crystaLiZe: path forward

Hao Chen, Ryan Gibbons, Scott Haselschwardt, Scott Kravitz, Peter Sorensen, Shilo Xia

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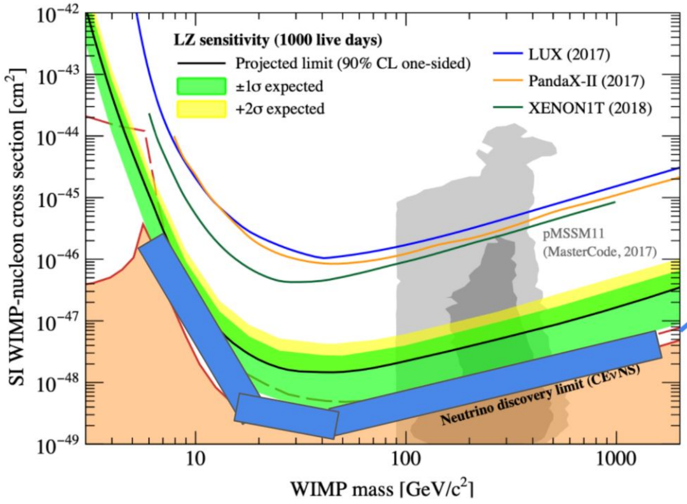
snowmass@lbl

Lesko slide

Physics Opportunities of a Xenon Observatory



- Dark Matter
  - WIMP
  - EFT interpretations
  - Low Mass Sensitivity
  - Other DM models
- Neutrinoless Double-Beta Decay
- Astronomical Neutrinos
  - Solar
  - Atmospheric
  - Supernovae

LZ expects 200 pp neutrinos and 1000 betas (from Rn)

- If neutrinos were the limiting background, could just operate LZ until it reaches the neutrino floor
- If LZ were a crystalline xenon TPC, radon decays would have a unique (E,x,y,z,t) signature. >98% Rn tagging. **Neutrino Limited**
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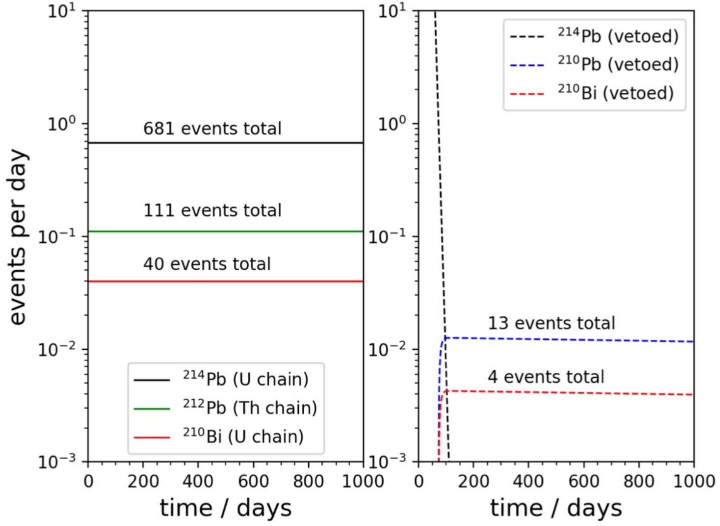
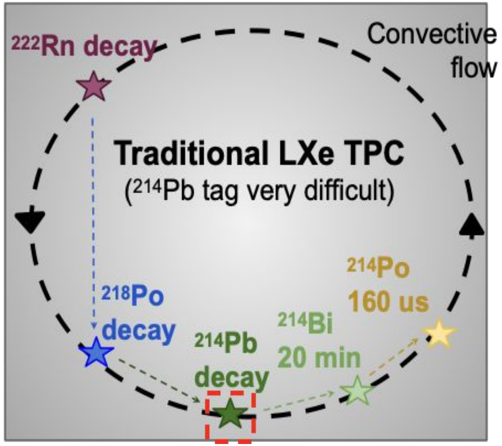
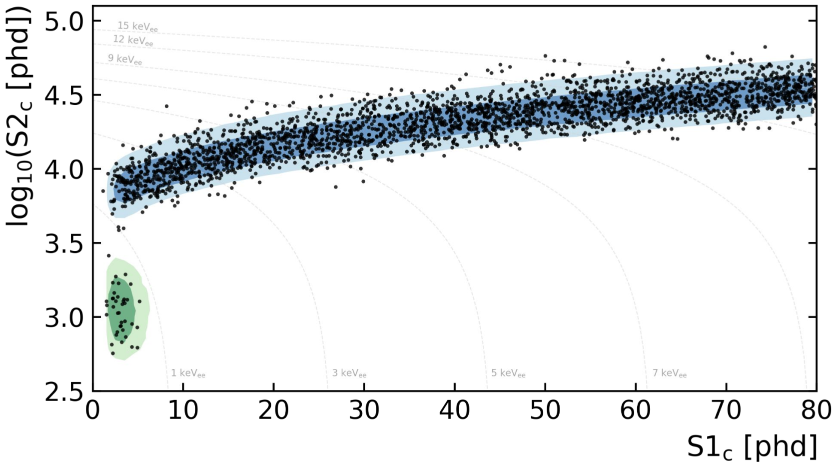


