Current status of LZ and LUX Dark Matter Experiments

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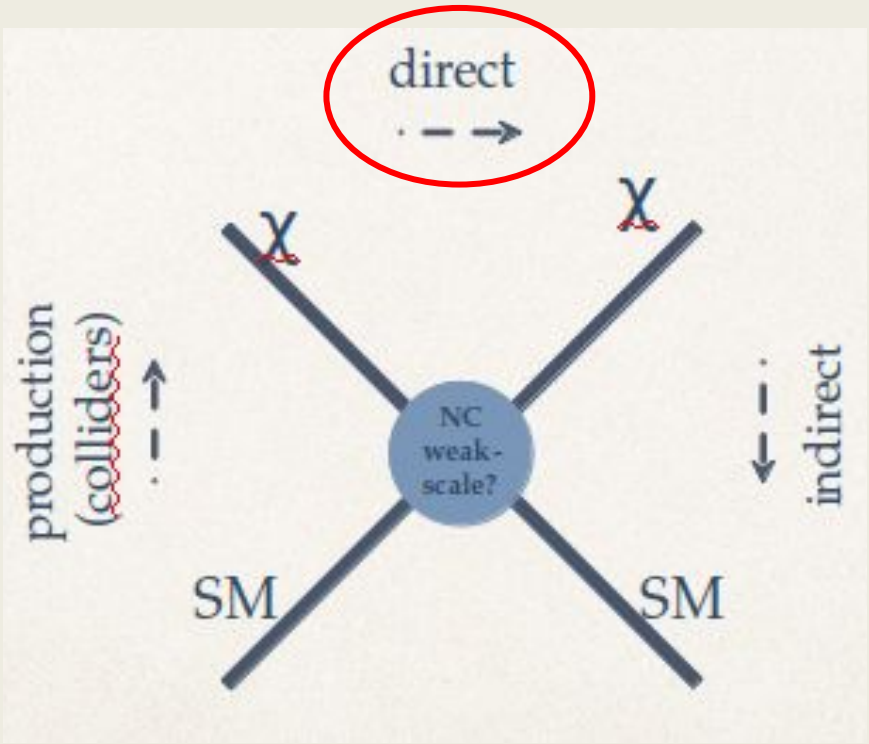
on behalf of the LUX and LZ Collaborations

ICPPA, Moscow, 25 October 2018

WIMPs and Liquid Xenon

- Main objective of the LZ project: direct search for dark matter in the form of Weakly Interacting Massive Particles (WIMPs)
- We are doing it by looking for elastic scattering of WIMPs on a liquid xenon (LXe) target. Momentum transfer from a WIMP to a Xe nucleus results in Xe nuclear recoil (NR). Most of background events produce electron recoil (ER) signal

