CRYSTALIZE: A SOLID FUTURE FOR LZ

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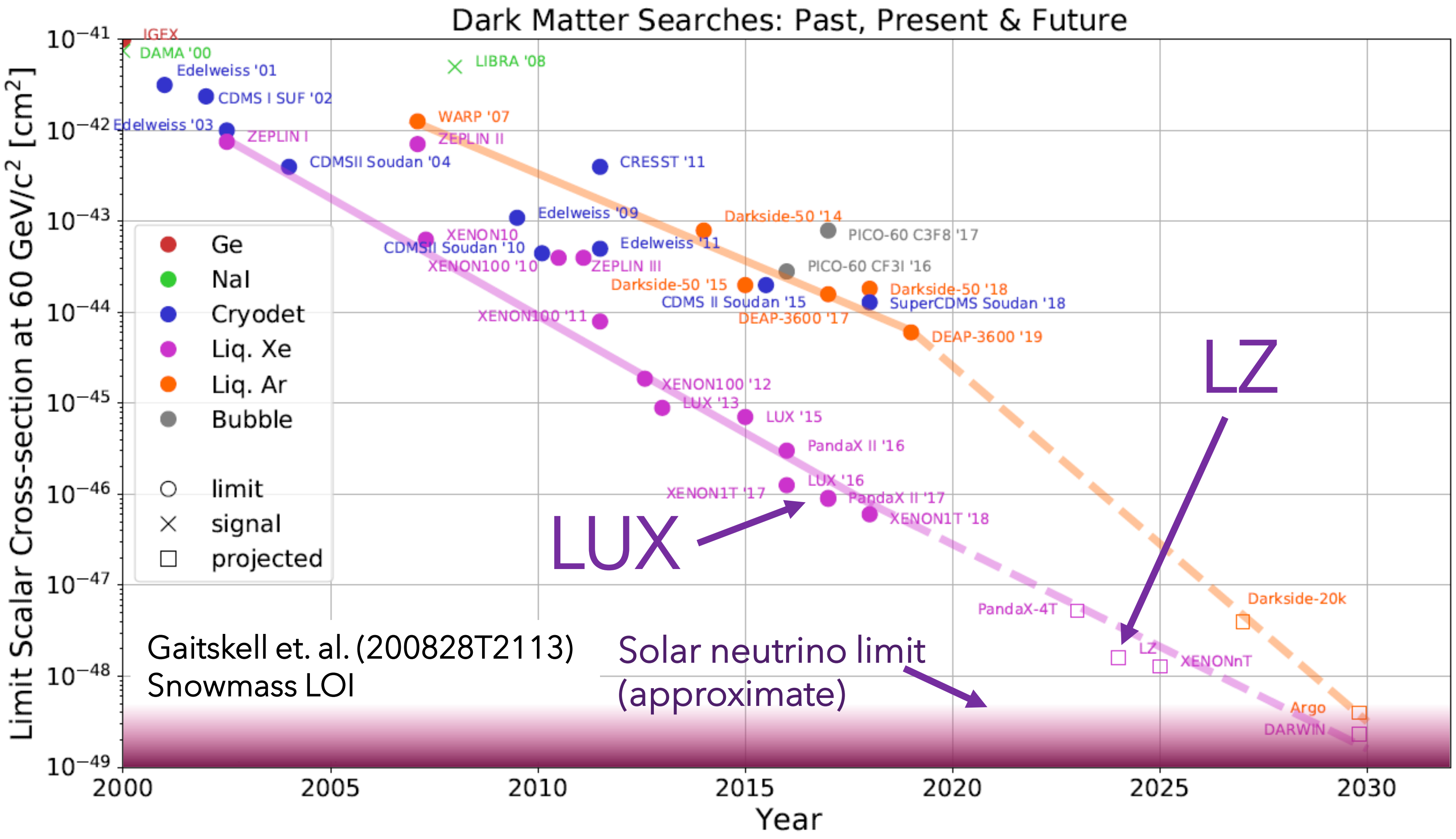
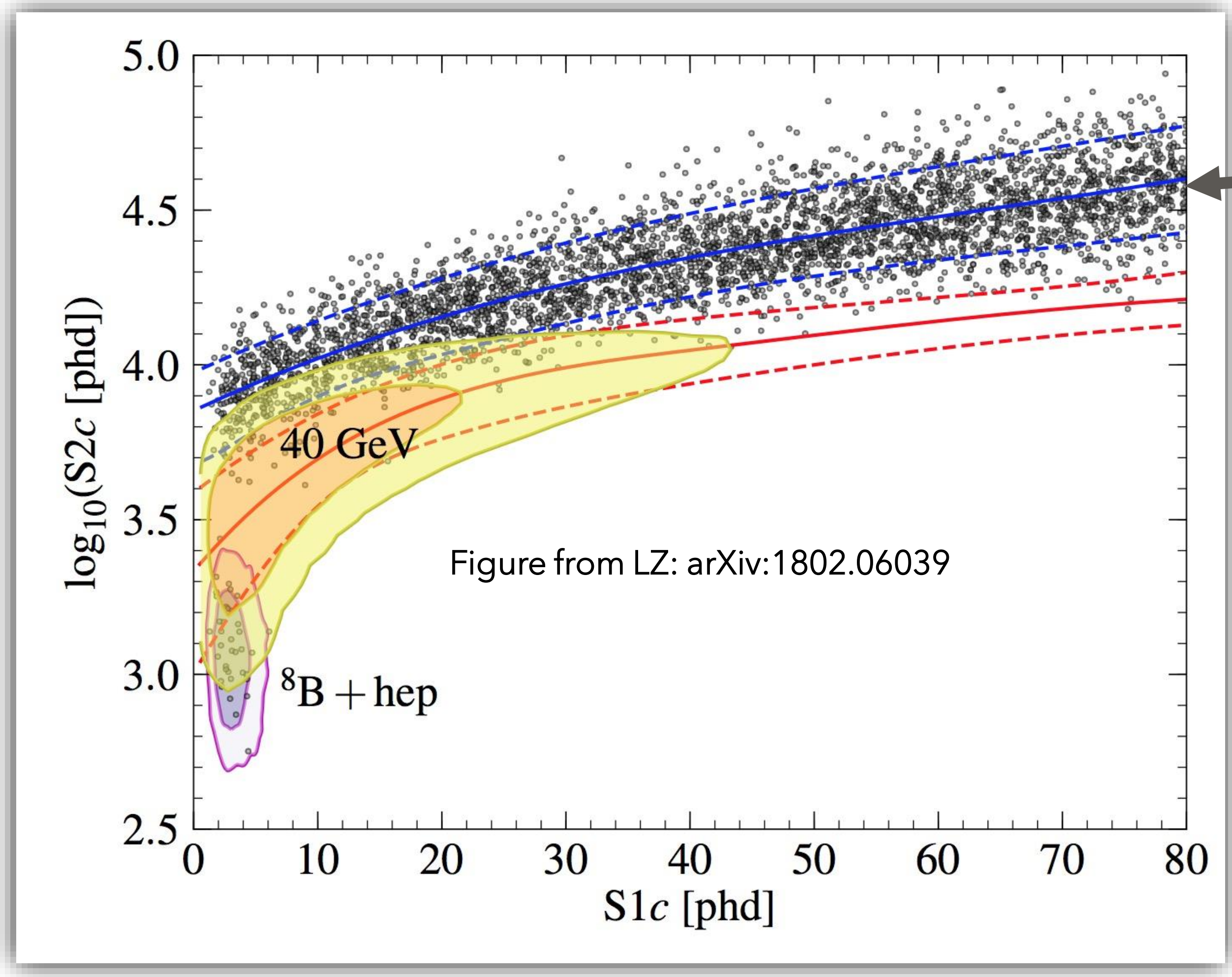
THE FUTURE OF DIRECT DETECTION

- Xe TPCs excel at WIMP direct detection searches
- LZ: next generation Xe TPC – physics data this year!
- What happens next?
- Ultimate goal: detect DM or reach neutrino floor/fog
- Simply increasing detector size likely insufficient!



