DARK MATTER DETECTION AND BEYOND WITH CRYSTAL XENON

SCOTT KRAVITZ

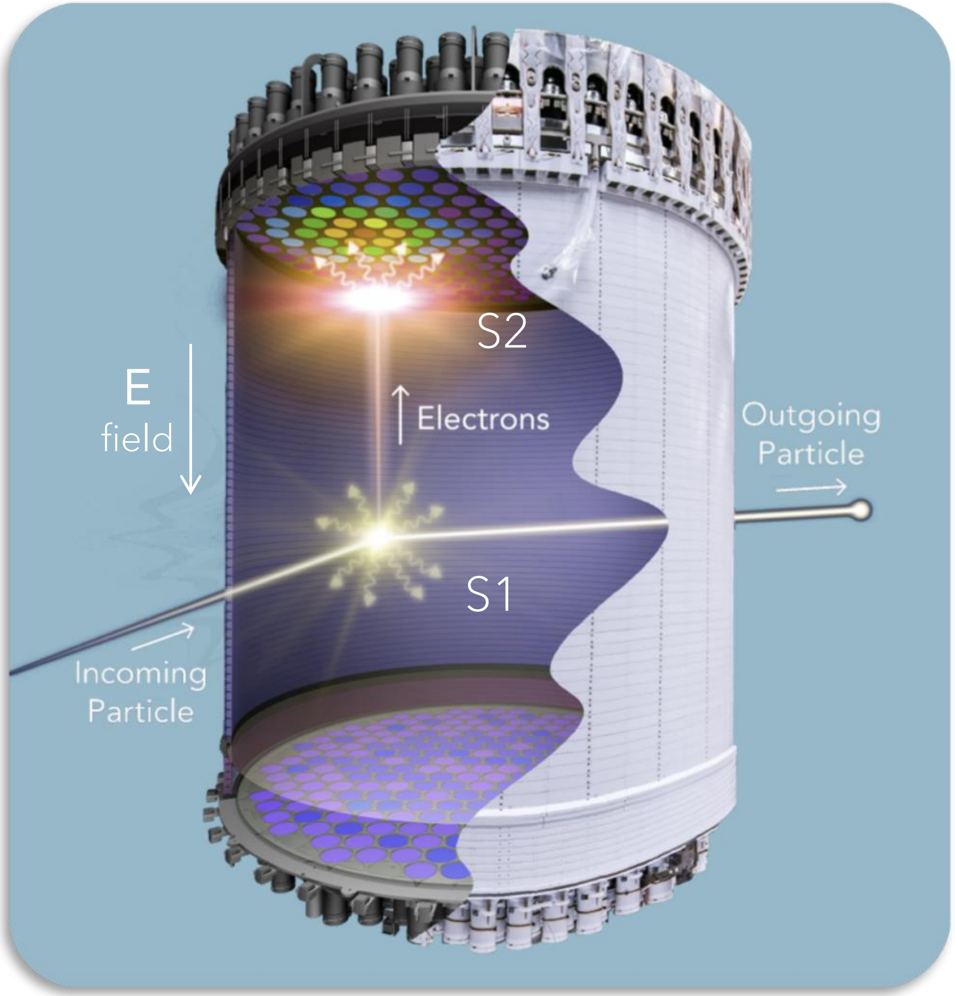
UT AUSTIN

CPAD RDC1 MEETING – MAY 21, 2024

BERKELEY LAB

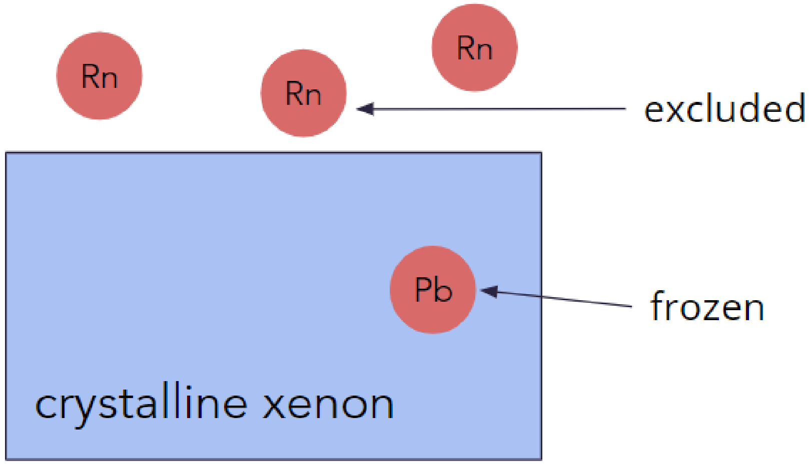
Lawrence Berkeley National Laboratory

LXE TPC: SUCCESS & LIMITATIONS



- Used in world-leading rare event searches
  - Dark matter direct detection (e.g. LZ, XENONnT)
  - Neutrinoless double beta decay (e.g. EXO-200/nEXO)
- As experiments grow…
  - External bkgs (e.g. gammas) get attenuated further
  - Internal bkgs (e.g. dissolved radon chain daughters) become relatively more important
- For dark matter, reaching the neutrino fog first requires dealing with **radon – ~80% of bkg events** in LZ-scale expts!
  - Reach theory benchmarks sooner
  - More robust discovery potential
  - Cleaner data = much easier to find the unexpected