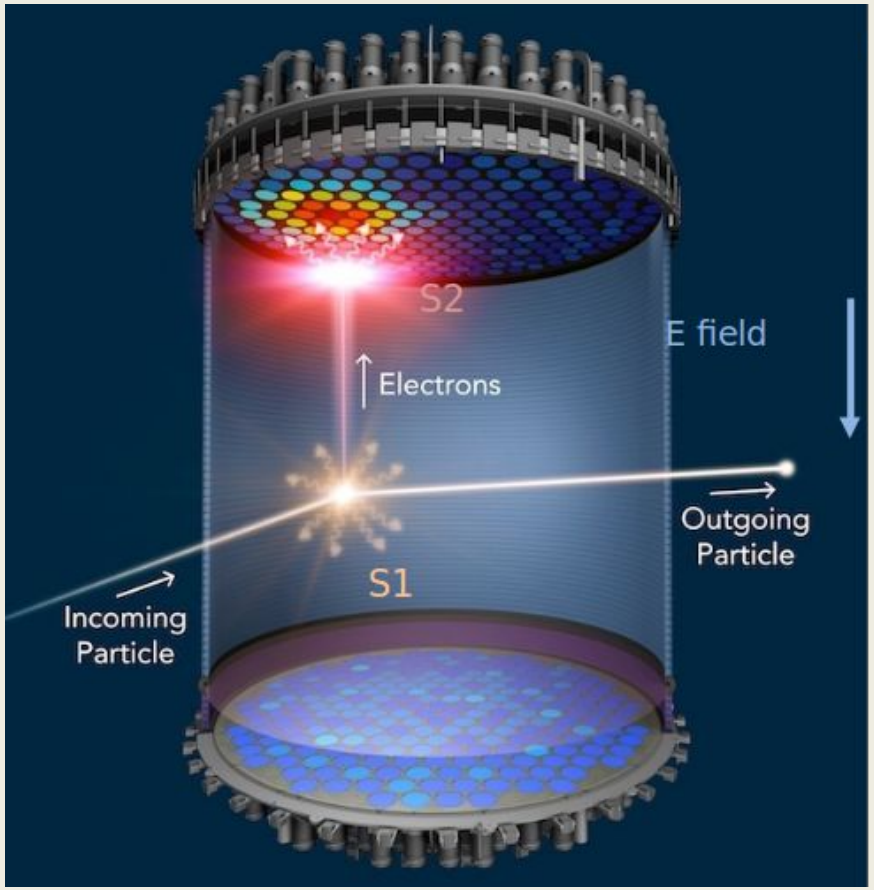


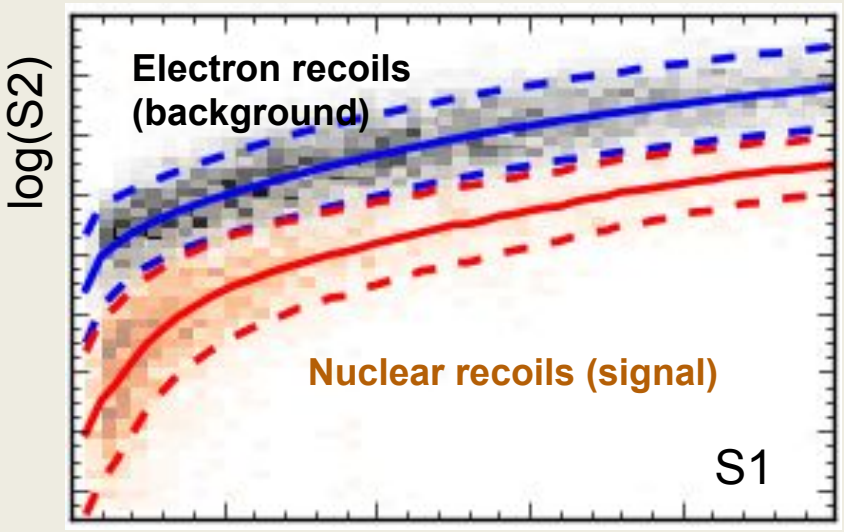
Why LXe

- Relatively high density (2.9 g/cm^3)
- High atomic mass ($\sigma_{SI} \sim A^2$)
- Spin-dependent sensitive isotopes
- High light output and fast response
- No intrinsic backgrounds
- Self-shielding capability
- Two channel (light+charge) output allows discrimination between NR and ER
- Scalable to multi-ton size

Dual-phase Xenon TPC

- **S1** - Primary scintillation
- **S2** - Proportional scintillation (light due to electrons extracted to the gas phase) - proportional to the charge
- Position sensitivity:
  - **X** and **Y** from the S2 light distribution across the top PMT array
  - **Z** from the drift time (delay between S1 and S2)



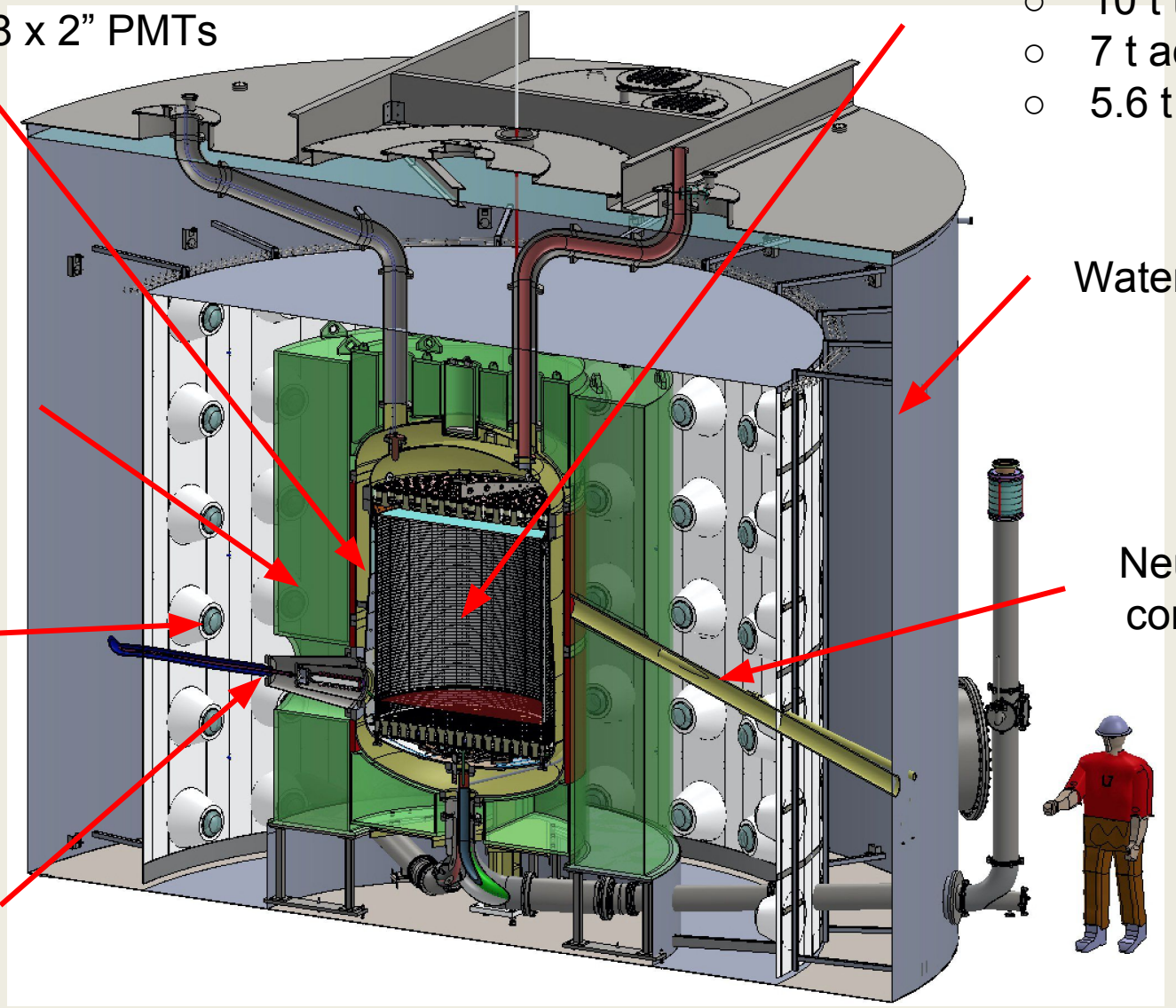


- Only single events (one S1 and one S2) are accepted
- **S2 vs S1** depends on the recoil type