LZ LIMITATIONS FROM BACKGROUNDS



1100 BG events
800 from Rn
200 from solar nu
<1 atm. nu
40 8B nu

w/ 99.5% ER/NR discrimination,
4 of 6 bkg events from Rn
1 from solar nu ER

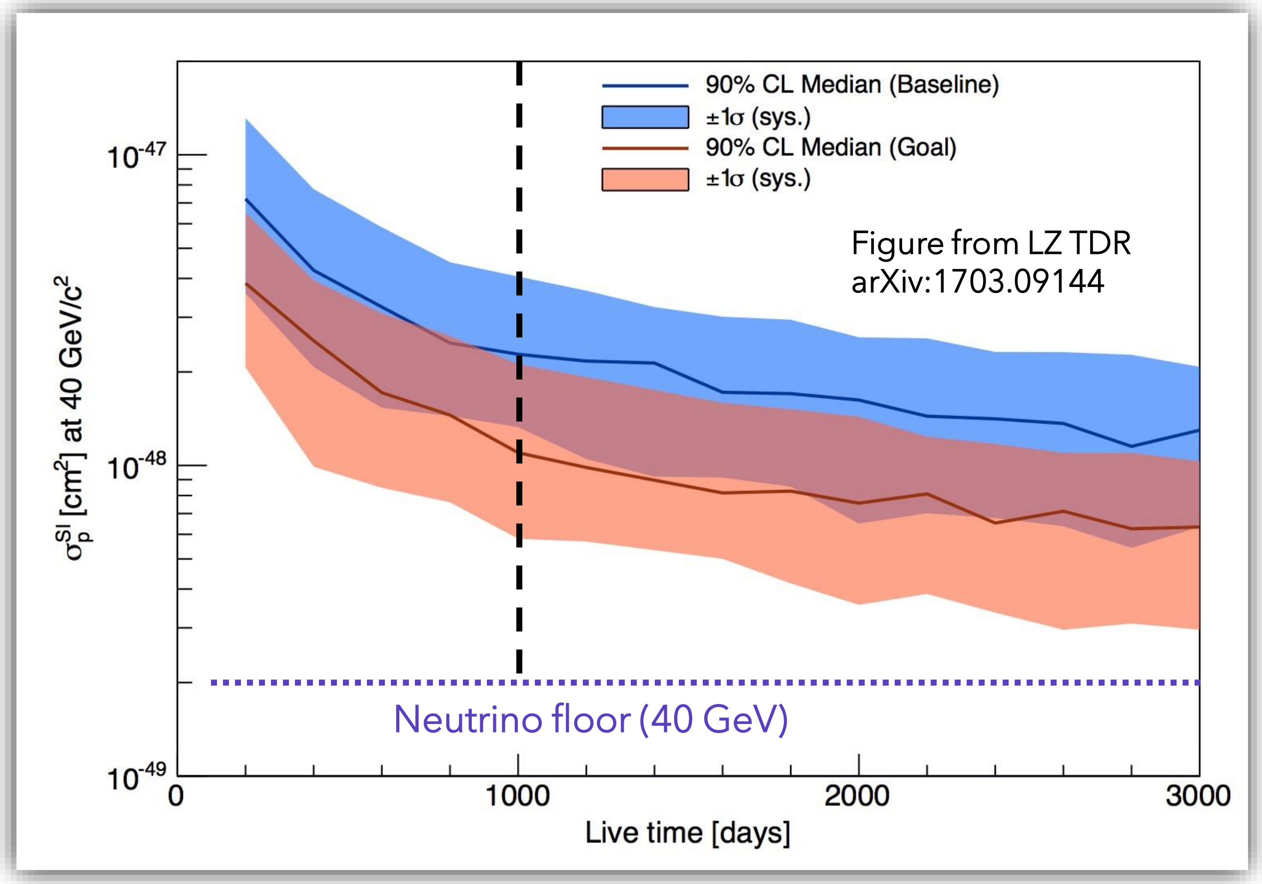
Internal backgrounds!

RUN LZ FOR LONGER?

Doesn't work.
Backgrounds win,
mostly radon

Sensitivity scales poorly
with exposure
when bkg limited

Discovery potential depends even more strongly on background level than sensitivity



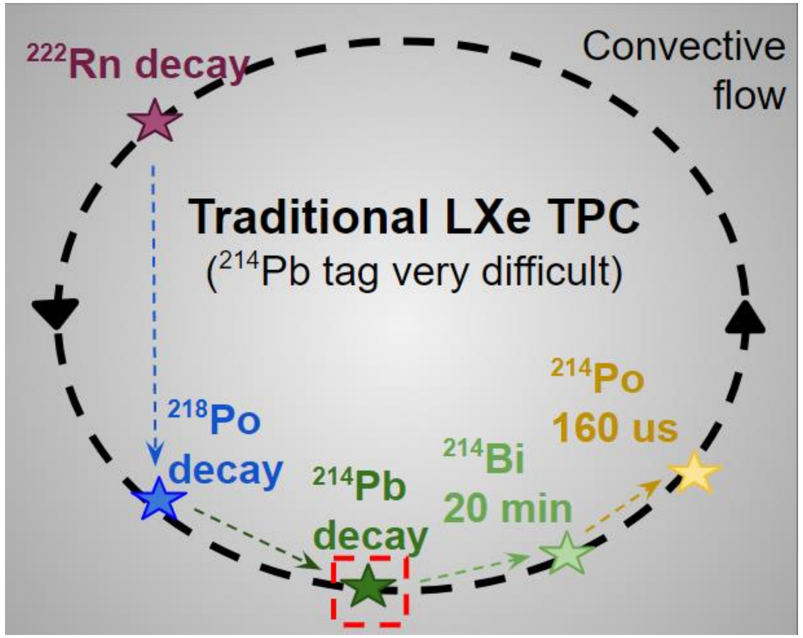
GET BETTER AT RADON REDUCTION?