THE PROMISE OF CRYSTAL XENON

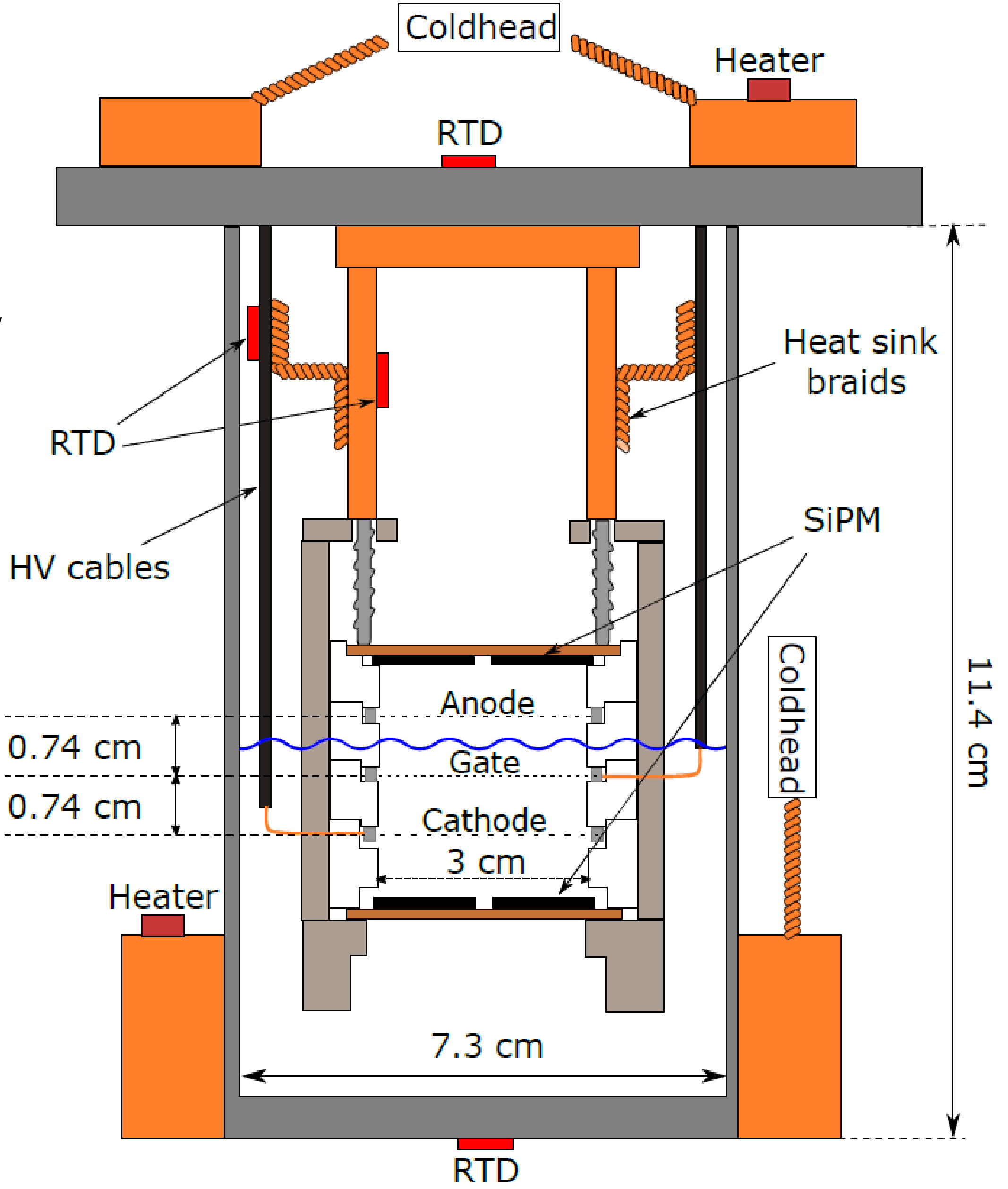


- With a crystal/vapor two-phase TPC: Radon emanated from surfaces is now **excluded** from the bulk crystal
- Rn in bulk target from LXe phase would be fixed, decay away in O(100) days leading to >100x reduction in Rn decay chain backgrounds
- Promising, novel, and relatively unexplored: many potential applications
- We aim to develop the technology so that it can be widely applied in particle physics by exploring its advantages and establishing its scalability

THE CRYSTAL XE TPC

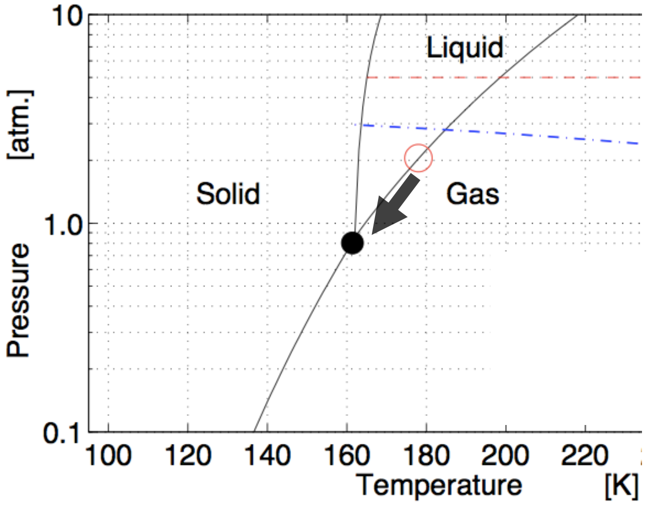
- Two phase Xe TPC at LBL
- ~700 g Xe when full
- S1 and S2 readout:
  32 SiPMs
  (16 top, 16 bottom; Hamamatsu S13370)

JINST 17 (2022) P04014
[arXiv 2201.05740]
S.K., H. Chen, R. Gibbons,
S.J. Haselschwardt,
Q. Xia, P. Sorensen