LZ detector

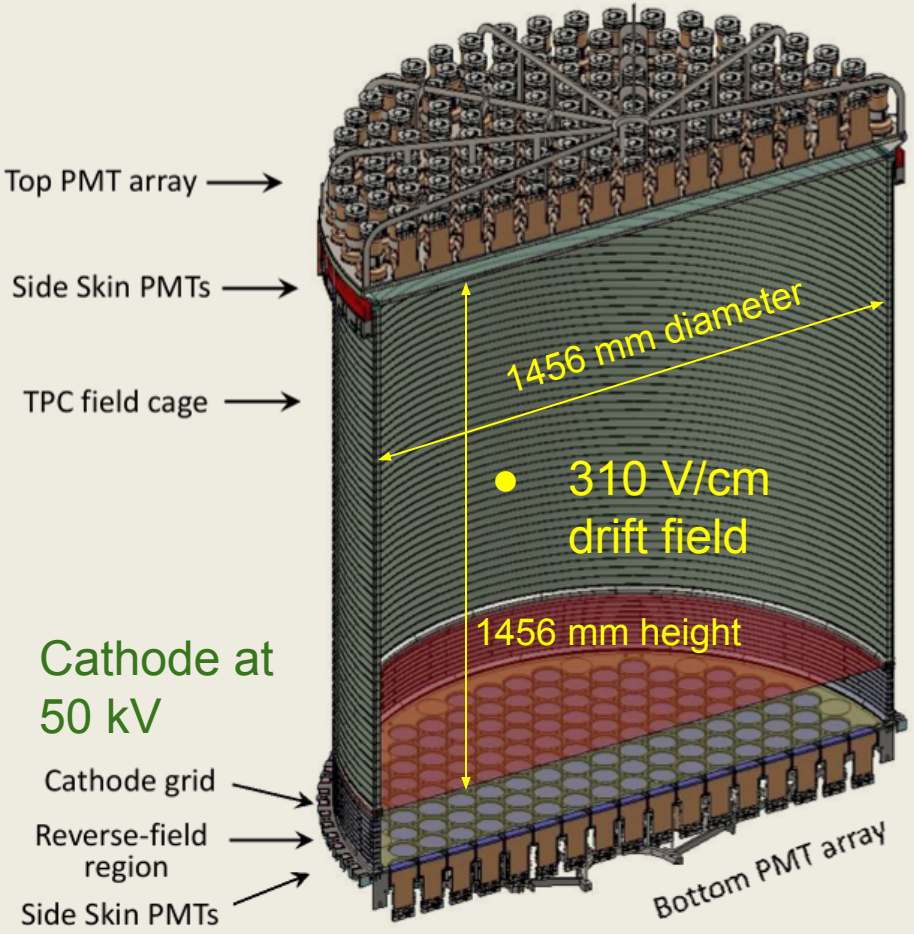
Instrumented Xe skin:
93 x 1” and 38 x 2” PMTs

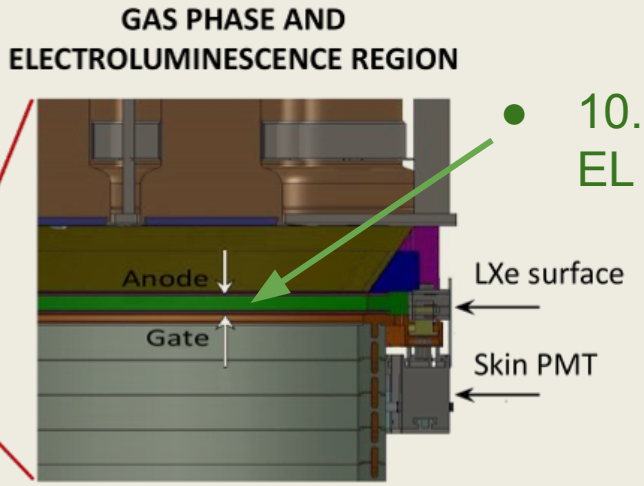
Liquid Xe TPC
- 10 t total
- 7 t active
- 5.6 t fiducial