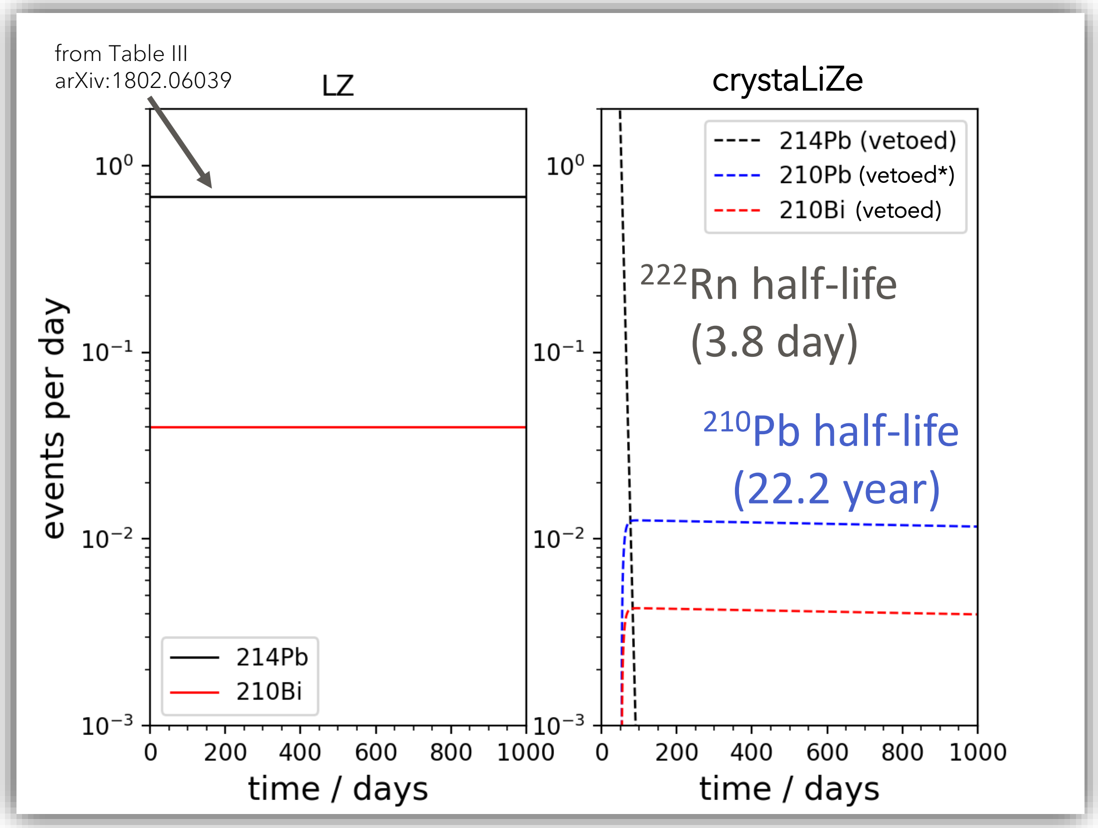
- Active area of R&D. HARD.
- Limited prospects for Rn removal during circulation/purification
  - Removal w/ carbon traps problematic due to activity of traps
  - Perfect removal at purification site (e.g. cryogenic distillation) requires 2000 slpm flow rate for 10x Rn reduction at LZ scale
  - Larger experiments require even more flow

XENON1T cryogenic distillation achieves ~20% Rn reduction
(slides)

Solution: CrystaLiZe

- Freeze LZ:
  Radon emanated from surfaces now **excluded** from solid bulk*
- In crystaLiZe, Rn in bulk target from LXe phase would be fixed, decay away in O(100) days





same LZ emanation and dust assumptions

- In crystal, radon decay daughters stay at same (x,y,z) as parent* -> **tagging/veto**
- Reduction in Rn chain daughters of nearly 100x

*Diffusion of Rn in solid Xe to be studied to verify

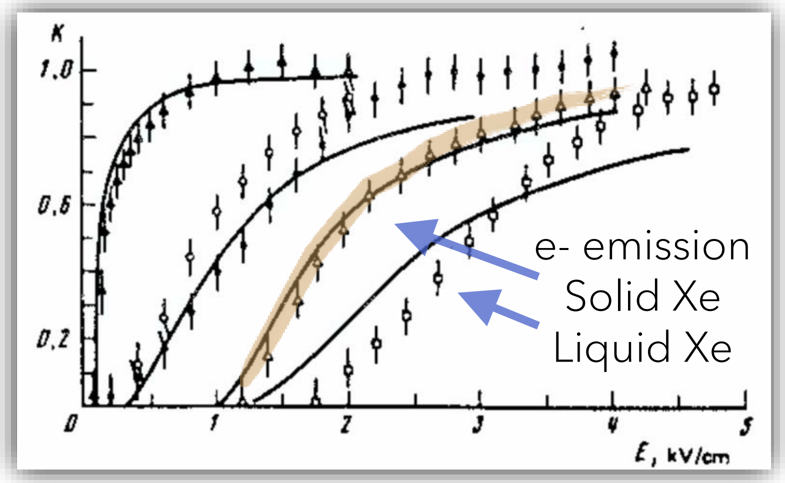
CRYSTAL XE AS A PARTICLE DETECTOR

- Solid and liquid xenon have similar physical properties
- **Solid/gas two-phase xenon TPC** is expected to perform as well as a liquid/gas xenon emission TPC
  - **band gap (E -> detectable signal)**
  - **electron mobility (doubled)**
  - electron emission
  - density (20% bonus!)
  - high voltage
- **Similar scintillation signal observed in solid and liquid**
- cf. arXiv:1410.6496 and arXiv:1508.05903
- **Potential for improved ER/NR discrimination** (due to changes in e-/Xe^+ recombination)

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

	Solid $T=161.2\ ^\circ K$	Liquid $T=163\ ^\circ K$	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

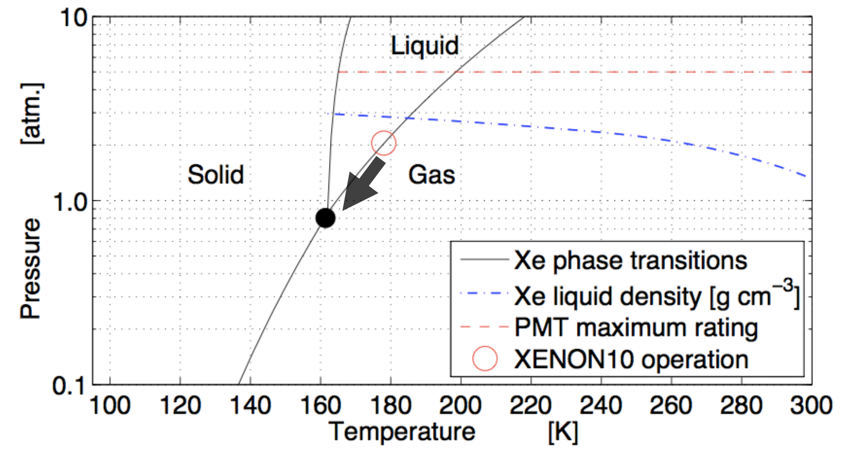
Phys Rev B 10 4464 (1974)



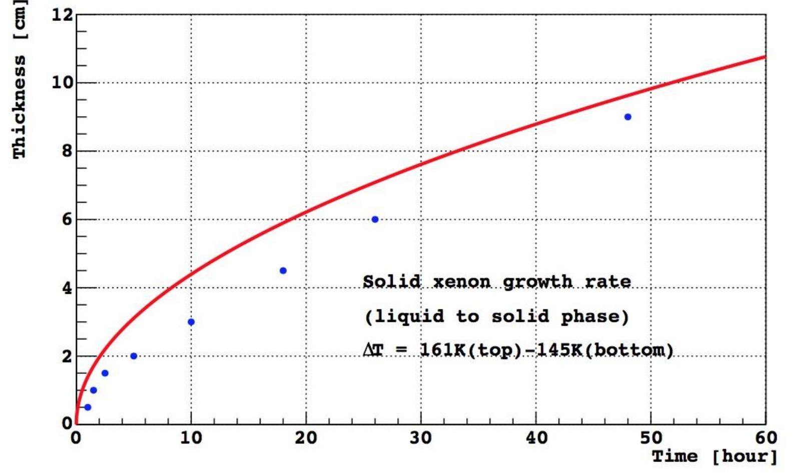
JETP 55 860 (1982)

