CRYSTALIZE:
A SOLID FUTURE FOR LZ

SCOTT KRAVITZ, HAO CHEN, RYAN GIBBONS,
SCOTT HASELSCHWARDT, SHILO XIA, PETER SORENSEN
LAWRENCE BERKELEY NATIONAL LAB

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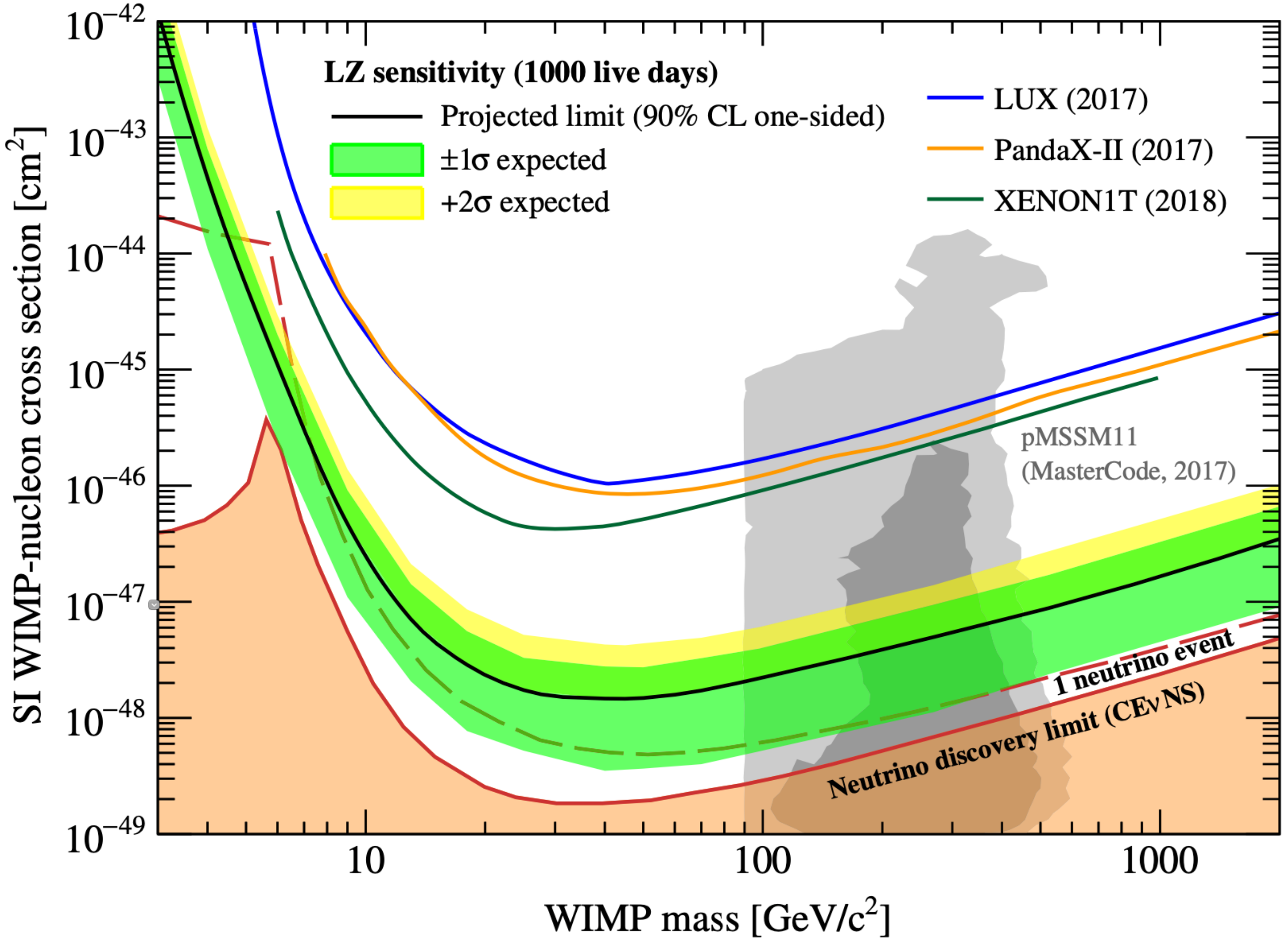
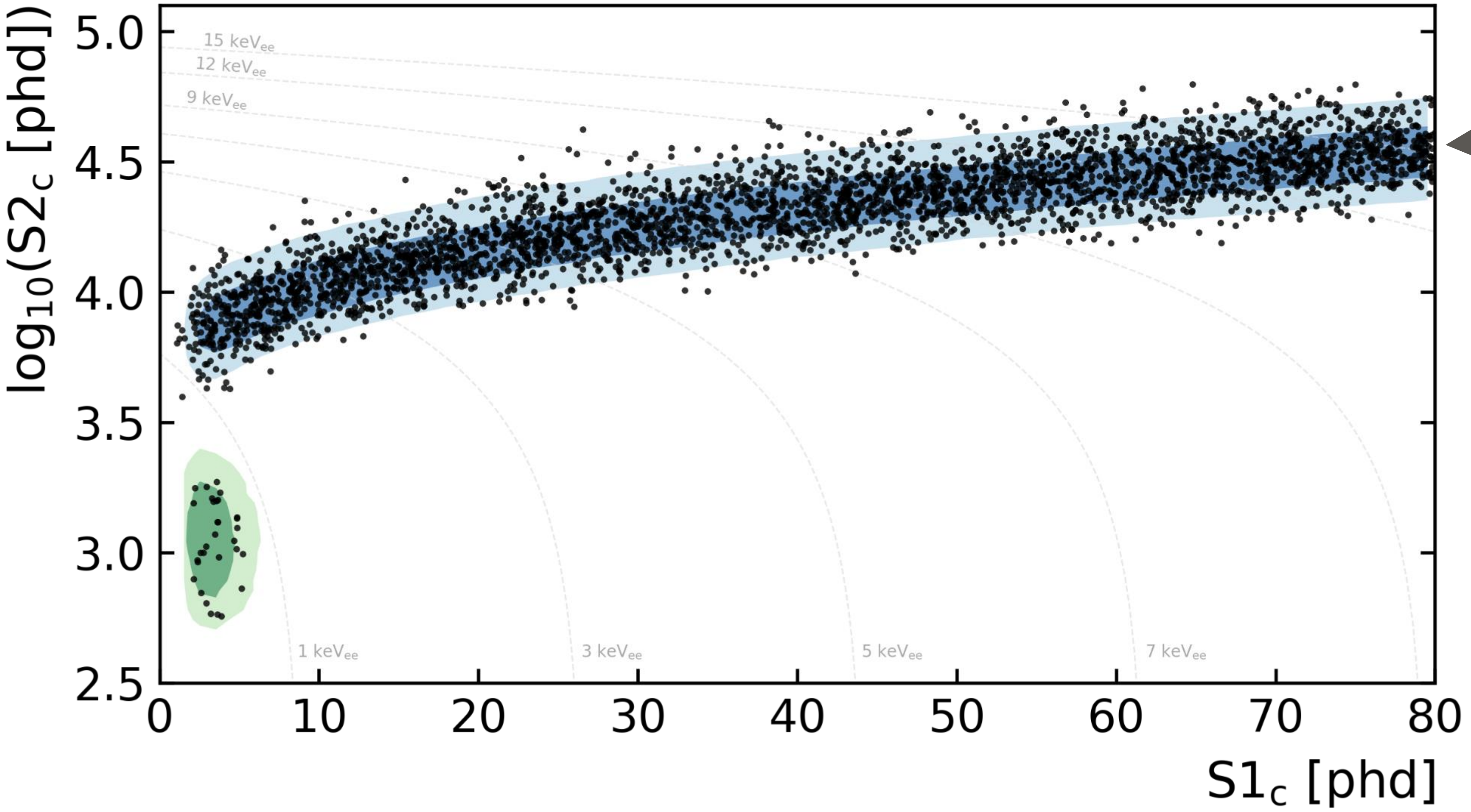
THE FUTURE OF DIRECT DETECTION