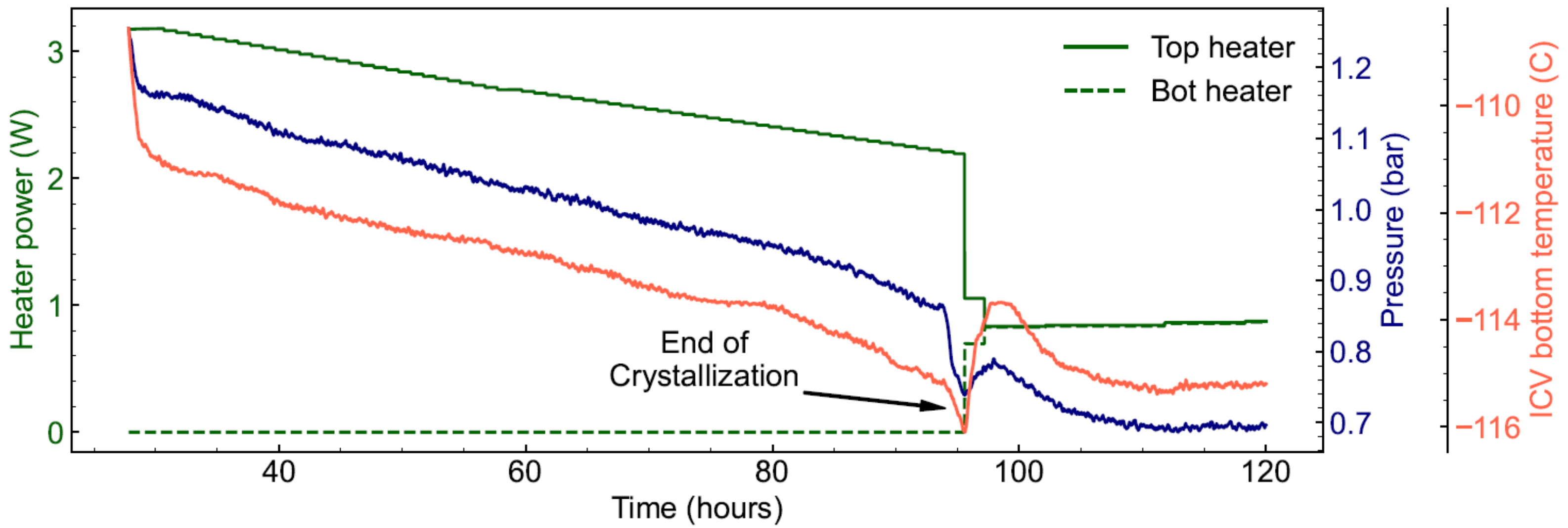


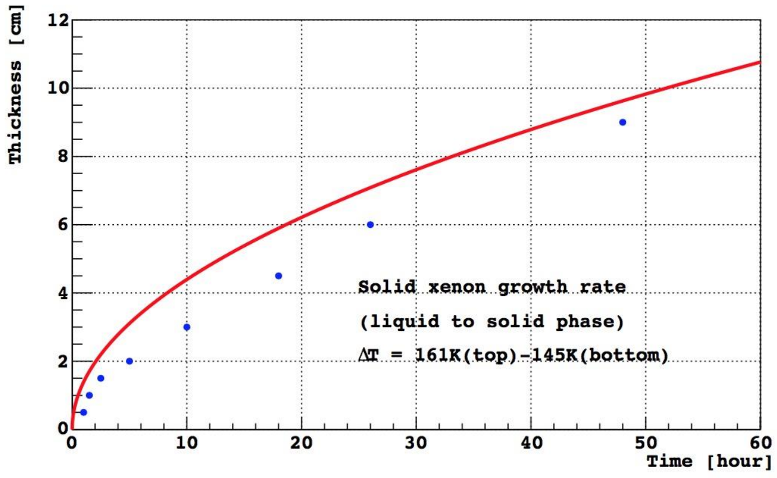
CRYOGENICS

- ~20 K colder than typical LXe operation
- Key challenge is careful crystal growth: Bridgeman method w/ constant gradient*