CHALLENGES BEING STUDIED

- Single e- sensitivity for S2s? (HV)
- Retaining high purity while crystallizing
  - Likely requiring elevated temperature bakeout
  - Would take multiple months to crystallize LZ w/o defects (unknown if this is necessary for good signal collection)
- Precise temperature gradients require more elaborate control/measurement of T
- R&D: use small scale crystalline Xe TPC test bed to gauge performance

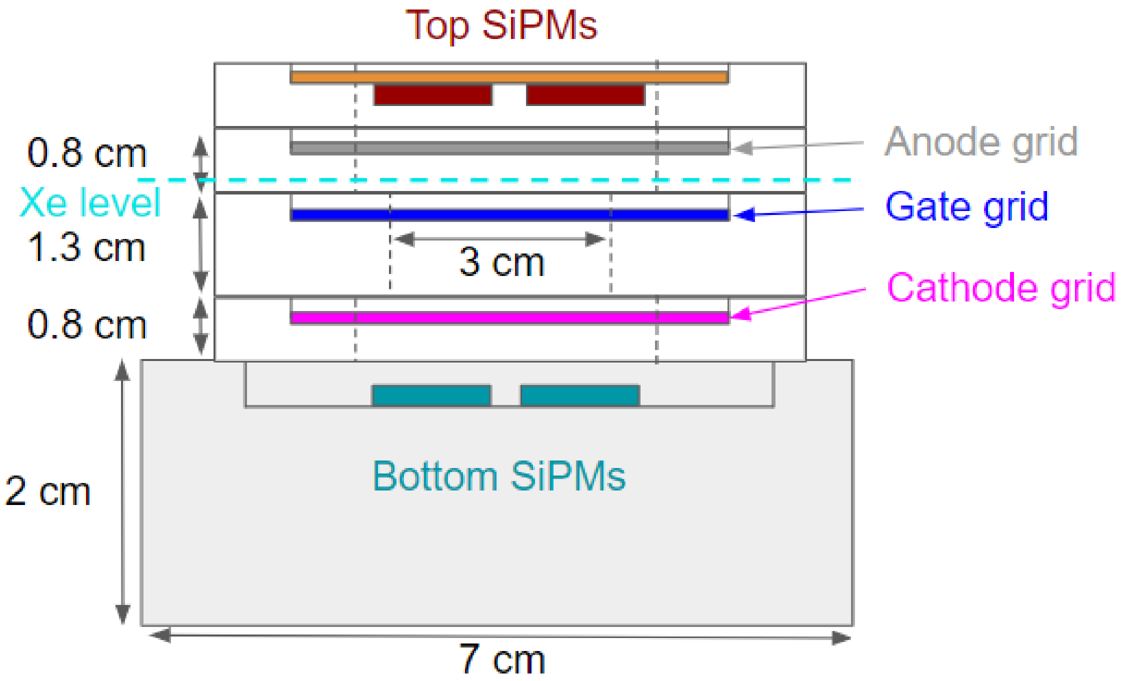


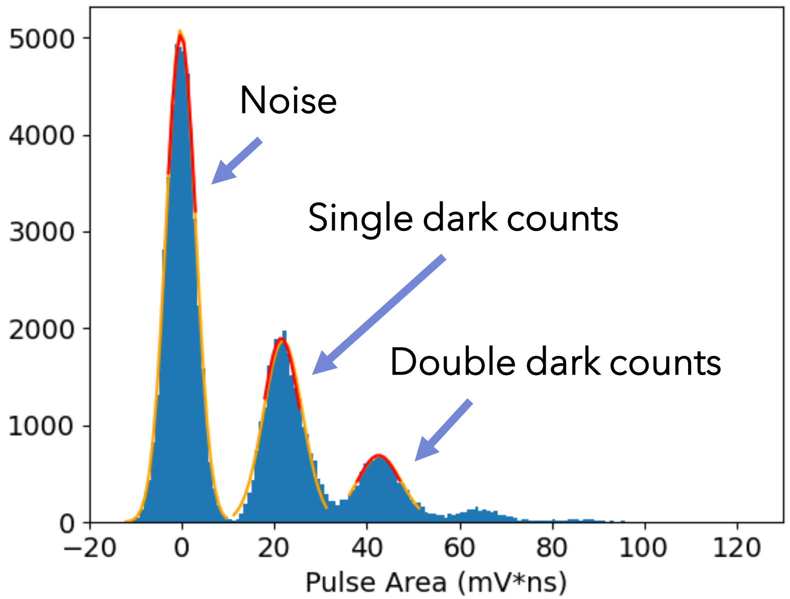
arXiv:1410.6496

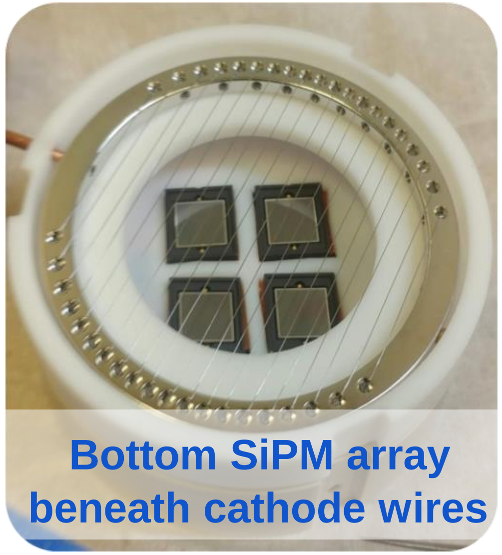


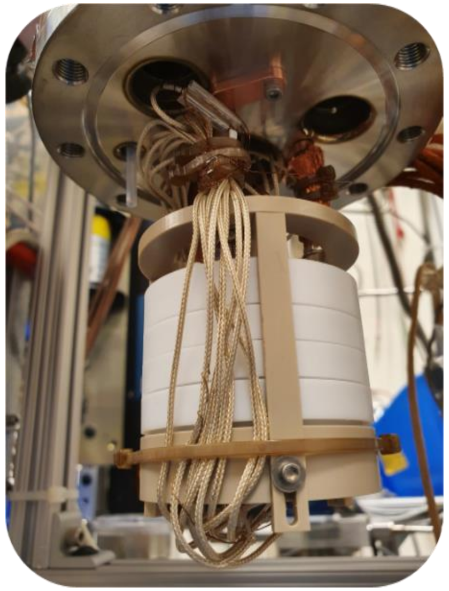
TEST BED DESIGN

- Two phase Xe mini-TPC at LBL
- ~700 g Xe when full
- S1 and S2 readout:
  8 SiPMs (4 top, 4 bottom; Hamamatsu S13370)