- 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



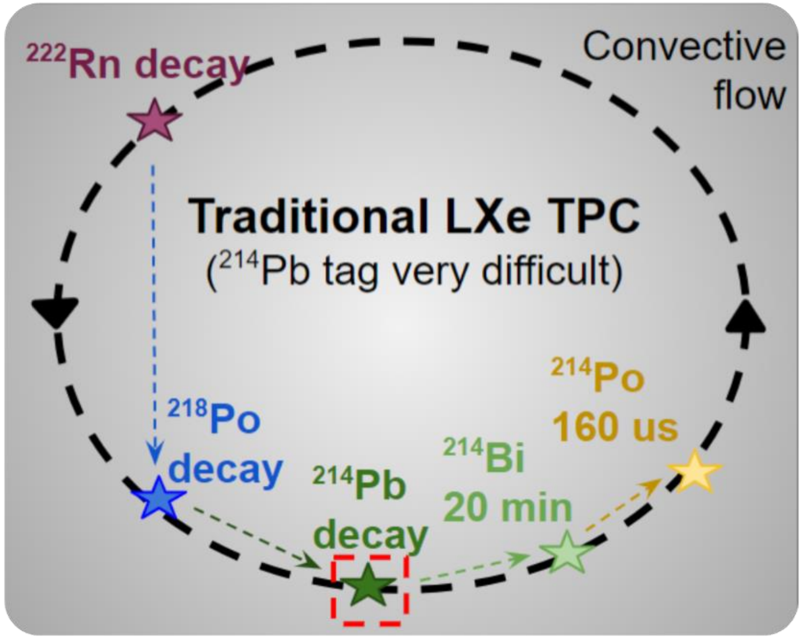
1100 BG events <6.5 keV$_{ee}$
800 from Rn
200 from solar nu
<1 atm. nu
40 8B nu

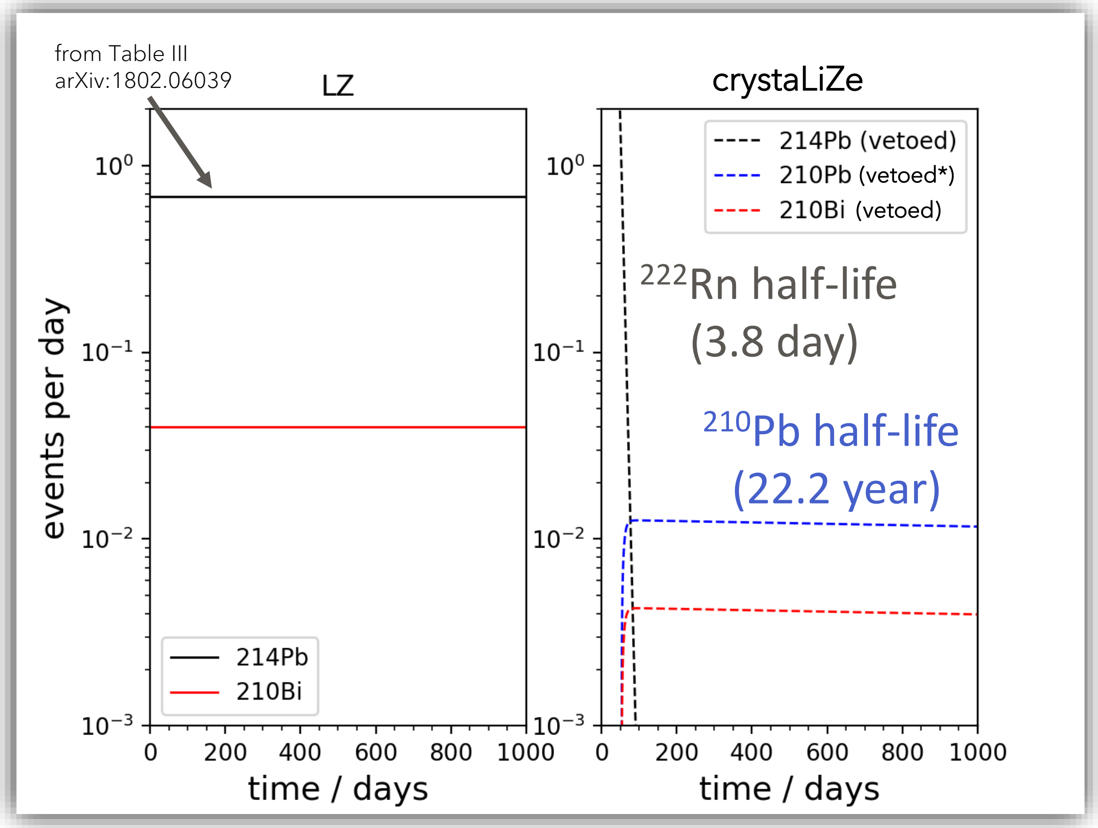
w/ 99.5% ER/NR discrimination,
4 of 6 bkg events from Rn
1 from solar nu ER

Internal backgrounds!

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

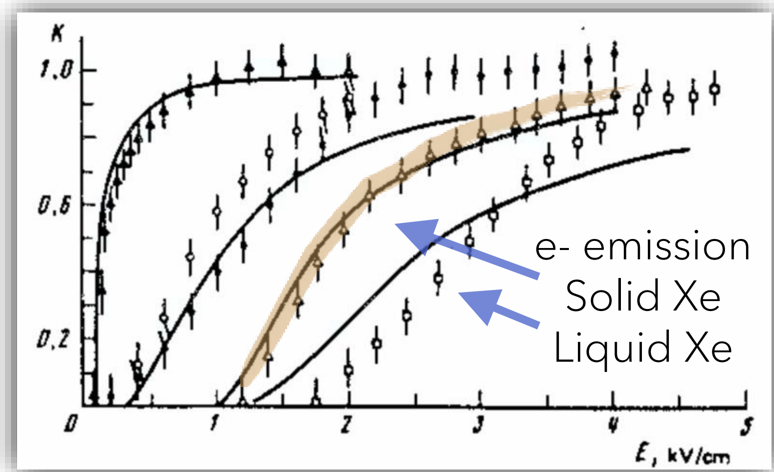
CRYSTAL XE AS A PARTICLE DETECTOR

Solid/gas two-phase xenon TPC is expected to perform as well as in liquid due to very similar physical properties

