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!

Dark Matter Searches: Past, Present & Future

Gaitskell et al. (200828T2113) Snowmass LOI

Solar neutrino limit (approximate)
LZ LIMITATIONS FROM BACKGROUNDS

Figure from LZ: arXiv:1802.06039

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 cristaLiZe, Rn in bulk target from LXe phase would be fixed, decay away in O(100) days

- 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
  • Potential for improved ER/NR discrimination (due to changes in e-/Xe\(^+\) recombination)
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
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)

![Graph showing noise, single dark counts, and double dark counts.]

![Diagram of Xe level in TPC.]

![Image of bottom SiPM array beneath cathode wires.]
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: $\alpha$ calibration source

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

Note: triple point
$T = -111.8 \, \text{C}, \quad p = 0.82 \, \text{Bar}$
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?

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

*arXiv:1410.6496
SIMULATION: REPRODUCE LUX BANDS

Simulate LUX bands in LXe
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)

SXe equivalent
(15% light -> charge)

Leakage fraction \(\sim (4-10)\times\) 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