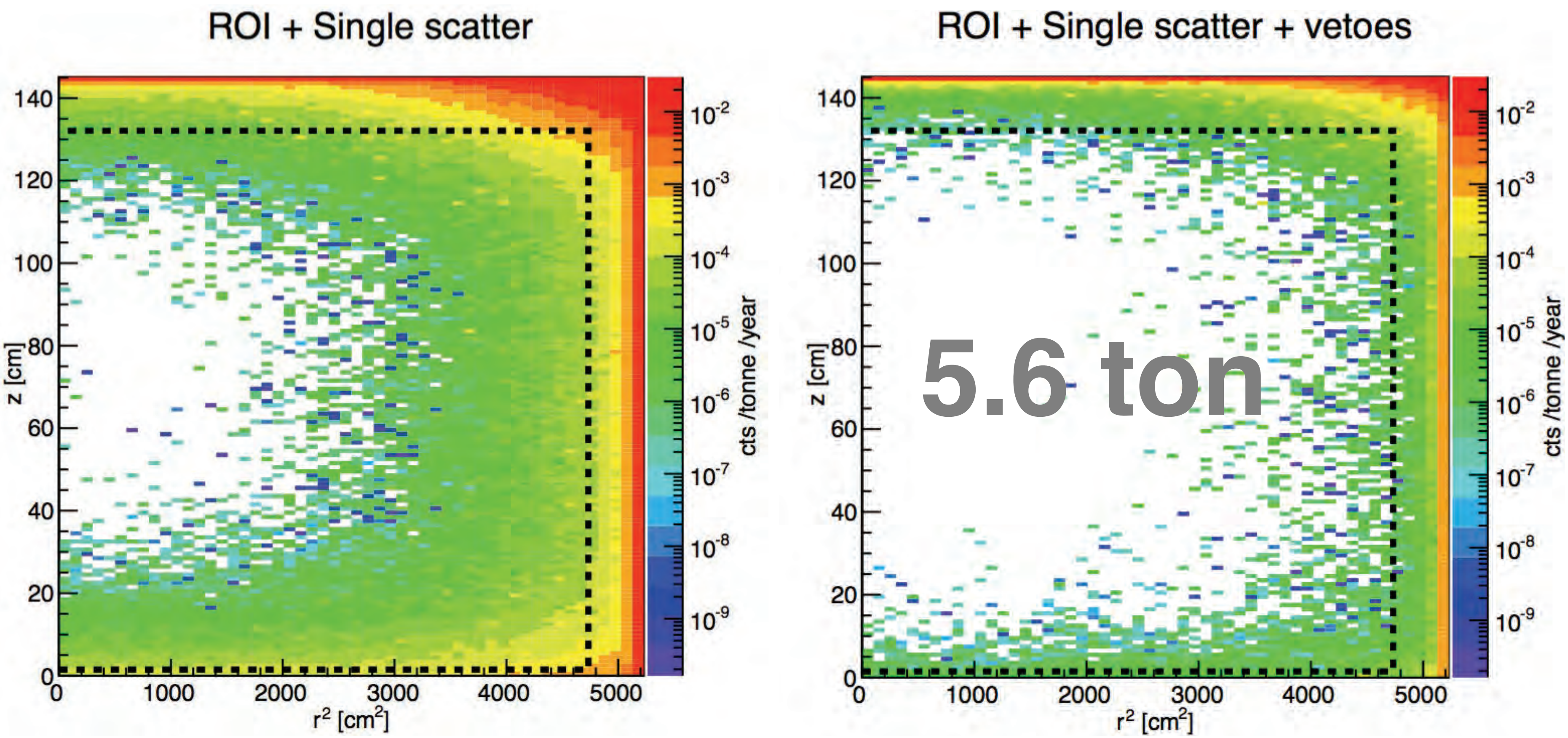
Background simulations

- 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 genertors 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].