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
$\lvert a \rvert$	3.8×10^{-9}	4.2×10^{-9}	cm
$\lvert E_{1CB} \rvert$	0.93	1.01	eV

Phys Rev B 10 4464 (1974)



JETP 55 860 (1982)

CRYSTAL XE AS A PARTICLE DETECTOR

- band gap (E -> detectable signal)
- electron mobility (doubled)
- electron emission
- density (20% bonus!)
- high voltage

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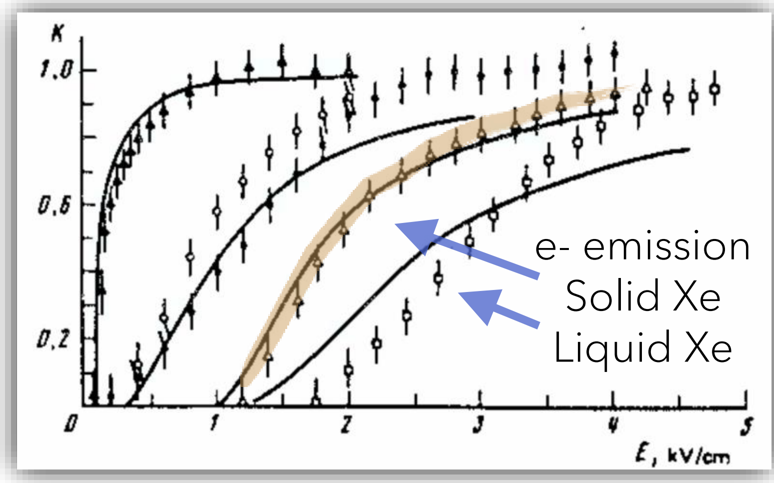
- Similar scintillation signal observed in solid and liquid
- cf. arXiv:1410.6496 and arXiv:1508.05903
- Potential for improved ER/NR discrimination (due to changes in e-/Xe^+ recombination)



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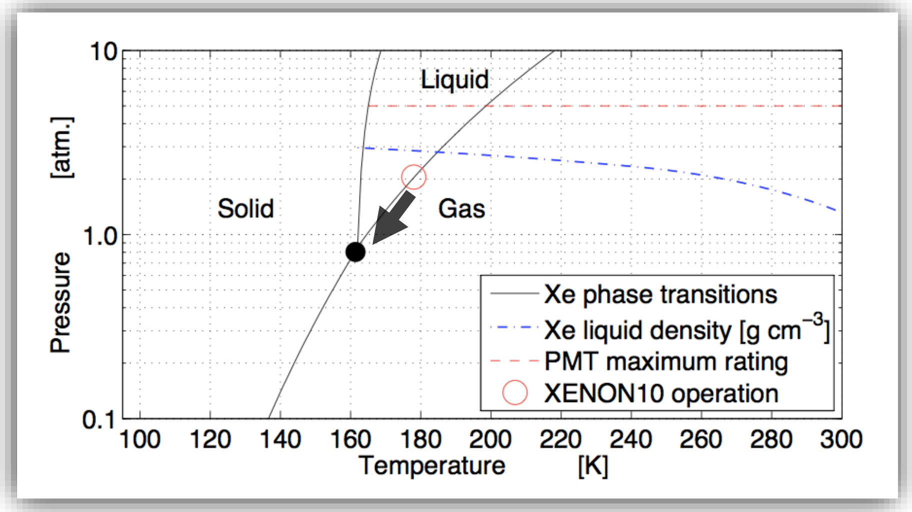
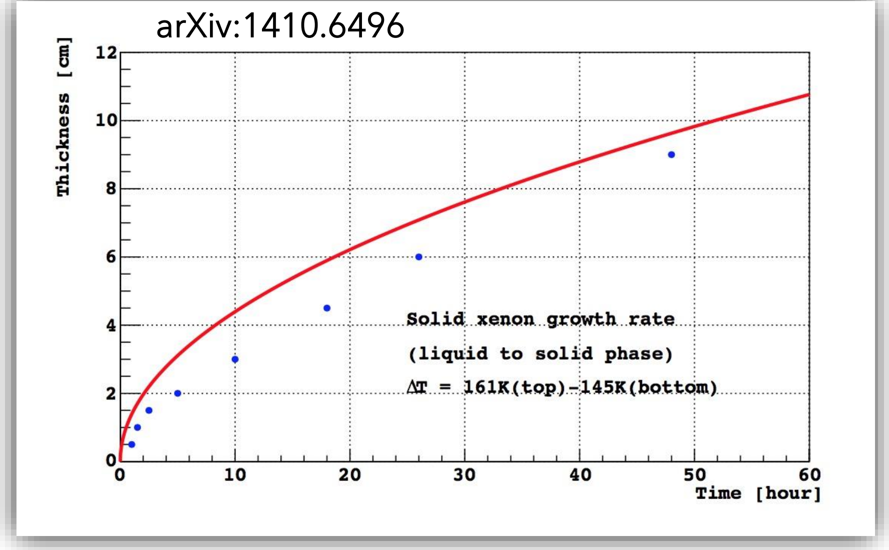
CHALLENGES BEING STUDIED

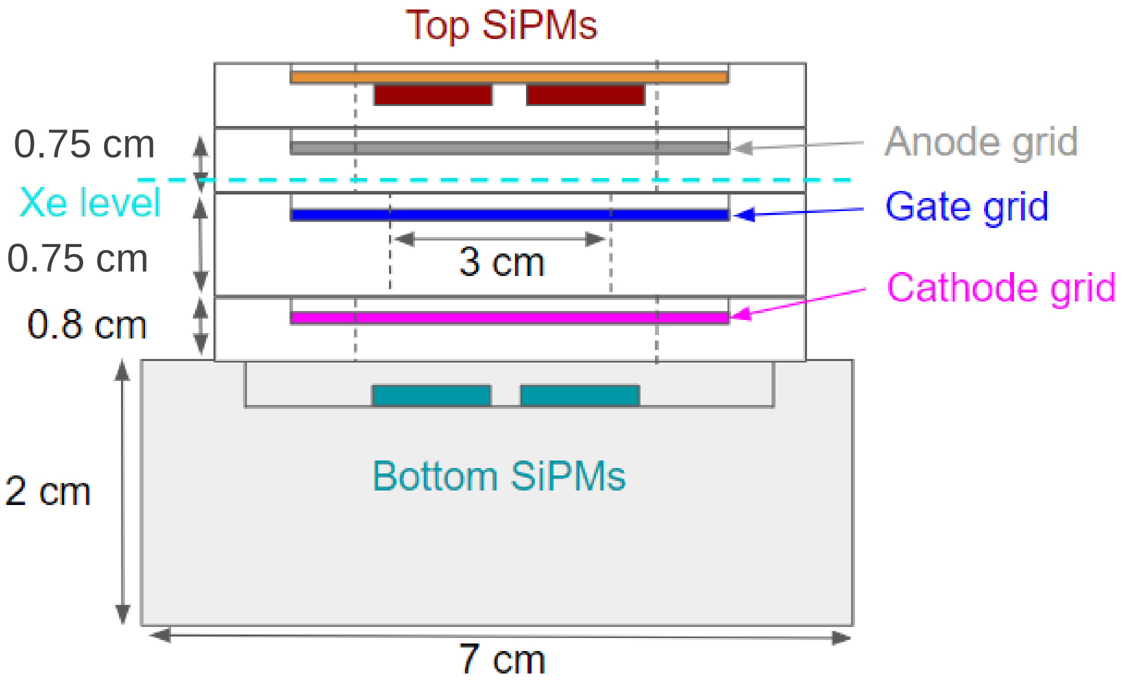
- Avoiding HV breakdown
- Retaining high purity while crystallizing
- Time to freeze: multiple months to crystallize LZ w/o defects (necessary for good signal collection?)
- Careful control/measurement of temperature gradients during crystallization
- R&D: use small scale crystalline Xe TPC test bed to gauge performance