LZ detector TPC

- PTFE wall with high reflectivity (>98%) for Xe scintillation light



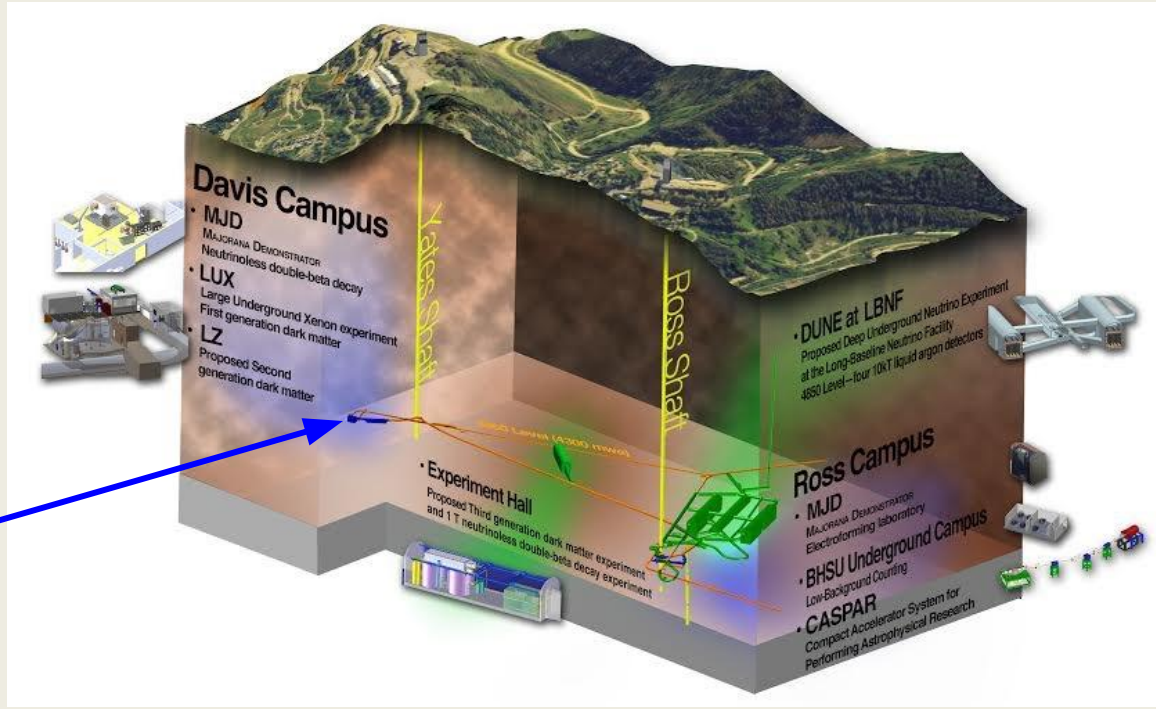


- 10.2 kV/cm EL field

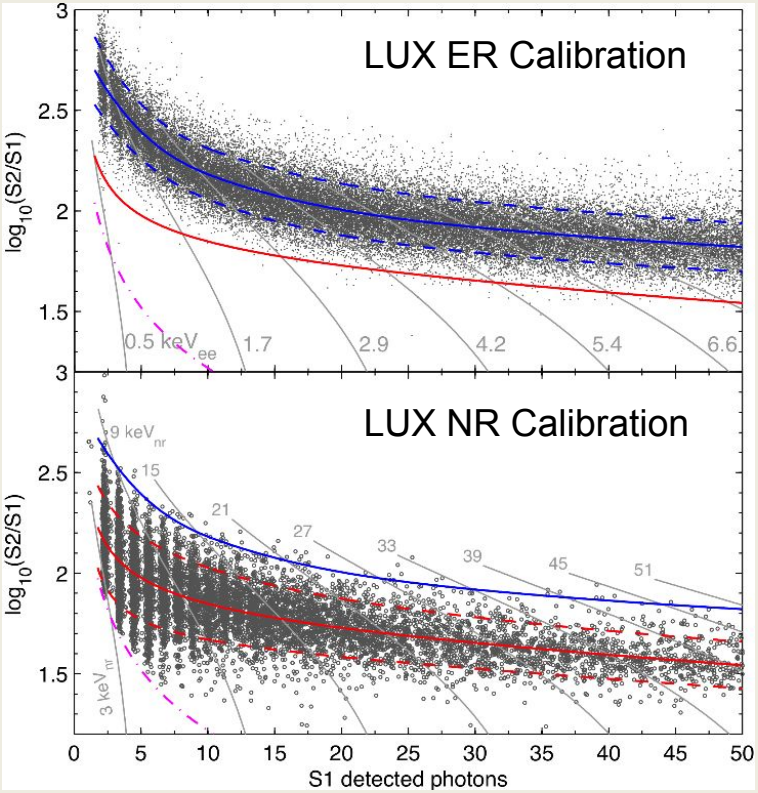
- TPC optical readout with 3” PMTs (Hamamatsu R11410)
  - 253 in the top array
  - 241 in the bottom array

LZ at SURF

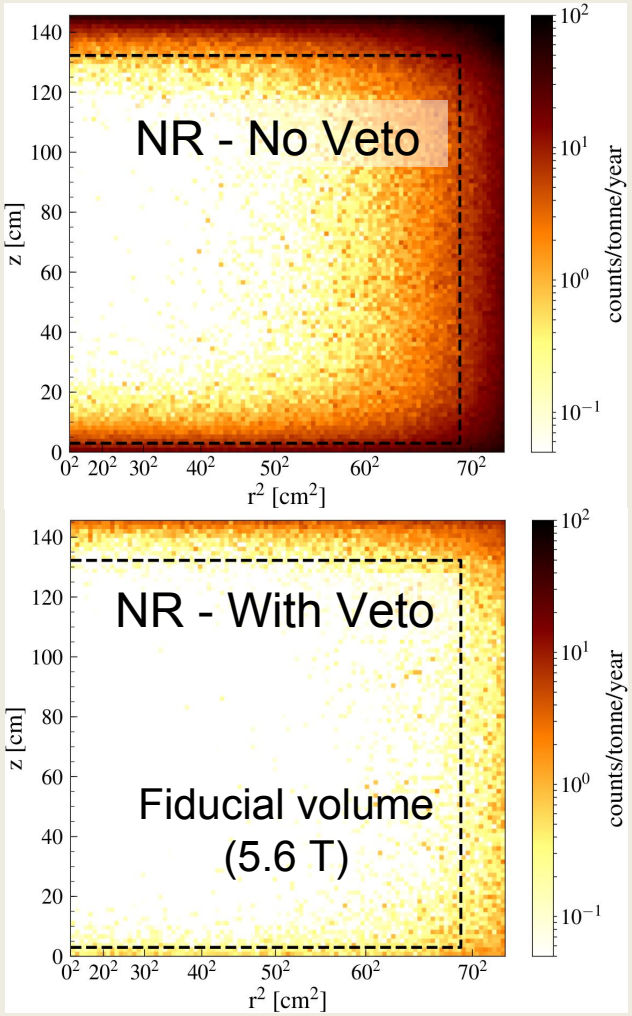
- 4850 feet (1478 m) underground
  - 4.3 km water equivalent
  - Muon flux reduced by 10^7
- LZ will be installed inside the existing LUX water tank
  - 8 m diameter, 6 m high
  - 300 t of purified water