- Realistic / scalable cryogenics for tonne-scale
- Bonus: expect ~**17% higher density** (contraction = less risk of damage to components)



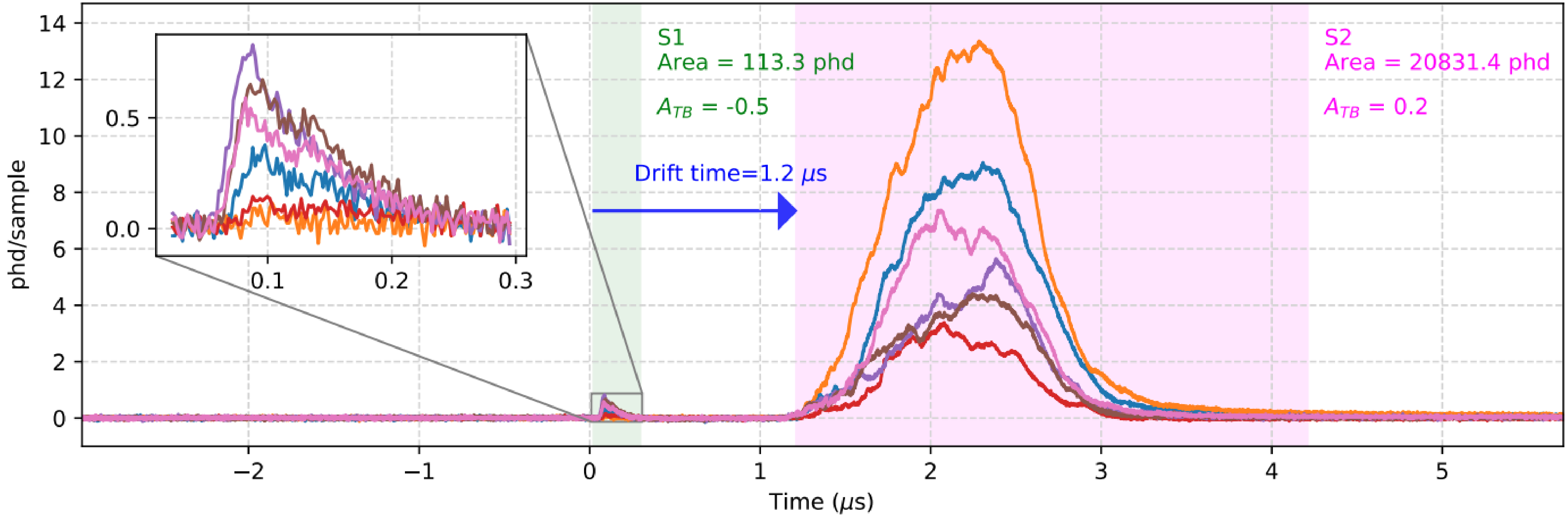
*Method/plot from Fermilab, arXiv:1410.6496