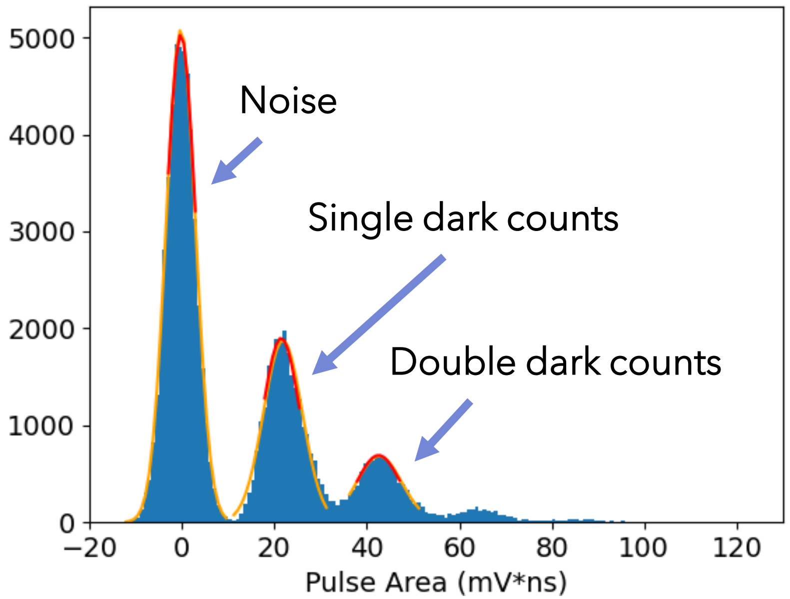


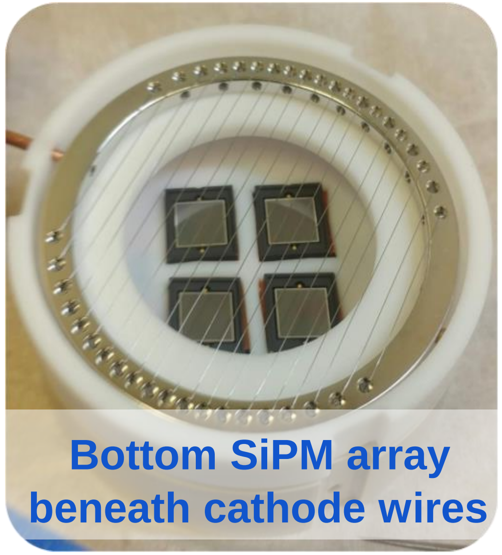


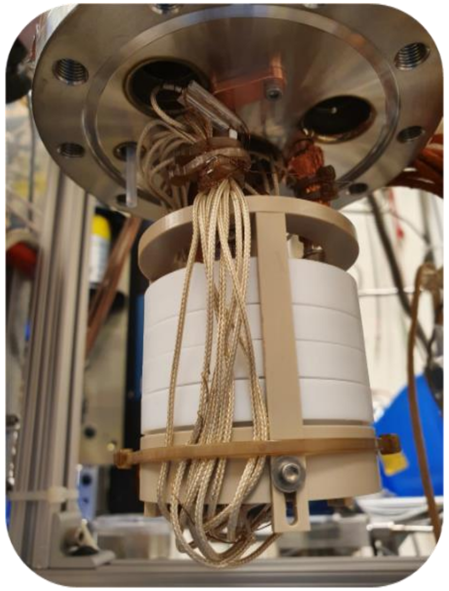
TEST BED DESIGN

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



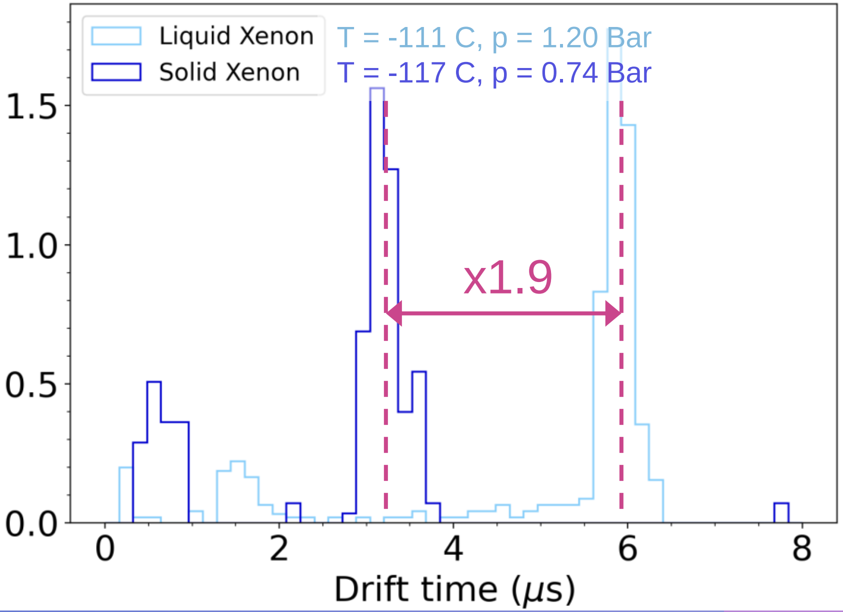






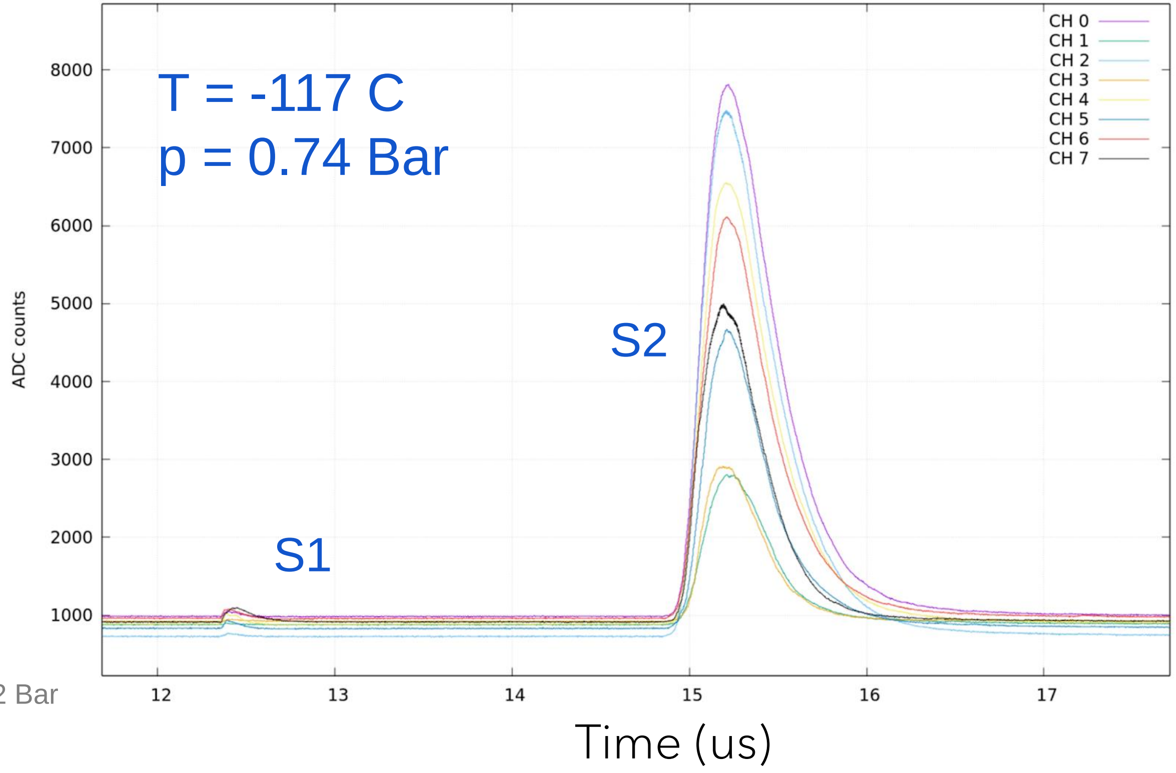
TPC OPERATION

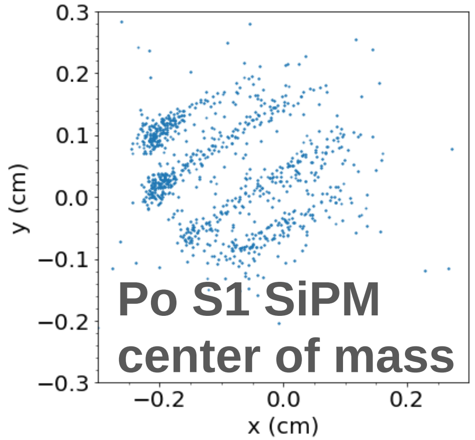
- Observe S1s and S2s in Xe
- Clear indications of freezing:
  - Vapor pressure below triple point
  - Drift time halves
- Po plated on cathode wires: α calibration source