Backgrounds suppression



LZ - simulation of NR background



- Electron recoil (ER) discrimination: S1 vs S2 analysis eliminates >99.5% of ER events
- Two veto systems (Instrumented Xe skin + Gd-loaded LS outer detector) further reduce NR background by factor of ≈10 in the 1.5-6 keV region of WIMP search

Backgrounds control

- Radio-assay campaign for all detector materials
  - γ-screening, ICP-MS, NAA
  - Rn emanation screening campaign
- Charcoal chromatography to remove ^{85}Kr and ^{39}Ar from the Xe target
  - Dedicated facility at SLAC
  - Final ^{nat}Kr/Xe 0.015 ppt (g/g)

- Controlling dust and Rn daughters plate-out
  - TPC Assembly in Rn-reduced cleanroom to limit daughter recoils on surfaces
  - Screening of dust and Rn daughters on exposed surfaces with witness plates
  - Rn-daughter plate-out on TPC walls < 0.5 mBq/m^2
  - Dust < 500 ng/cm^2 on all LXe wetted surfaces

Backgrounds summary

5.6 Tonne fiducial mass, 1000 live-days, ~1.5 - 6.5 keV, single scatters and veto

Background Source	ER (cts)	NR (cts)
Detector Components	9	0.07
Surface Contamination	40	0.39
Laboratory and Cosmogenics	5	0.06
Xenon Contaminants	819	0
222Rn	681	0
220Rn	111	0
natKr (0.015 ppt g/g)	24	0
natAr (0.45 ppb g/g)	3	0
Physics	322	0.51
136Xe 2νββ	67	0
Solar neutrinos (pp+7Be+13N)	255	0
Diffuse supernova neutrinos	0	0.05
Atmospheric neutrinos	0	0.46
Total	1195	1.03
with 99.5% ER discrim., 50% NR eff.	**5.97**	**0.51**