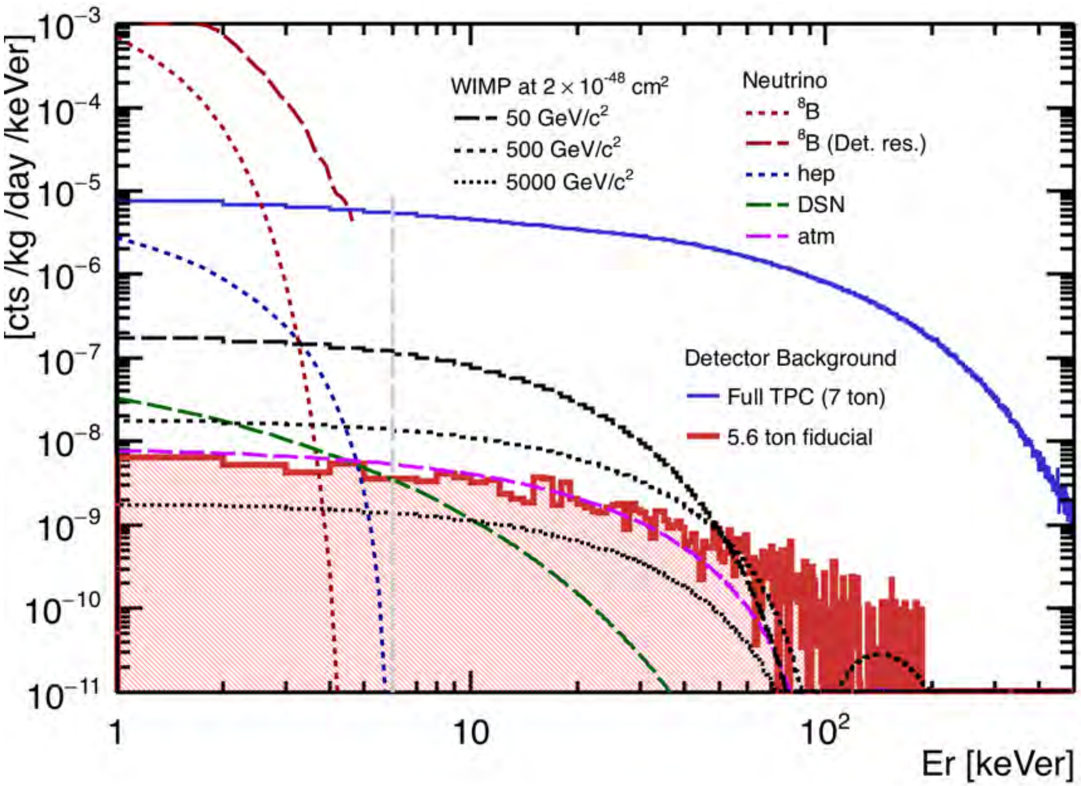
Fiducialisation



Other backgrounds

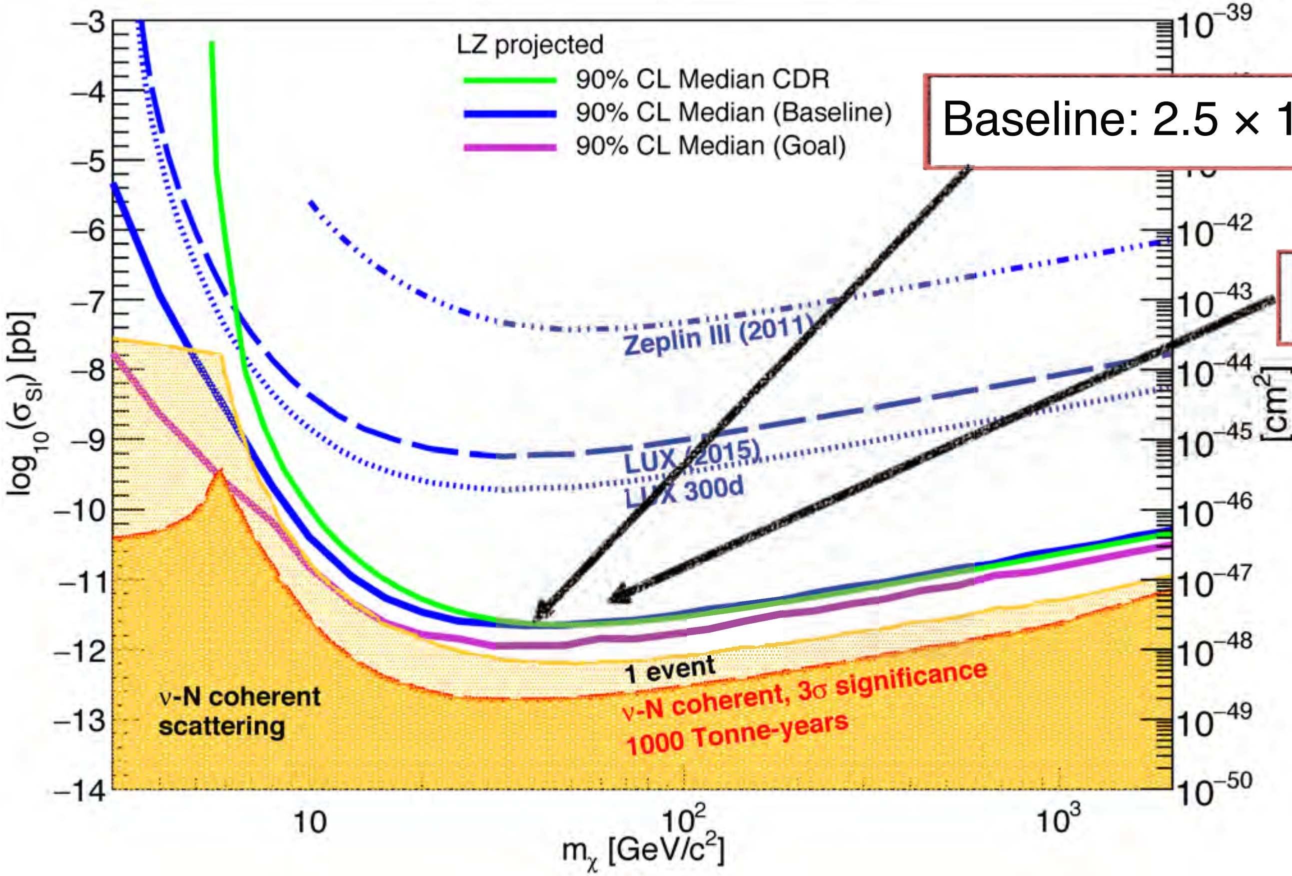
- ✧ **ER:** Neutrino-electron scattering from solar pp neutrinos, *2vbb* from ^{136}Xe.
- ✧ **NR:** Coherent-neutrino scattering from ^{8}B solar neutrinos, atmospheric and diffuse supernova neutrinos.

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}Xe *2vbb*	67.0	-
Neutrinos	255	0.72
Total events	1230	1.29
WIMP background events (99.5 % discrimination, 50% acceptance)	6.17	0.65
Total ER + NR	**6.82**	