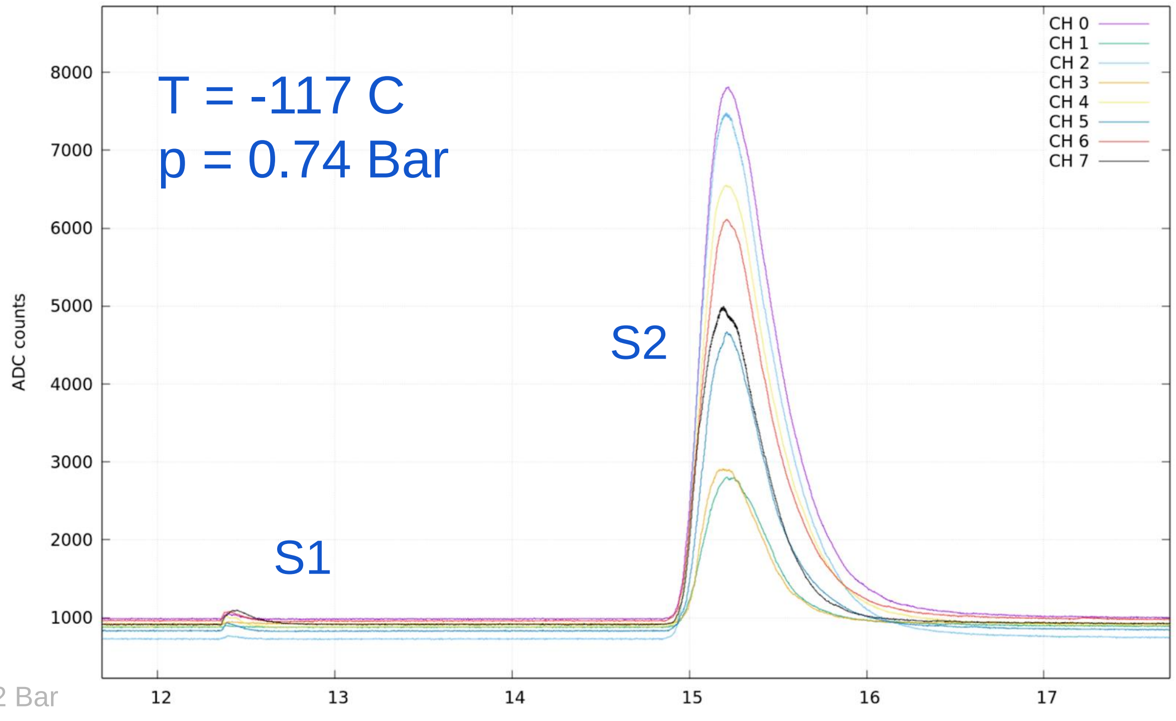


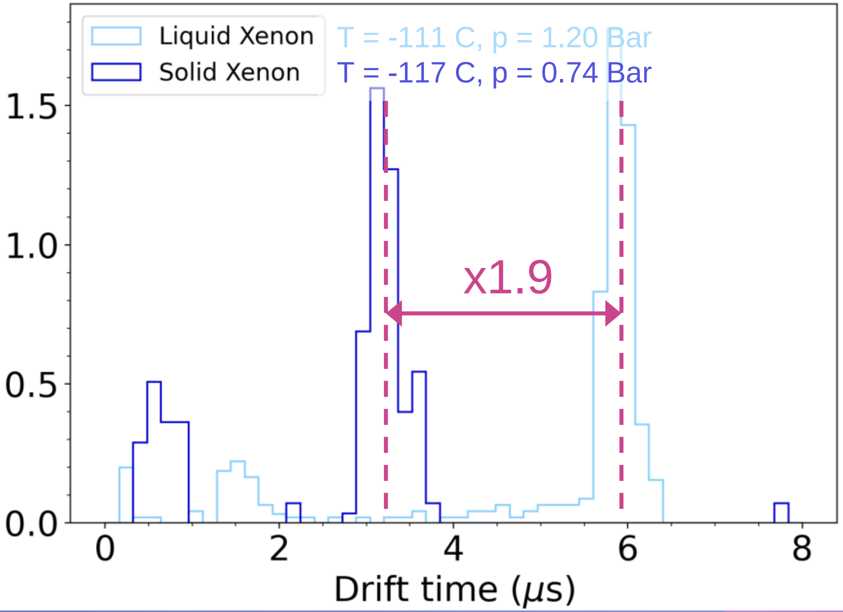


TPC OPERATION

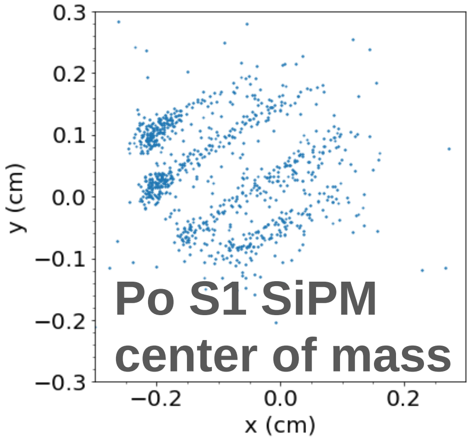
- Observe S1s and S2s in Xe
- Clear indications of freezing:
  - Vapor pressure below triple point
  - Drift time halves
- Po plated on cathode wires: α calibration source

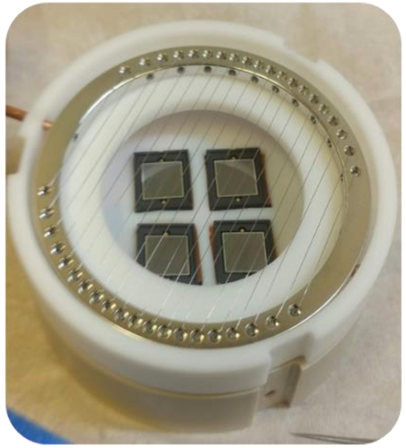
Typical ^{57}Co waveform recorded in crystalline/vapor TPC





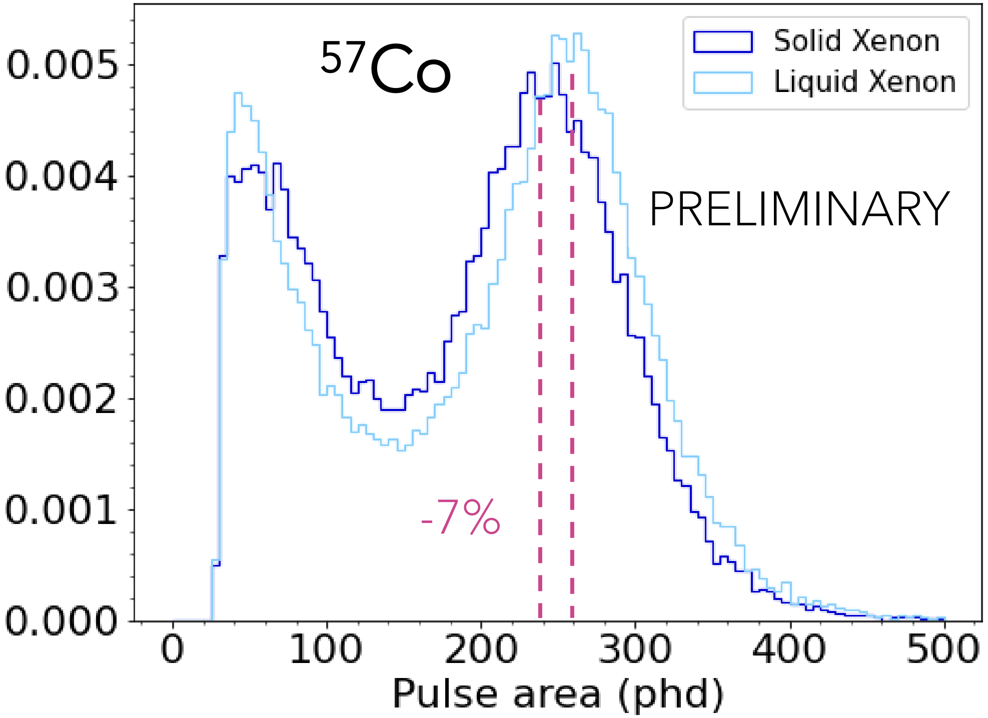
Note: triple point
T = -111.8 C, p = 0.82 Bar