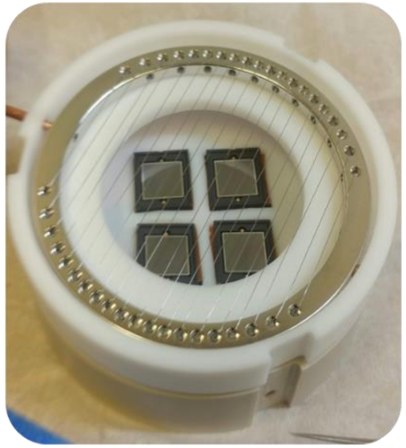


Note: triple point
T = -111.8 C, p = 0.82 Bar

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

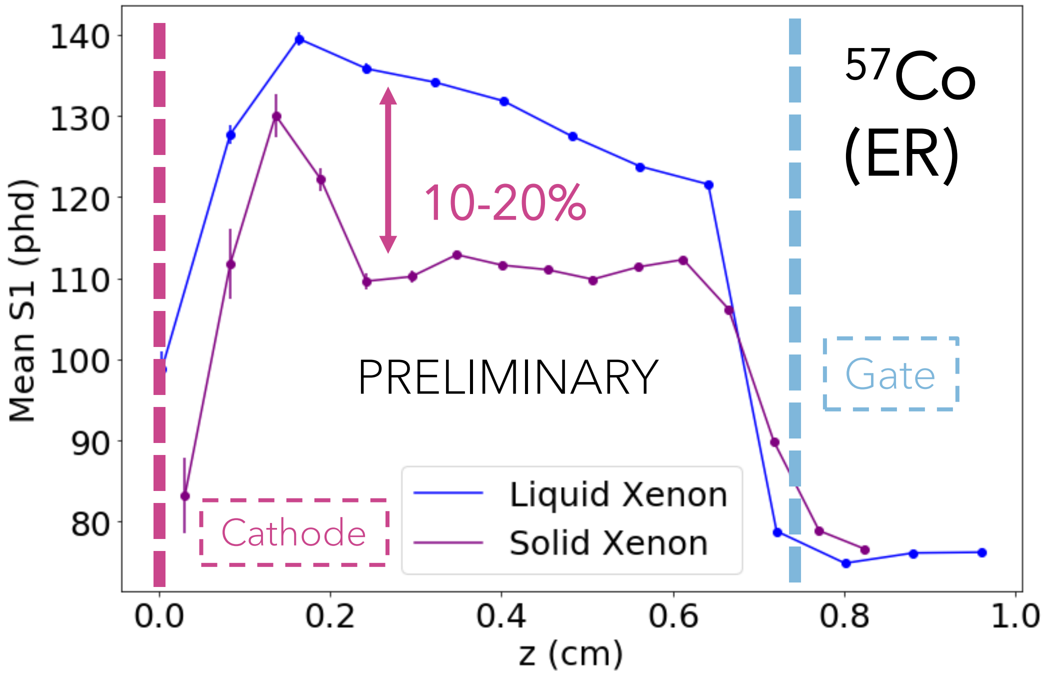




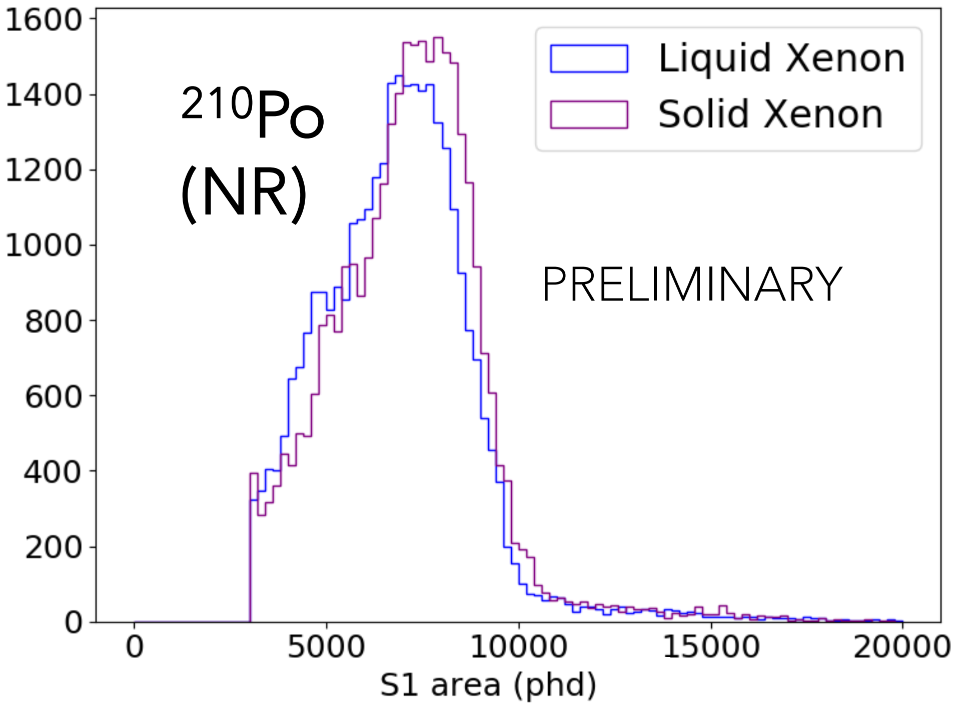


SCINTILLATION IN LXE VS SXE

- Co S1 smaller for same field (~270 V/cm)
  - 2014 FNAL work* also missing 15% of Co scintillation photons in crystalline state



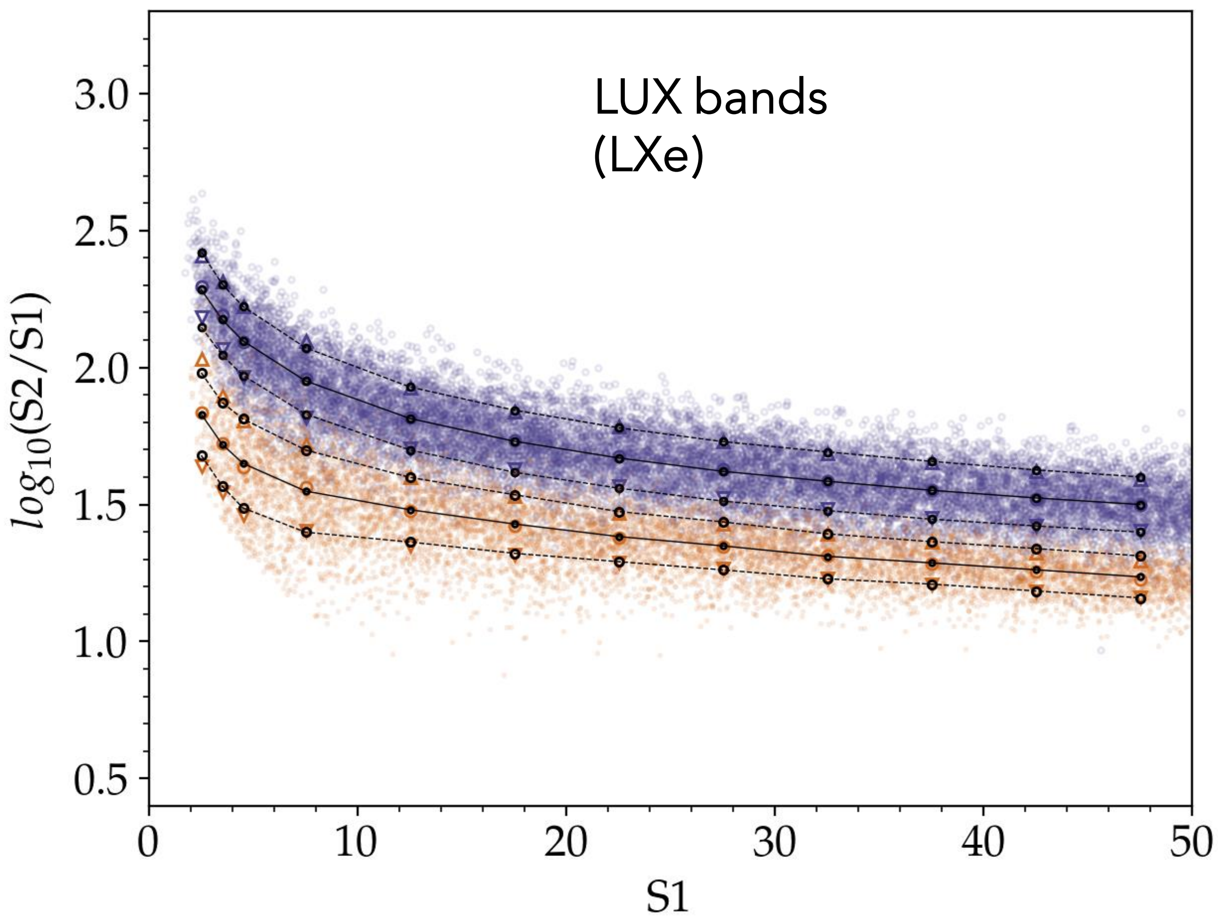
- Po S1 size similar or slightly larger
  - Cathode, gate at 0 V