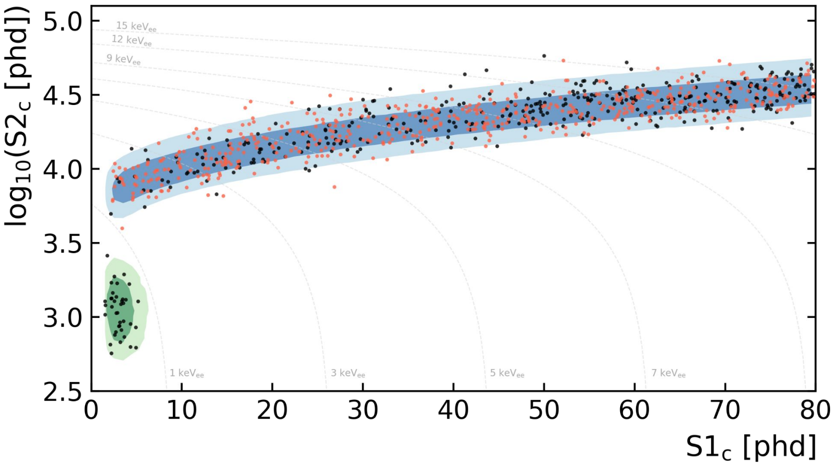


LZ with Rn (left) and without Rn (right)