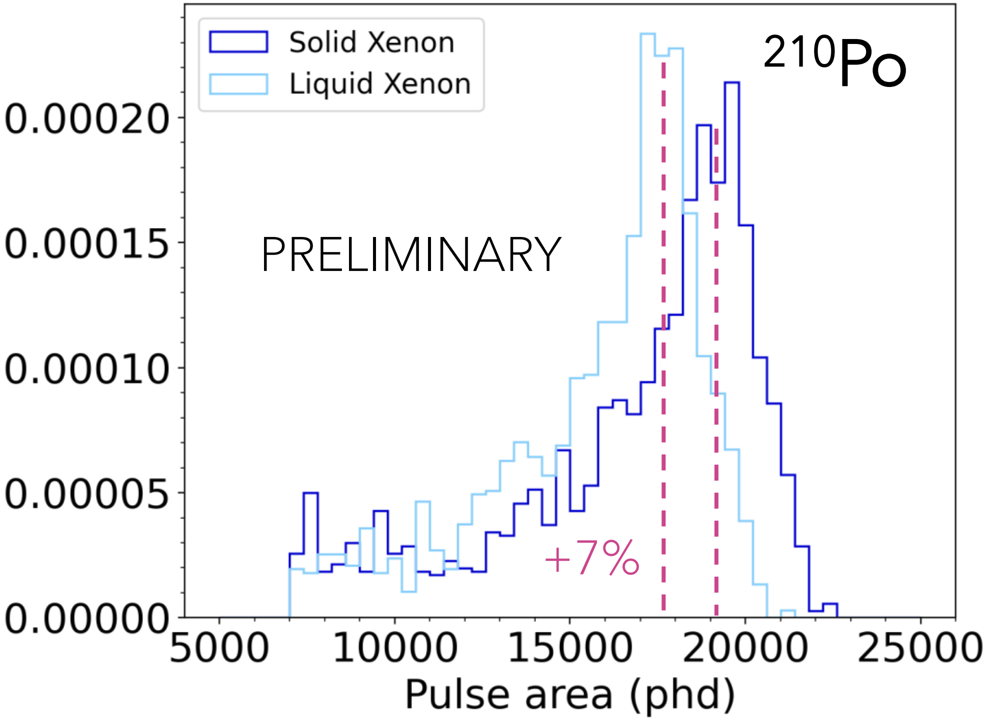


SCINTILLATION IN LXE VS SXE

- Co S1 size slightly smaller
  - 2014 FNAL work* also missing 15% of Co scintillation photons in crystalline state



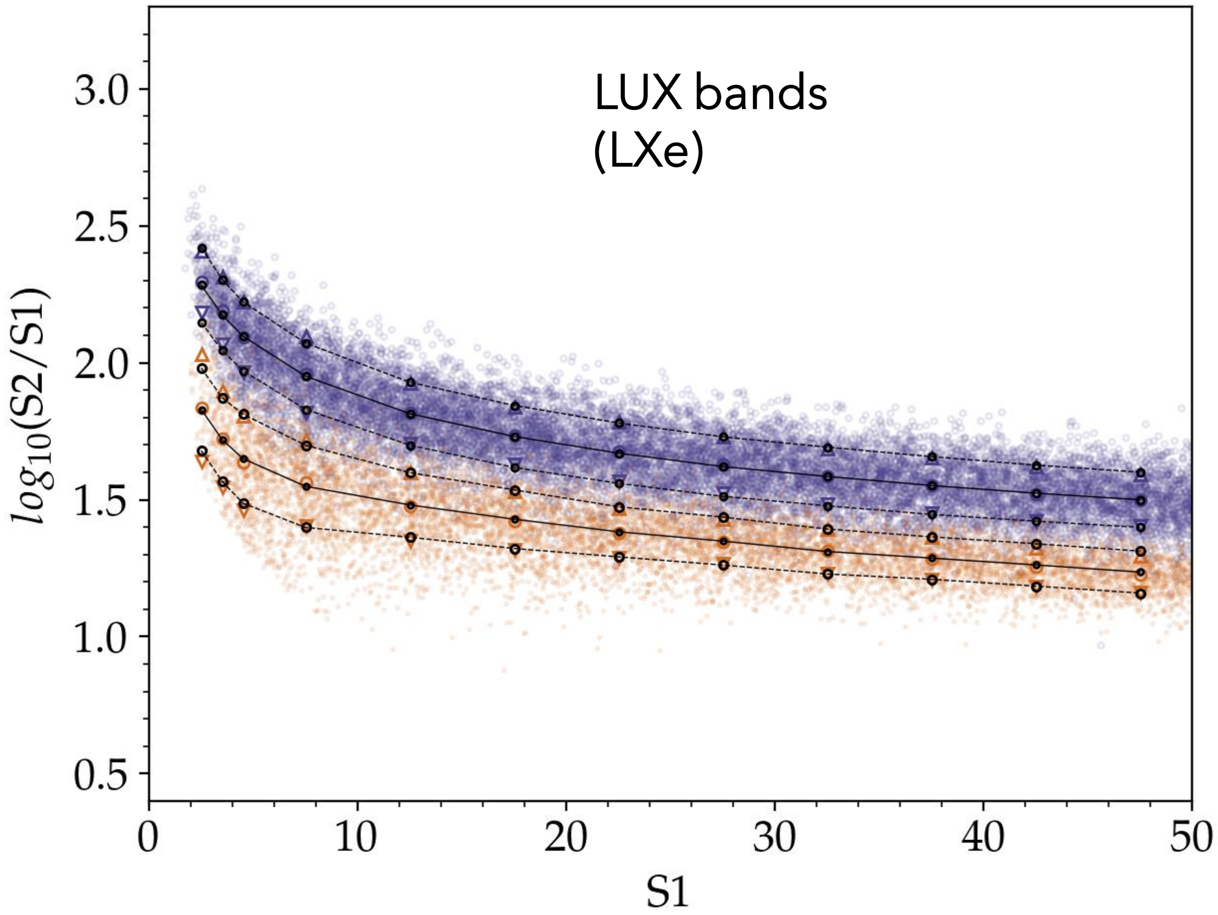
- Po S1 size similar or slightly larger
  - Possible instrumentation effect: calibrate out single photon size but cross-talk may vary?