*arXiv:1410.6496

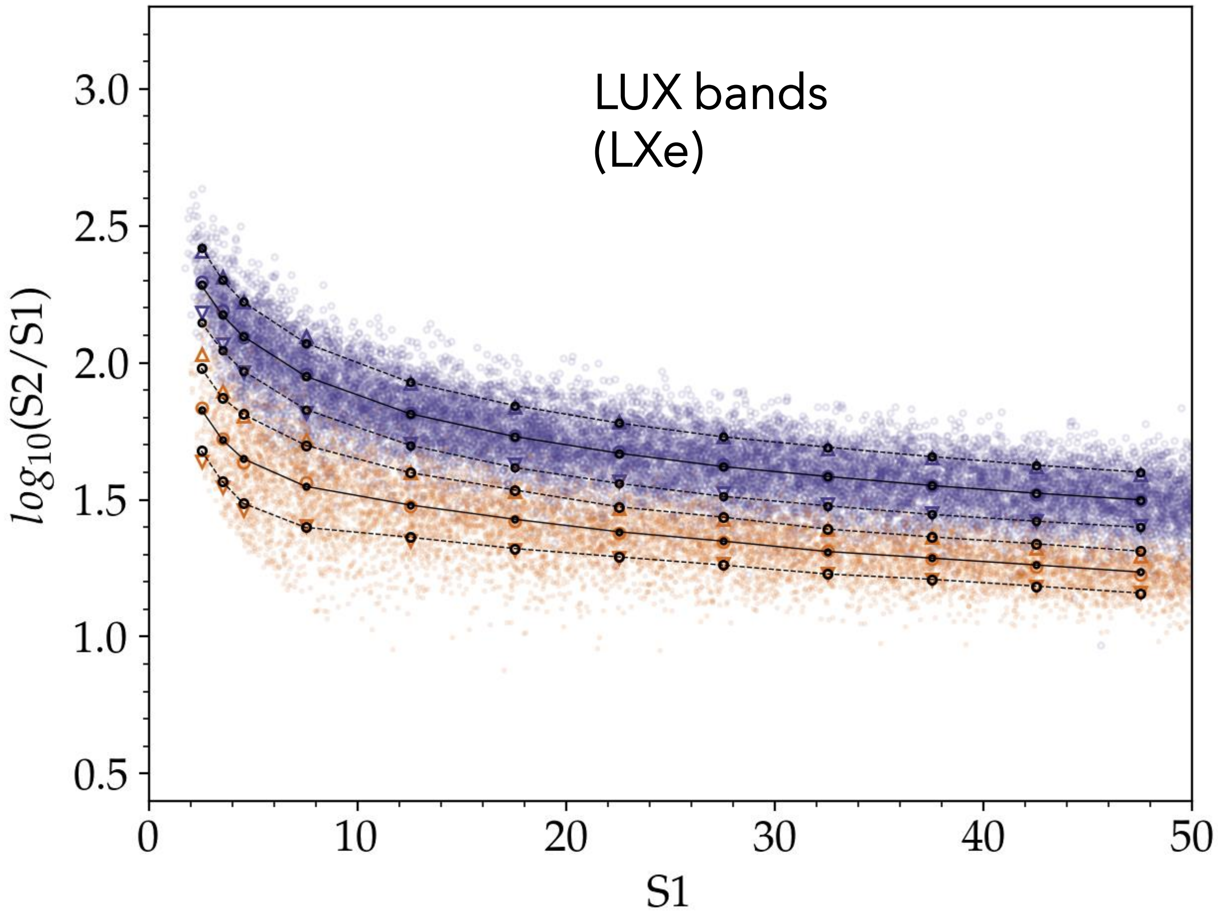
Systematic difference for Co (ER) vs Po (NR) – change in e-/Xe+ recombination?