LZ 1000 day, with Rn

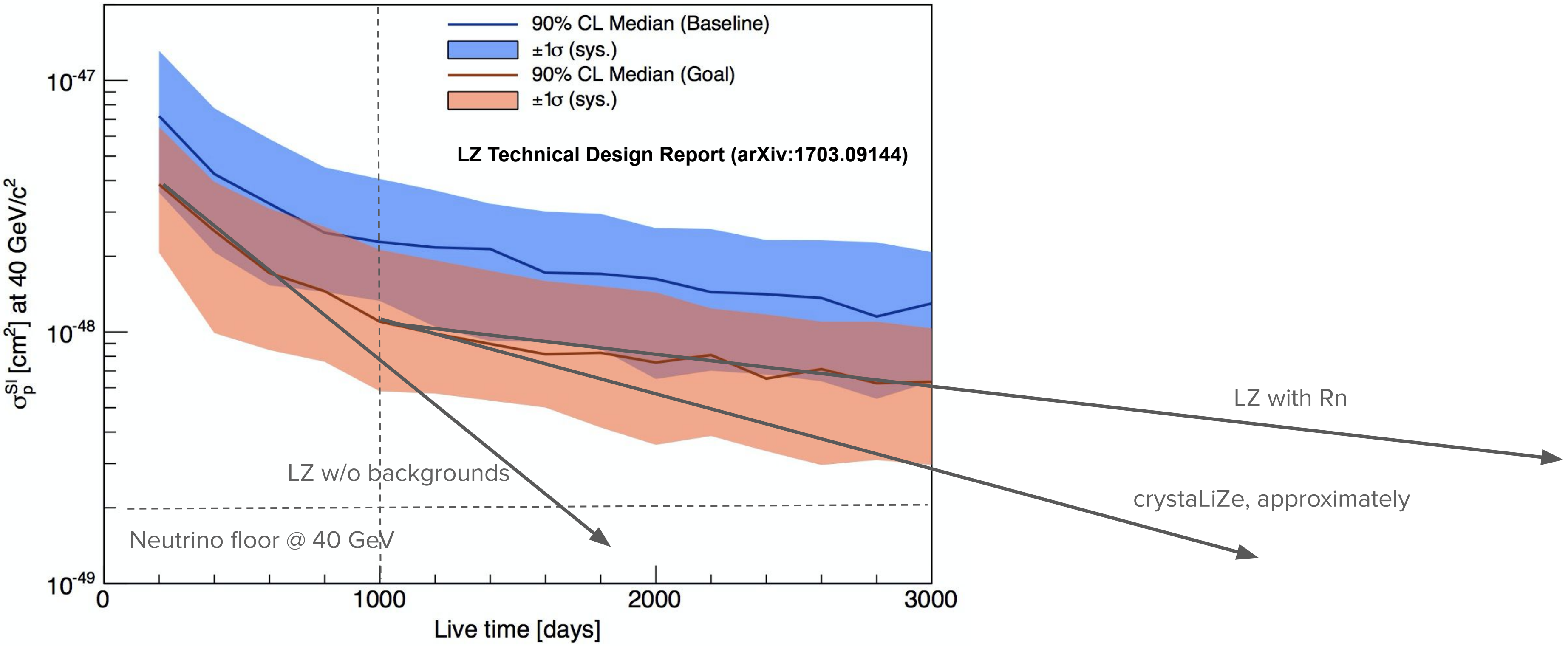


crystaLiZe 1000 day, without Rn



Could further remove another 67 BG events (⅓ of pp neutrino number) if 136Xe were swapped out – e.g. to nEXO

LZ sensitivity vs time



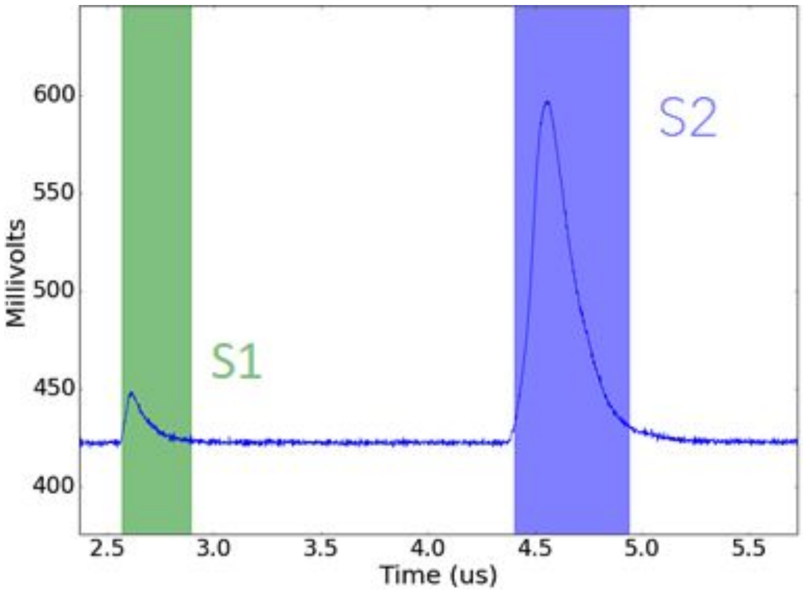
Why pursue crystaLiZe?

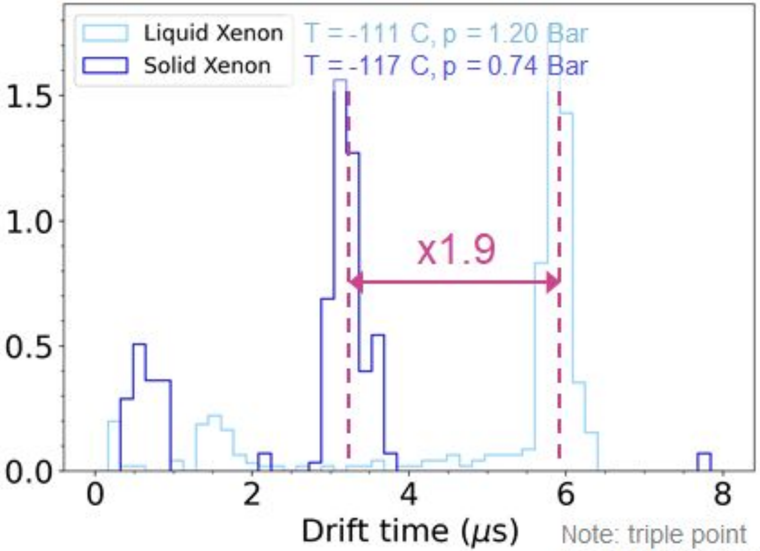
pros	cons
- G3 will be politically fraught, expensive (guess ~$250M) and time-consuming (at least 10 years from CD0) – *will it happen??* - LZ infrastructure exists, in principle it is a small* perturbation to crystalize it - electron mobility x2 - Potential for improved discrimination (still hypothetical)	- Technical challenges - Demonstrated at the cm scale, need O(100) cm 10-20 years to reach neutrino limit

**small: guess $25M / 2.5 years*

R&D status: basic concept appears to work nicely

- First demonstration of a dual-phase crystalline/vapor xenon TPC
  - Manuscript in progress (Scott Kravitz / Hao Chen lead on analysis & writing)
- Photon yield demonstrated same as in liquid
- Subsequent study will focus on e- yield and emission across crystal/vapor interface
- + Rn tagging (!!)