Neutrons, mostly from alpha-n on PTFE

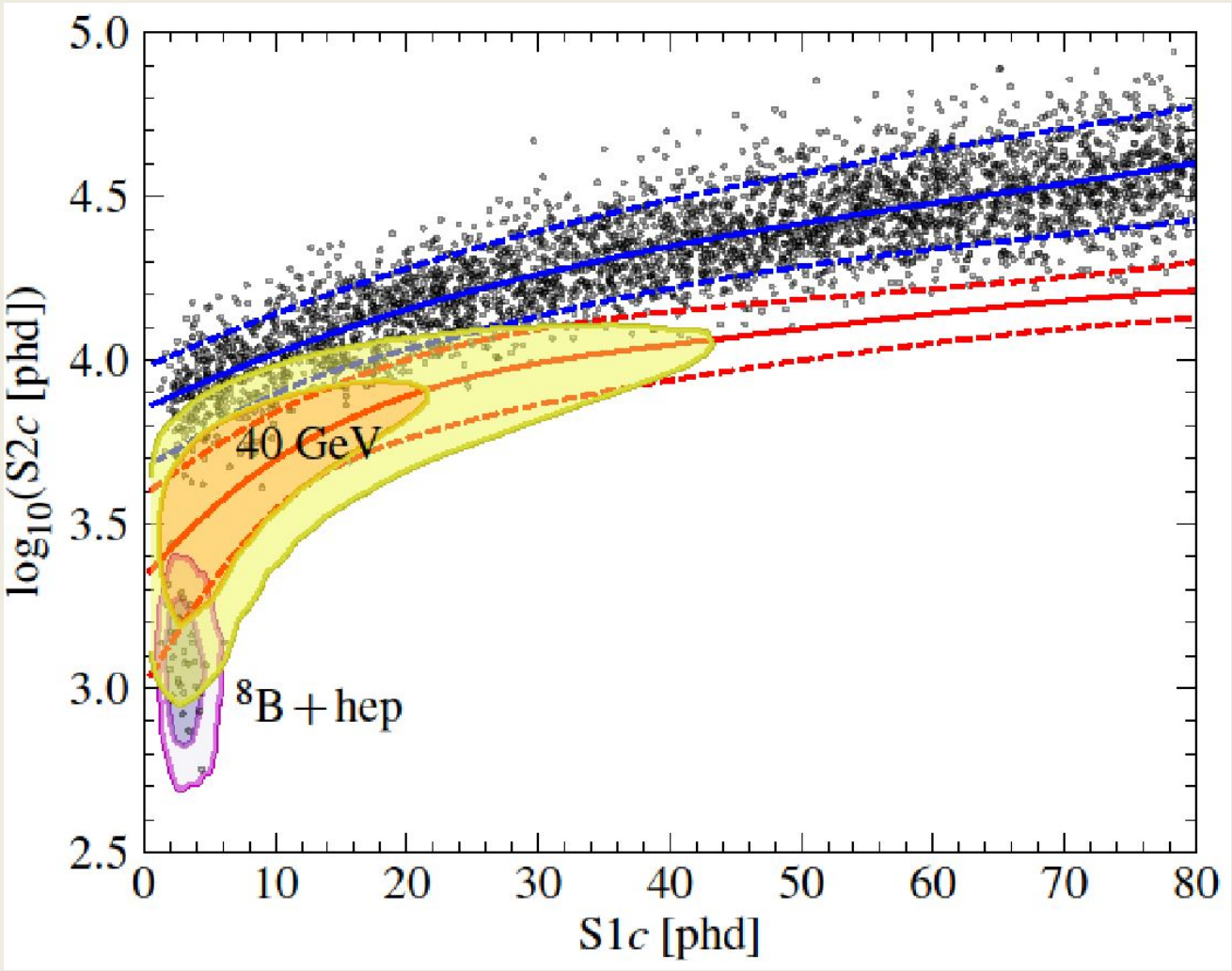
Radon dominates ER backgrounds

νe scattering of *pp* solar νs; (atomic electron recoils)

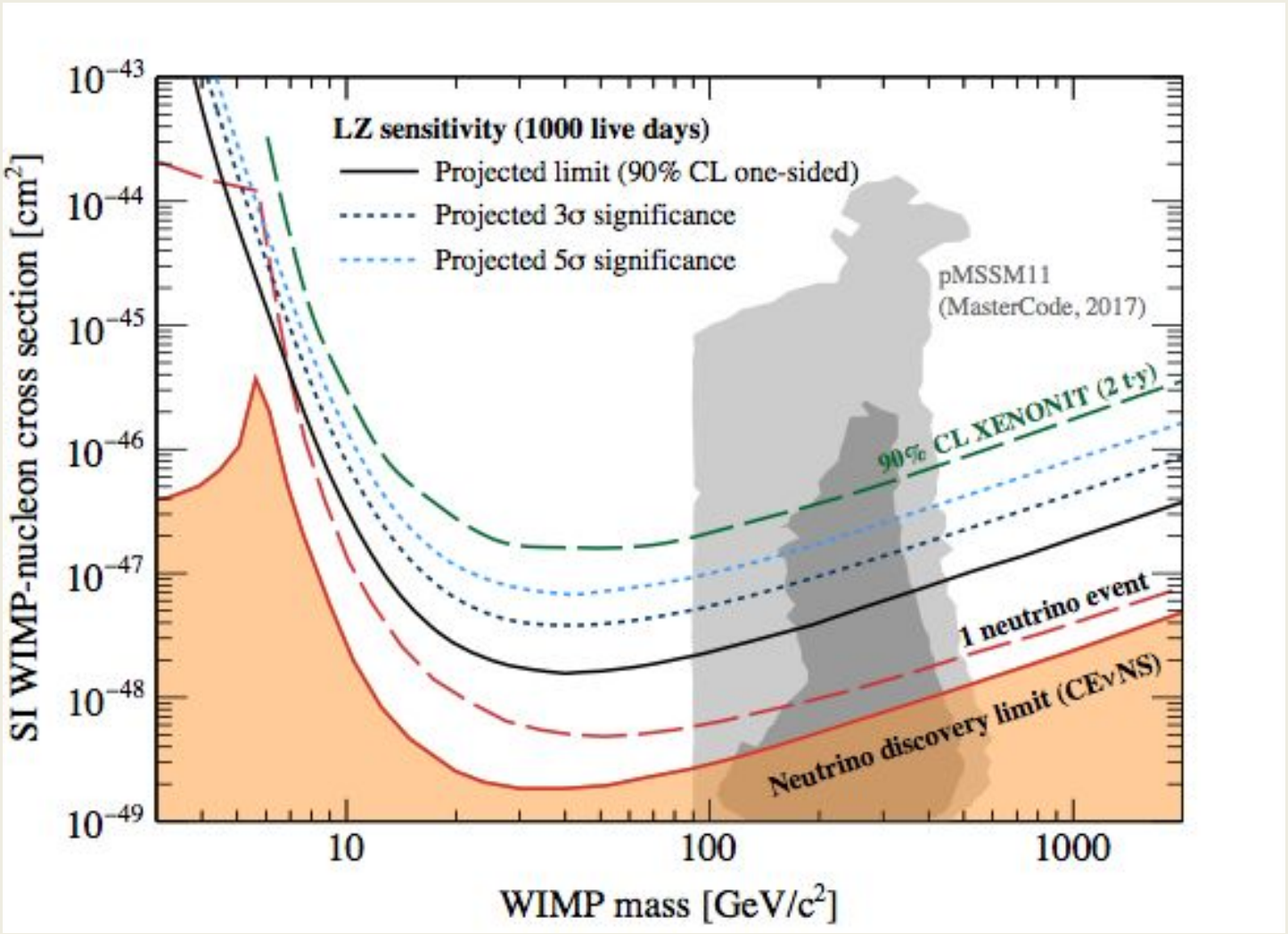
Coherent scattering of atmospheric νs on Xe nuclei