Projected sensitivity

WIMP-nucleon SI scattering



Baseline: 2.5×10^{-48} cm^2 @ 40 GeV/c^2

Goal: 1.3×10^{-48} cm^2

LZ Timeline

Year	Month	Activity
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

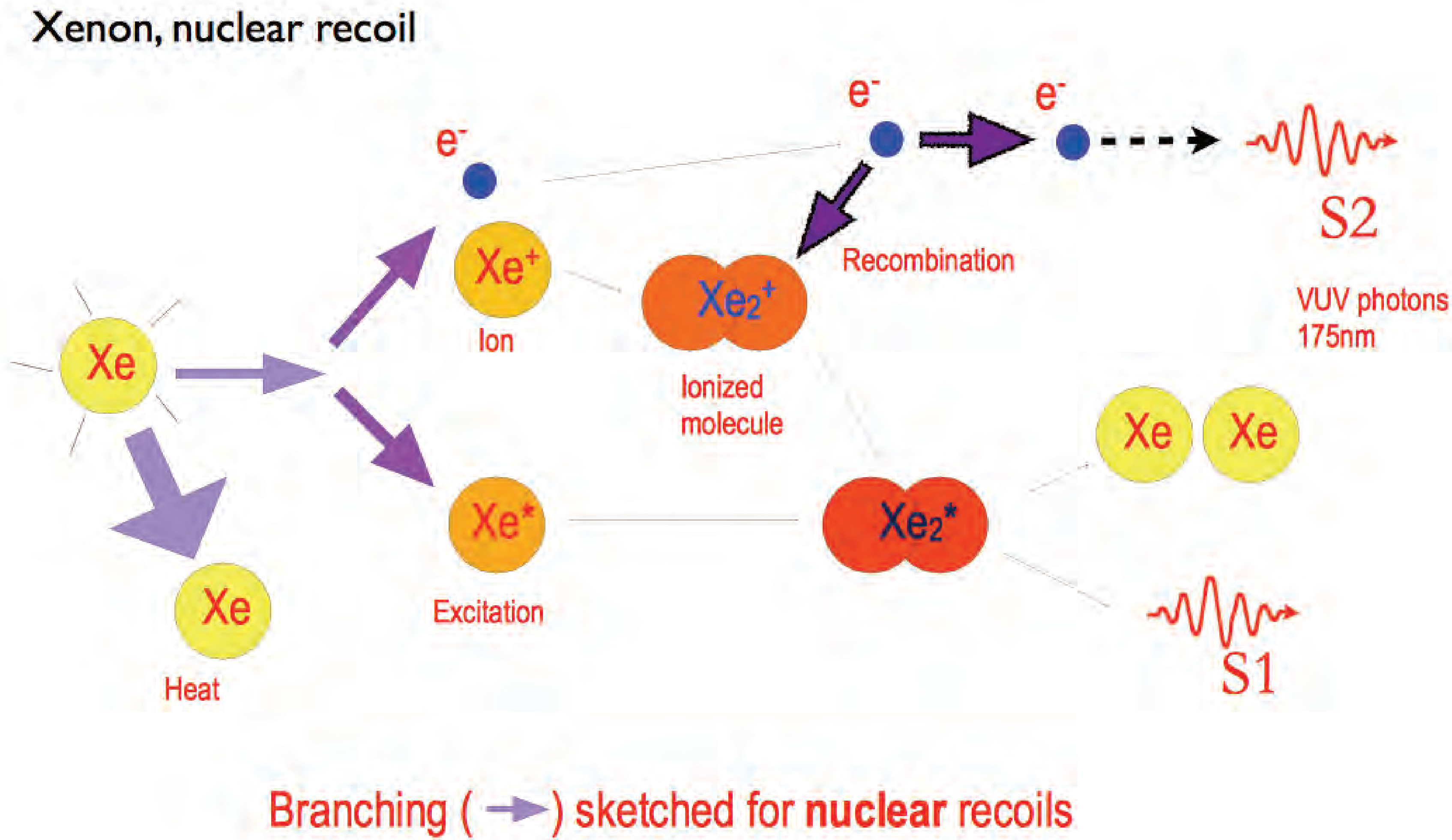
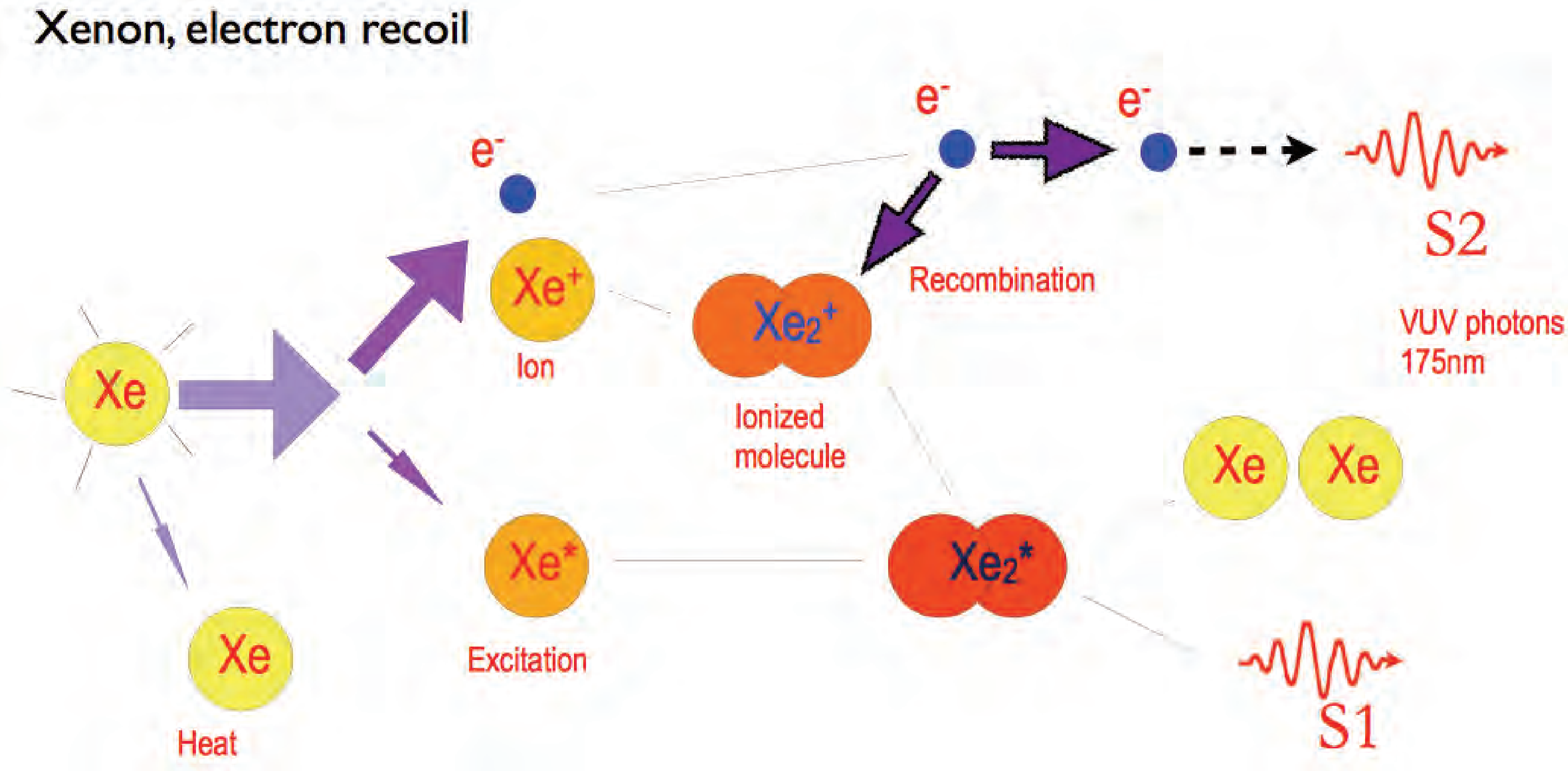