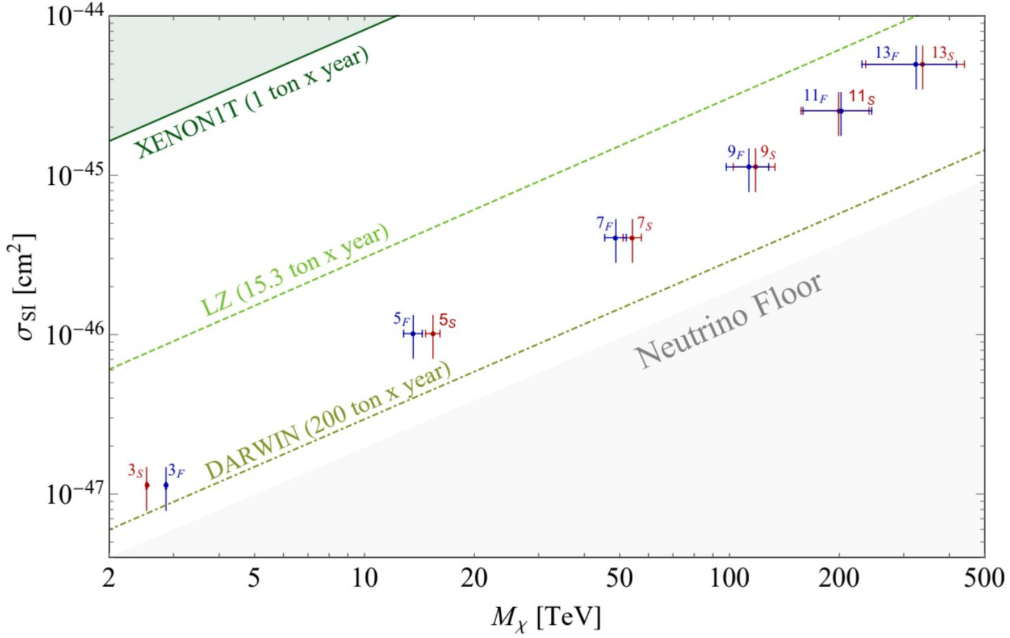
Note: triple point
T = -111.8 C, p = 0.82 Bar

Next steps

1. IF08 LOI => White paper
2. R&D demonstration of S2 stability and performance (FY22)
3. R&D demonstration of Rn-tagging (FY23-FY24)
4. Community buy-in
5. Engineering design studies
   a. For retrofitting LZ as-needed, with temperature sensors and heaters
   b. Also SiPMs

Extra slide: we need to close the window on WIMP DM

Plot from arXiv:2107.09688



Extra slide: technical details

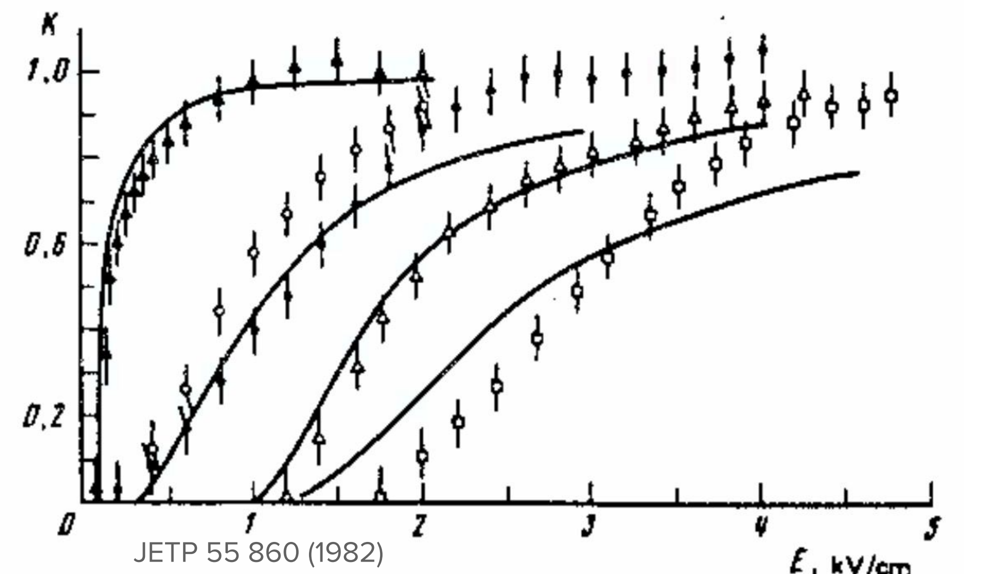
Solid xenon emission TPC is expected to perform at least as well as a liquid xenon emission TPC:

- electron mobility: x2
- electron emission: easier
- band gap (hence W-value): same
- density: 20% bonus
- high voltage: similar dielectric constant but challenge due to ice-fishing effect

TABLE II. Comparison of transport parameters in solid and liquid xenon. Values of other data used in the calculations are also quoted.