*arXiv:1410.6496

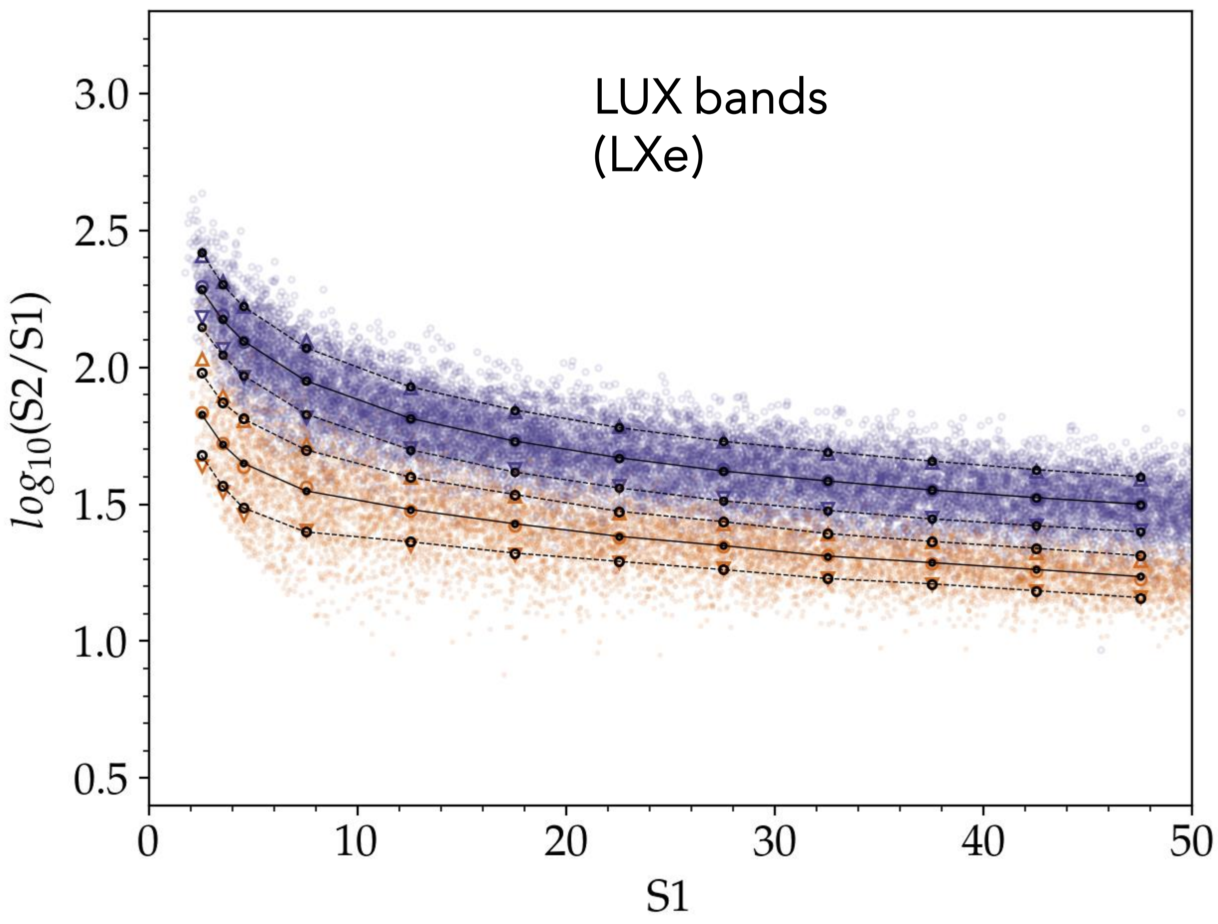
Systematic difference for Co (ER) vs Po (NR) – change in e-/Xe+ recombination?