SIMULATION: REPRODUCE LUX BANDS



Simulate LUX bands in LXe

SIMULATION: REPRODUCE LUX BANDS



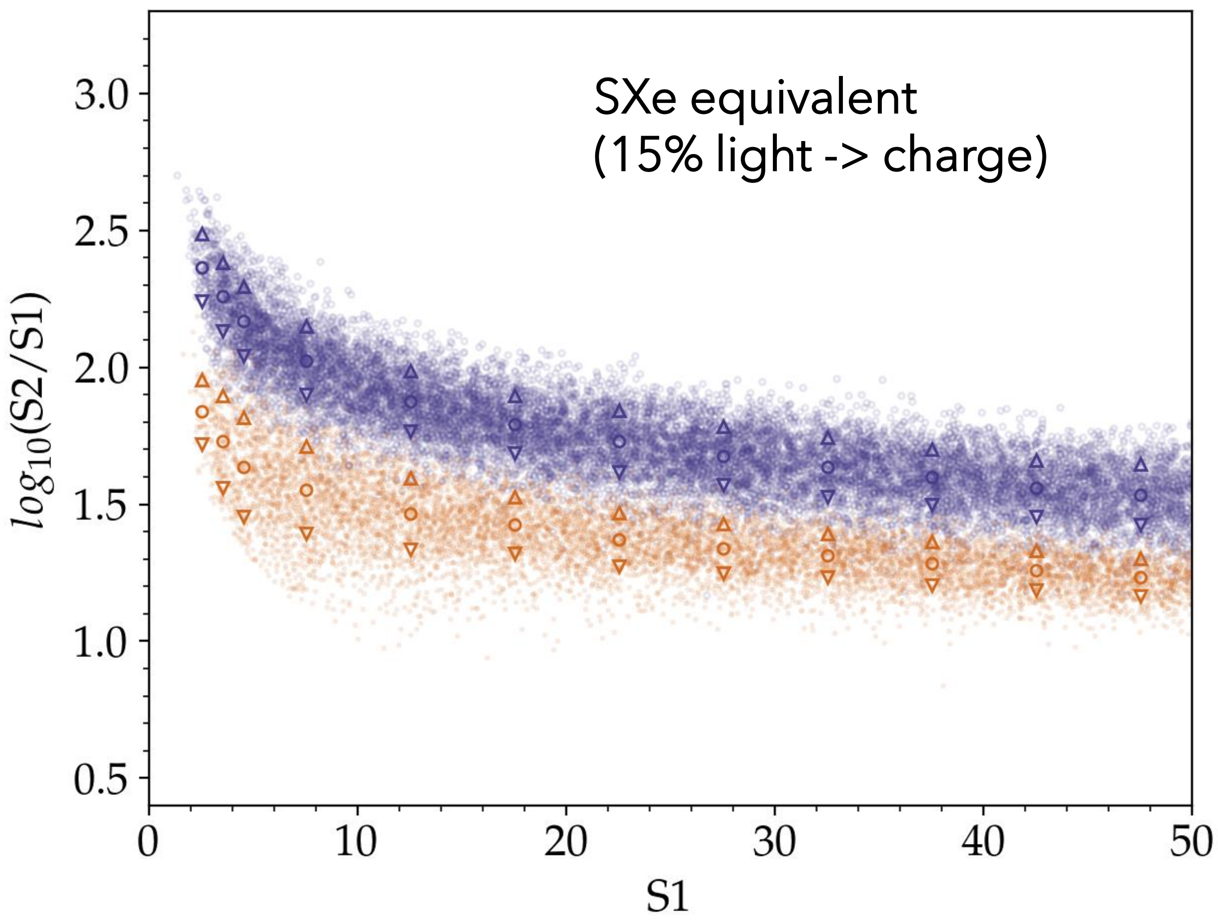
Simulate LUX bands in LXe

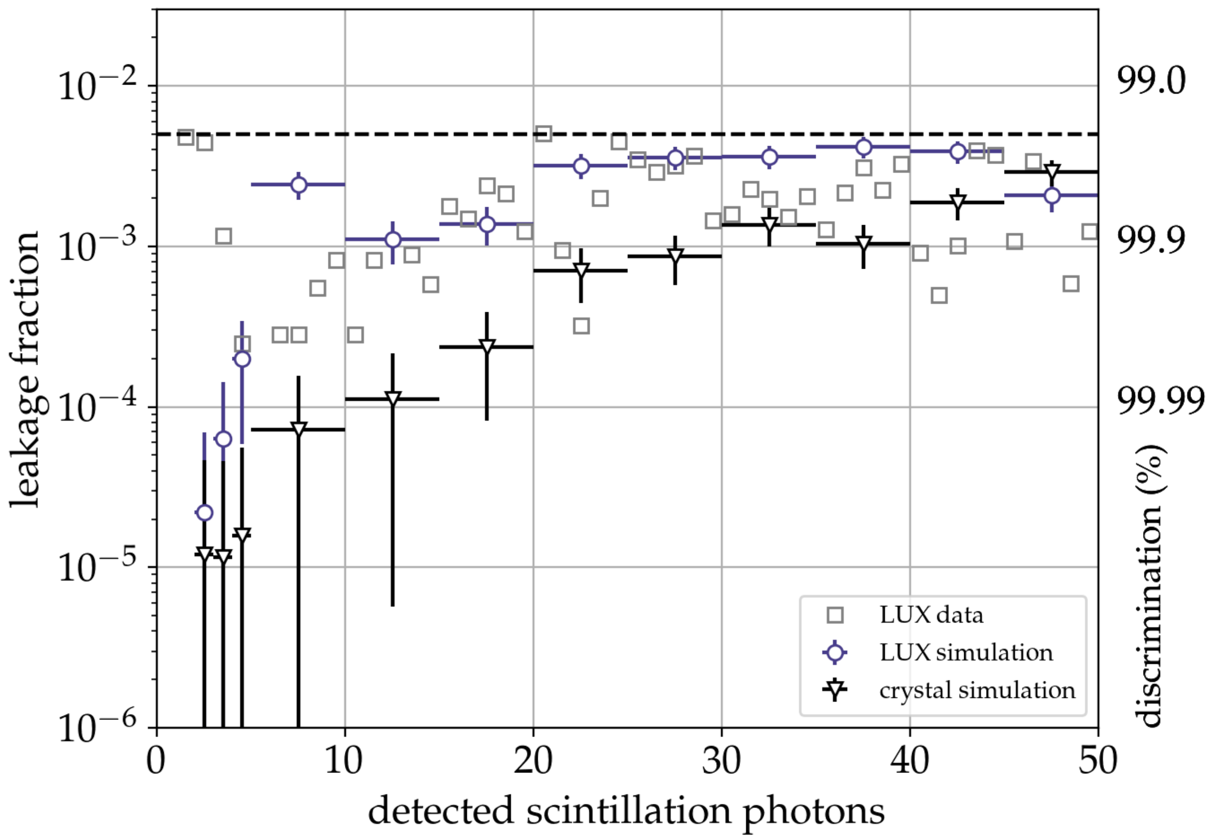
Assumptions for SXe:
Same as LXe except ERs get a 15% fewer photons which are replaced (one-to-one) by electrons (NR unchanged)

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)

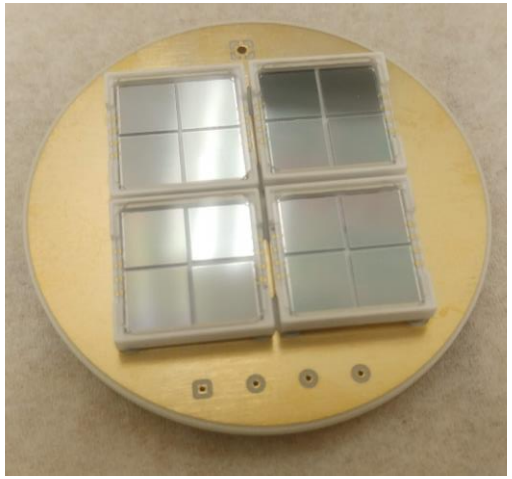


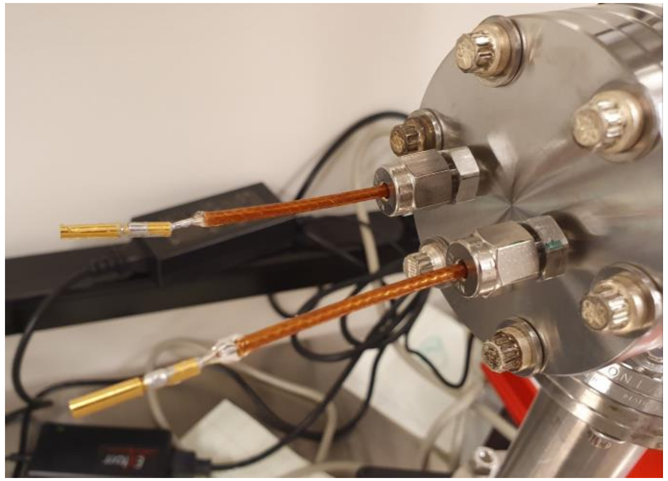


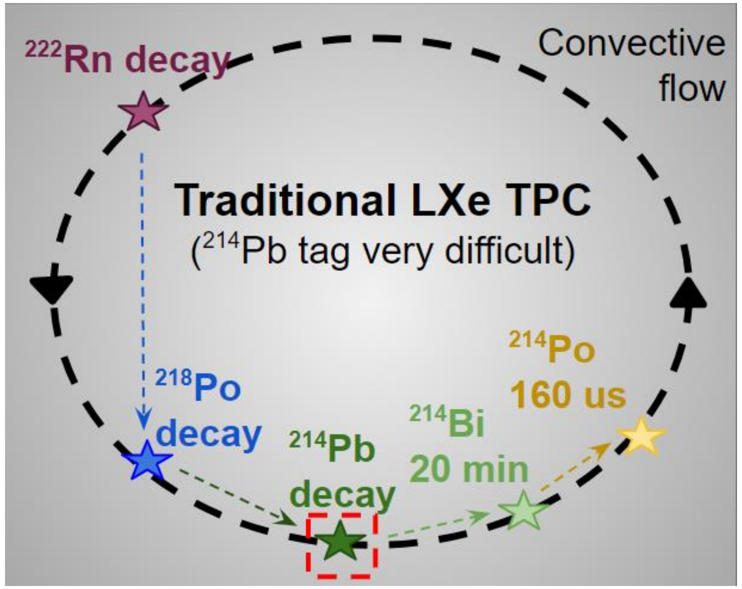
Leakage fraction ~(4-10)x smaller 10-30 phe: allows further reduction of remaining ER bkgs (neutrino ERs, Kr, ^{136}Xe, ...)

NEXT STEPS

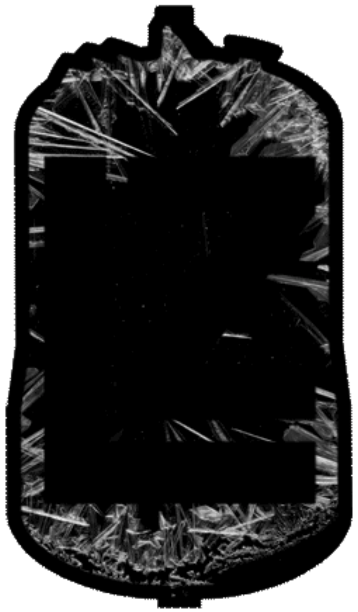
- Test bed upgrades:
  - More SiPMs, better light collection, position info
  - Higher extraction field w/ new HV feedthroughs
- Further measurements:
  - Proper study of charge (S2 size) in LXe vs SXe
  - Study Rn diffusion, Rn tagging
  - Single e- study
  - Effects of freezing speed/procedure







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!)
    - Can remove the primary DM background, internal radon
    - Potential for addressing remaining ER backgrounds through improved discrimination
- Operation of a two-phase SXe TPC has been demonstrated, with similar particle detection properties to LXe