	Solid $T = 161.2$ °K	Liquid $T = 163$ °K	Unit
E_G	9.272	9.22	eV
G	1.063	1.084	eV
ϵ_∞	2.00 [a]	1.85 [b]	···
m^*	0.31 [c]	0.27	electron mass
μ	4.5×10^3 [d]	2.2×10^3 [e]	$cm^2 V^{-1} sec^{-1}$
τ_p	8.0×10^{-13}	3.4×10^{-13}	sec
L	7.1×10^{-6}	3.3×10^{-6}	cm
β	1.36×10^{10} [f]	0.58×10^{10} [g]	dyn/cm^2
$\|a\|$	3.8×10^{-9}	4.2×10^{-9}	cm
$\|E_{1CB}\|$	0.93	1.01	eV

Phys Rev B 10 4464 (1974)



JETP 55 860 (1982)

Extra slide: 136Xe next up for removal

TABLE III. Estimated backgrounds from all significant sources in the LZ 1000 day WIMP search exposure. Counts are for a region of interest relevant to a 40 GeV/c^2 WIMP: approximately 1.5–6.5 keV for ERs and 6–30 keV for NRs; and after application of the single scatter, skin and OD veto, and 5.6 tonne fiducial volume cuts. Mass-weighted average activities are shown for composite materials and the ^{238}U and ^{232}Th chains are split into contributions from early- and late-chain, with the latter defined as those coming from isotopes below and including ^{226}Ra and ^{224}Ra, respectively.

Background Source	Mass (kg)	^{238}U$_e$	^{238}U$_l$	^{232}Th$_e$	^{232}Th$_l$	^{60}Co	^{40}K	n/yr	ER (cts)	NR (cts)
		mBq/kg								
Detector Components										
PMT systems	308	31.2	5.20	2.32	2.29	1.46	18.6	248	2.82	0.027
TPC systems	373	3.28	1.01	0.84	0.76	2.58	7.80	79.9	4.33	0.022
Cryostat	2778	2.88	0.63	0.48	0.51	0.31	2.62	323	1.27	0.018
Outer detector (OD)	22950	6.13	4.74	3.78	3.71	0.33	13.8	8061	0.62	0.001
All else	358	3.61	1.25	0.55	0.65	1.31	2.64	39.1	0.11	0.003
								subtotal	**9**	**0.07**
Surface Contamination										
Dust (intrinsic activity, 500 ng/cm^2)									0.2	0.05
Plate-out (PTFE panels, 50 nBq/cm^2)									-	0.05
^{210}Bi mobility (0.1 µBq/kg LXe)									40.0	-
Ion misreconstruction (50 nBq/cm^2)									-	0.16
^{210}Pb (in bulk PTFE, 10 mBq/kg PTFE)									-	0.12
								subtotal	**40**	**0.39**
Xenon contaminants										
^{222}Rn (1.8 µBq/kg)									681	-
^{220}Rn (0.09 µBq/kg)									111	-
^{nat}Kr (0.015 ppt g/g)									24.5	-
^{nat}Ar (0.45 ppb g/g)									2.5	-
								subtotal	**819**	**0**
Laboratory and Cosmogenics										
Laboratory rock walls									4.6	0.00
Muon induced neutrons									-	0.06
Cosmogenic activation									0.2	-
								subtotal	**5**	**0.06**
Physics										
^{136}Xe $2\nu\beta\beta$									67	-
Solar neutrinos: pp+^{7}Be+^{13}N, ^{8}B+hep									191	0*
Diffuse supernova neutrinos (DSN)									-	0.05
Atmospheric neutrinos (Atm)									-	0.46
								subtotal	**258**	**0.51**
Total									1131	1.03
Total (with 99.5% ER discrimination, 50% NR efficiency)									5.66	0.52
Sum of ER and NR in LZ for 1000 days, 5.6 tonne FV, with all analysis cuts									**6.18**	

* Below the 6 keV NR threshold used here.

- Could imagine swapping enriched xenon with nEXO
- crystaLiZe gets lower BG, nEXO gets higher sensitivity
- win-win for physics