Diagram by T Shutt

Electron recoils in xenon

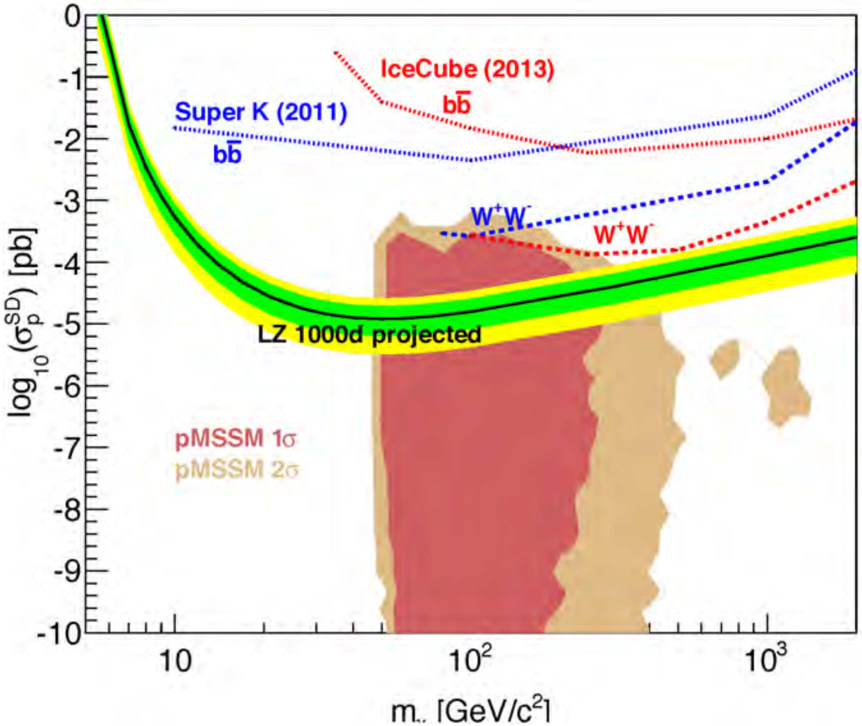


Branching ( ) sketched for **electron** recoils

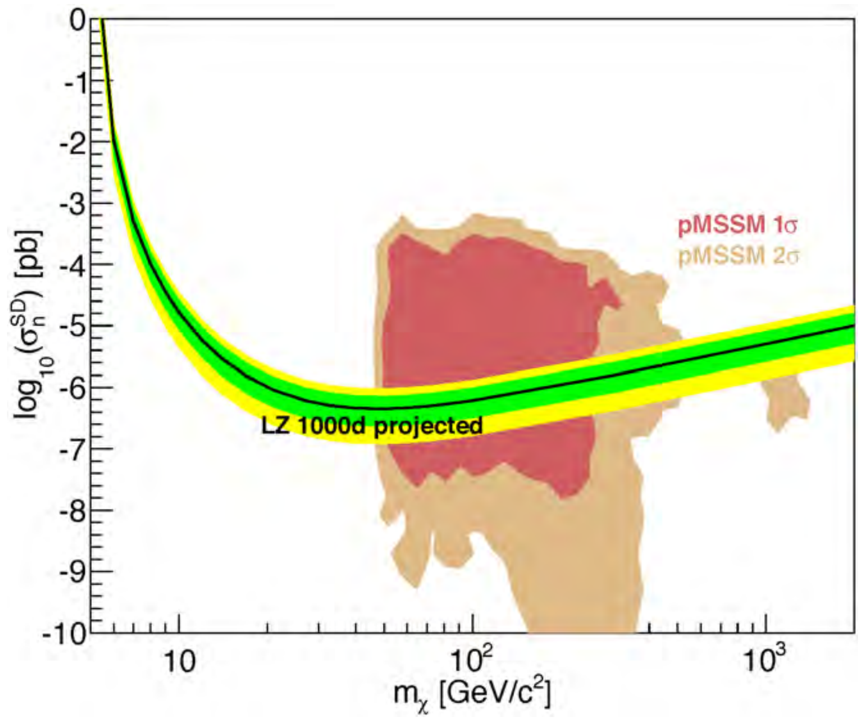
Diagram by T Shutt

Spin-dependent sensitivity

WIMP-proton SD scattering

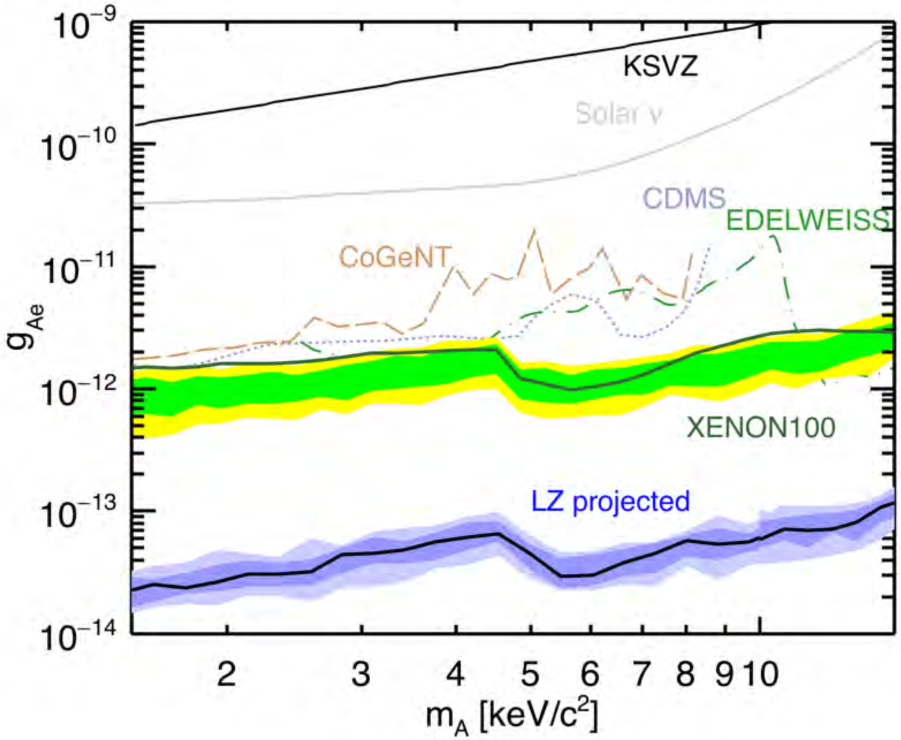


WIMP-neutron SD scattering



Axion sensitivity

Dark matter axion



Solar axion