Simulated LZ full exposure

40 GeV/c^2 WIMP, 1000 days, 5.6 tonnes

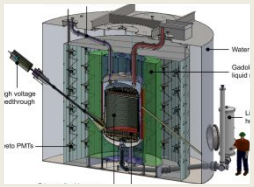


WIMP Discovery Potential

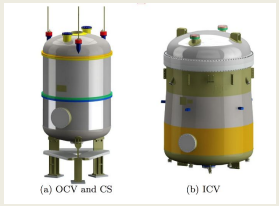


LZ Timeline

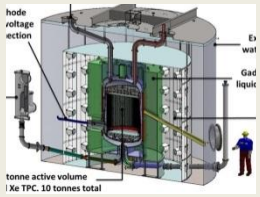
CDR, Sept 2015



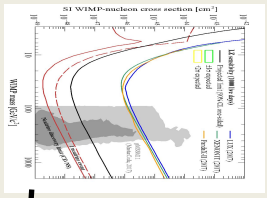
Titanium paper, Feb 2017



TDR, March 2017



WIMP sensitivity paper, Feb 2018



2015 2016 2017 2018 2019 2020

Alabama

Coimbra

LLNL

Oxford

SLAC

SURF

FNAL

Coimbra

Brandeis

US CD-1 March 2015

US CD-2 April 2016

US CD-3 Jan 2017

UK project 97% complete March 2018

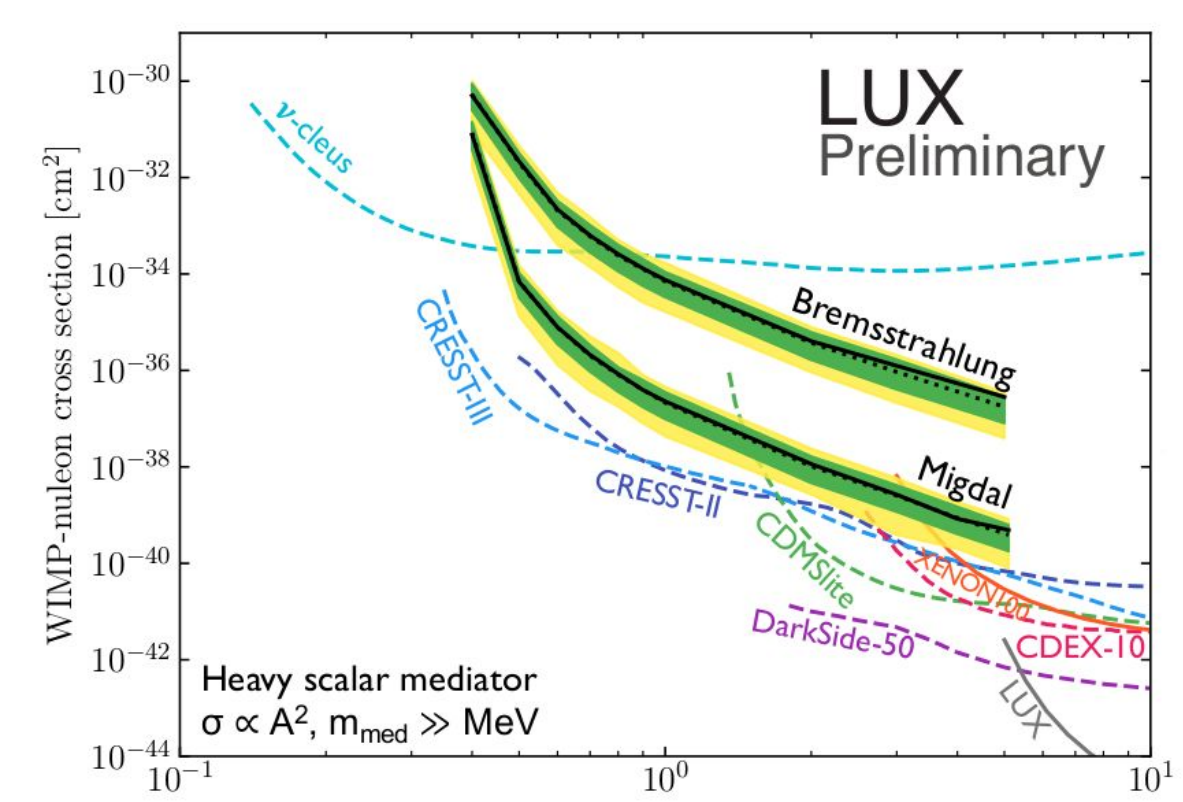
TPC moves underground, Summer 2019

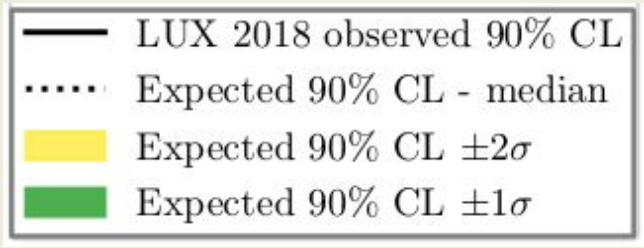
US CD-4 and operations start, April 2020

= Collaboration meeting

LUX update: Sub-GeV WIMPs

based on analysis of 2013 data





WIMP-nucleus interactions produce a polarised xenon atom. Sometimes, this may result in:

- keV-range electron emission (Migdal effect)
- X-ray photon emission (bremsstrahlung)

Through these effects, LUX is sensitive to very low mass WIMPs (down to 0.4 GeV/c^2)