SIMULATION: REPRODUCE LUX BANDS



Simulate LUX bands in LXe

SIMULATION: REPRODUCE LUX BANDS



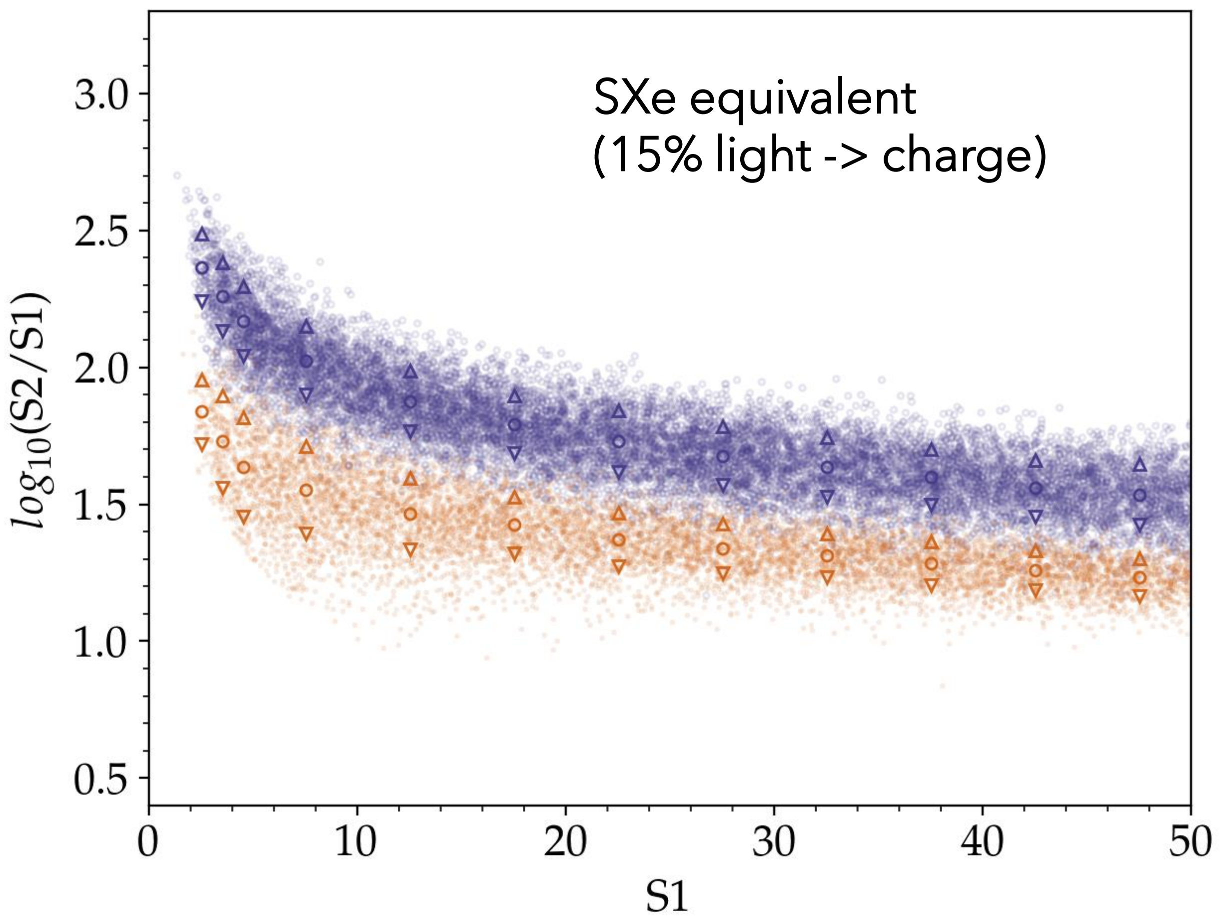
Simulate LUX bands in LXe

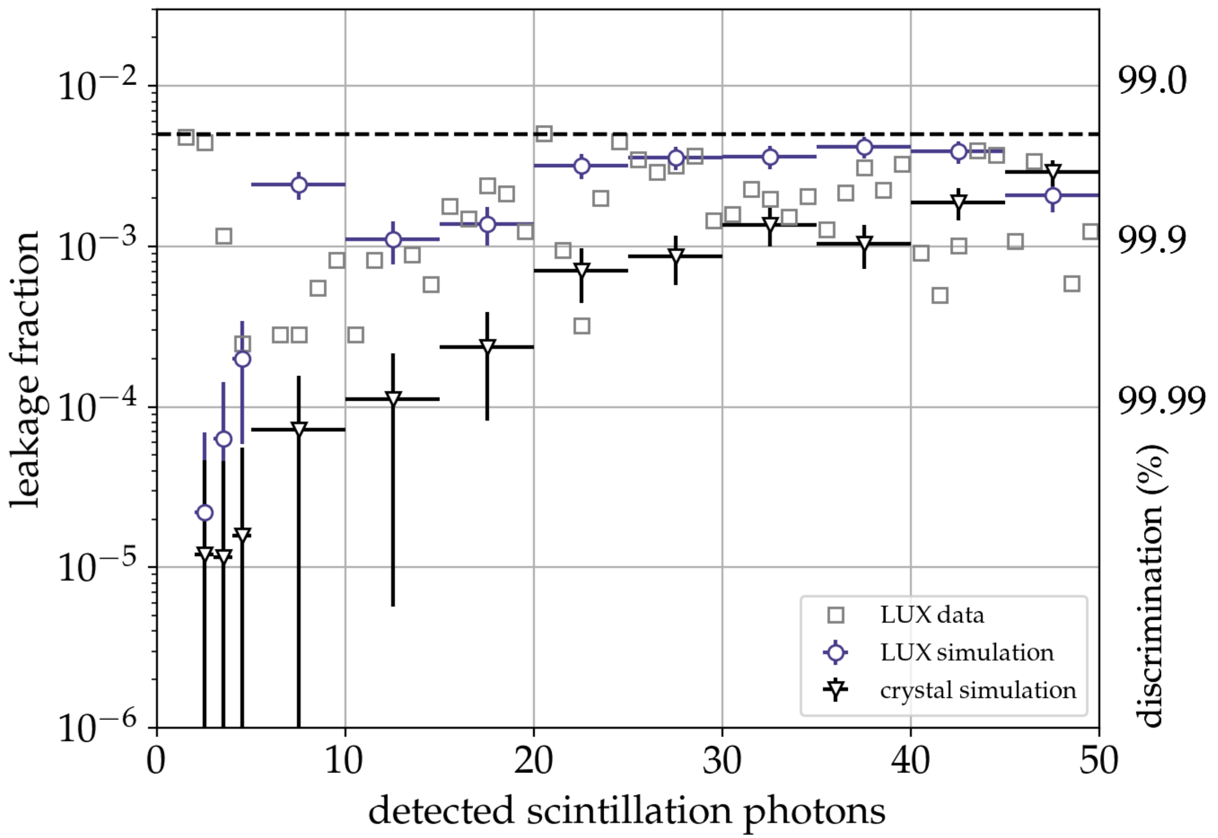
Assumptions for SXe:
Same as LXe except ERs get a 15% fewer photons which are replaced (one-to-one) by electrons (NR unchanged)

Worse light collection -> wider ER band
But also band means separate

Net effect is an improvement in discrimination

SIMULATION: ER/NR BAND SEPARATION
(HYPOTHETICAL 15% RECOMBINATION SHIFT)

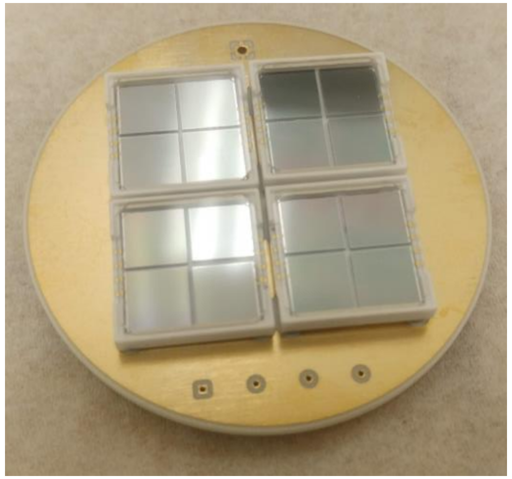


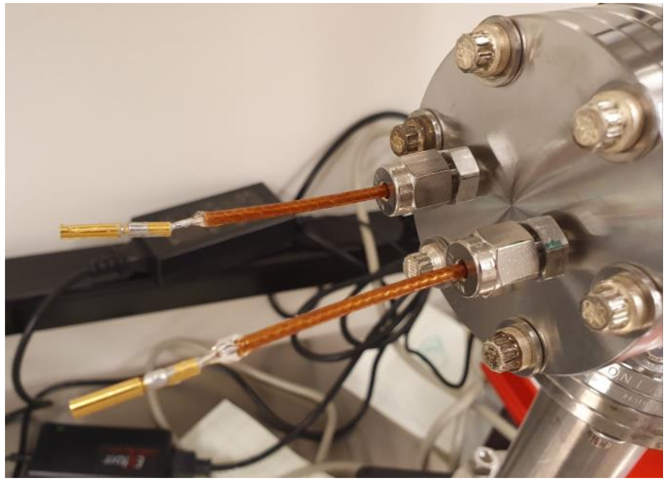


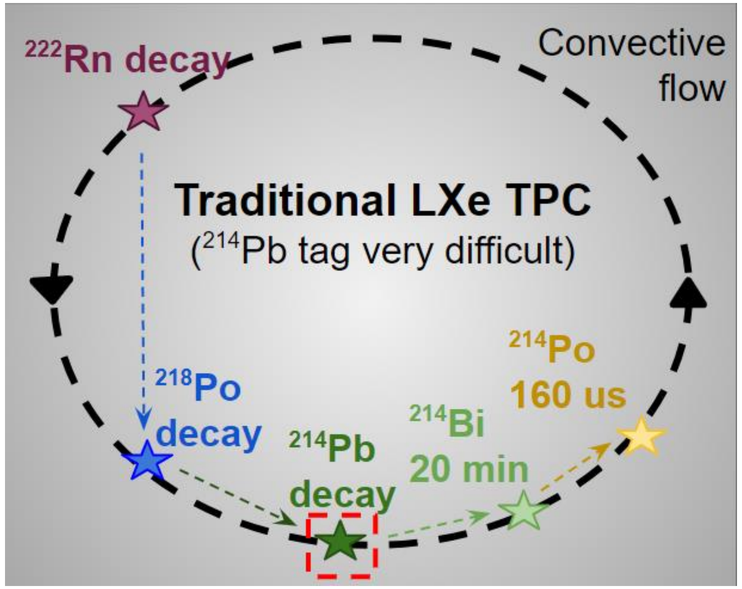
Leakage fraction ~(4-10)x smaller 10-30 phe: allows further reduction of remaining ER bkgs (neutrino ERs, Kr, ^{136}Xe, …)

NEXT STEPS

- Test bed upgrades:
  - More SiPMs, better light collection, position info
  - Higher extraction field w/ new HV feedthroughs
- Further measurements:
  - Proper study of charge (S2 size) in LXe vs SXe
  - Study Rn diffusion, Rn tagging
  - Single e- study
  - Effects of freezing speed/procedure







SUMMARY

- Reaching the solar neutrino limit for DM direct detection will require innovation in detector design
- The solid xenon TPC is a promising new particle detector technology
  - Expected to maintain the benefits of LXe TPCs (or more!)
  - Ability to remove the primary background to DM searches, internal radon
  - Potential for further addressing remaining ER backgrounds through improved discrimination