Upcoming publication: will be posted to arXiv in the next few weeks

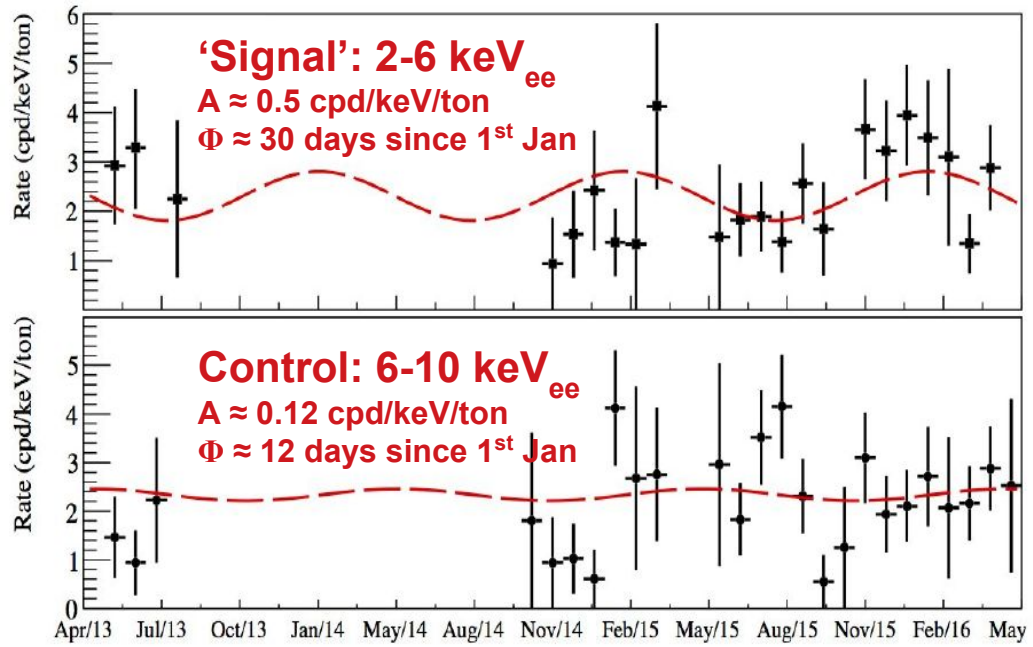
Analysis of 2014-2016 data is in progress.

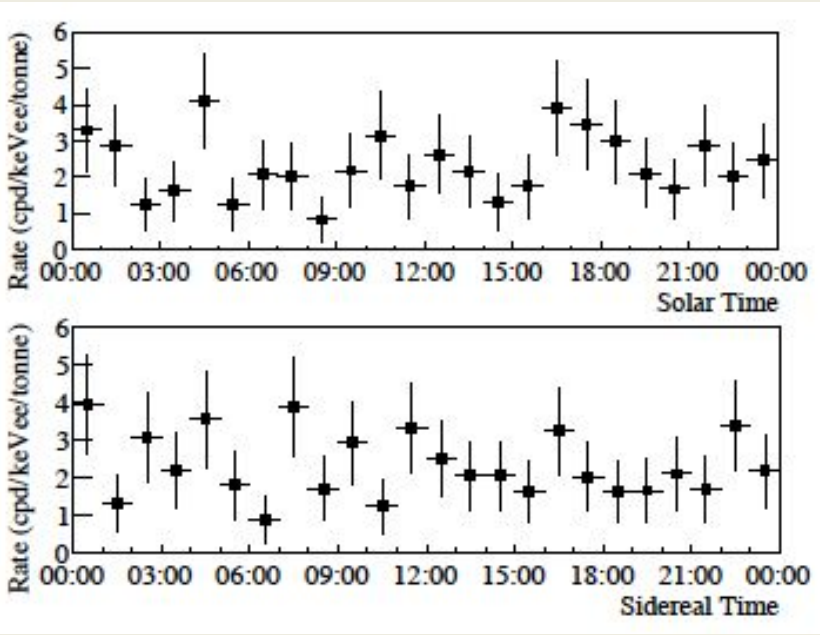
LUX update: modulation studies

Annual

Diurnal

day/night: 2.28 / 2.36 cpd/keV/ton (siderial)
Asymmetry: -1.7% ± 8.7% (stats only)





- The rate at low energies: ~2 events/tonne/day/keV, modulation amplitude is 10-20 times lower than reported by DAMA.
- No statistically significant annual or diurnal modulation found.

Phys. Rev. D 98, 062005 (2018)

LUX and LZ Collaborations

LUX collaboration:

- 30 institutions
- ~100 scientists

LZ collaboration:

- 38 institutions
- ~250 scientists, engineers and technicians

Thank you!

LZ: Not only WIMPs

- **Elastic Scattering of Solar Neutrinos**: expected 838 pp events, 69 events from ^{7}Be and <10 from ^{13}N (E_{ν} <220 keV) in the 1.5 to 20 keVee window (LZ will be sensitive to neutrinos energies significantly lower than SAGE or BOREXINO)
- **Coherent Nuclear Scattering of Solar Neutrinos**: Expected 36 events from ^{8}B neutrinos (with a signal very similar to a 6 GeV WIMP)
- **Neutrino Magnetic Moment**: the LZ ~1 keV energy threshold suggests an increase in sensitivity of ~1 order of magnitude relative to the upper limit of 5.4×10^{-11} μ_B set by BOREXINO;
- **Neutrinoless Double Beta Decay**: LZ has the potential to a sensitivity limit on the 0νββ half-life of ^{136}Xe of 0.74×10^{25} y, 90% C.L. (the current half-life limit is 1.07×10^{26} y set by KamLAND-Zen)