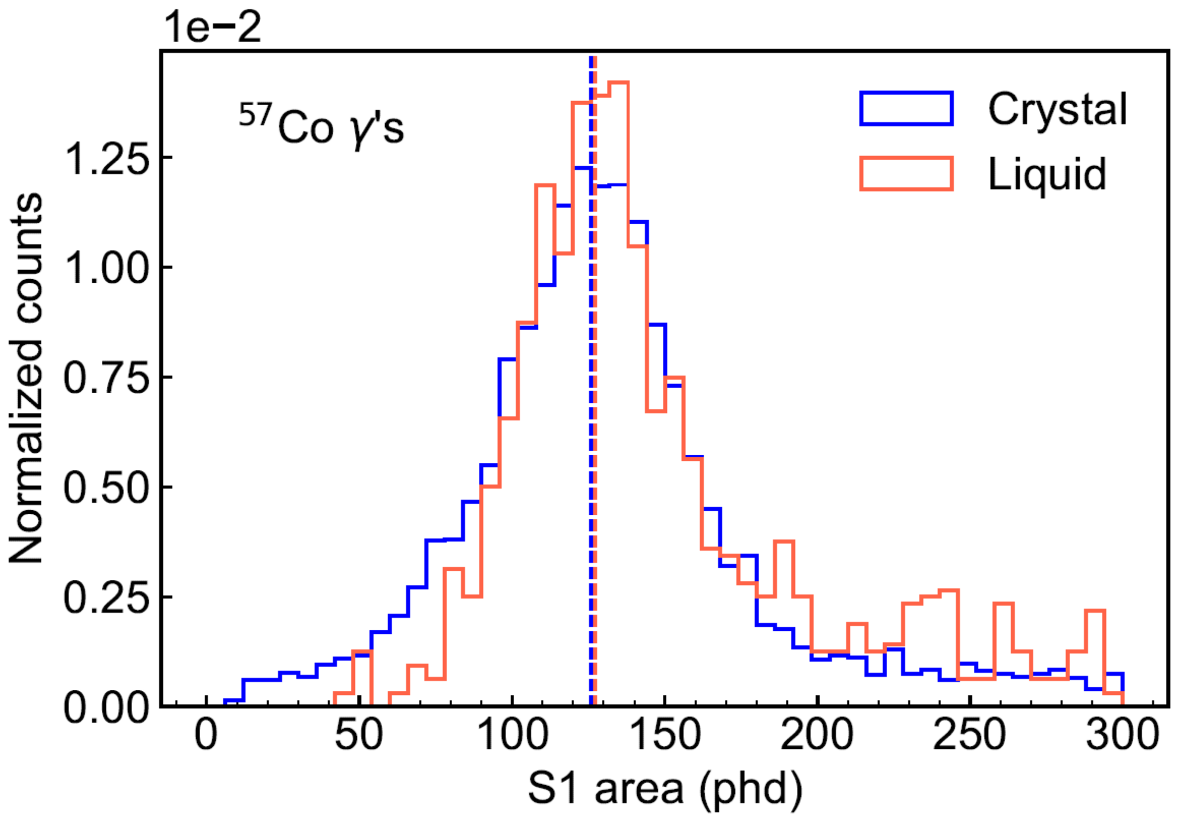
THE CRYSTAL XE TPC - DATA

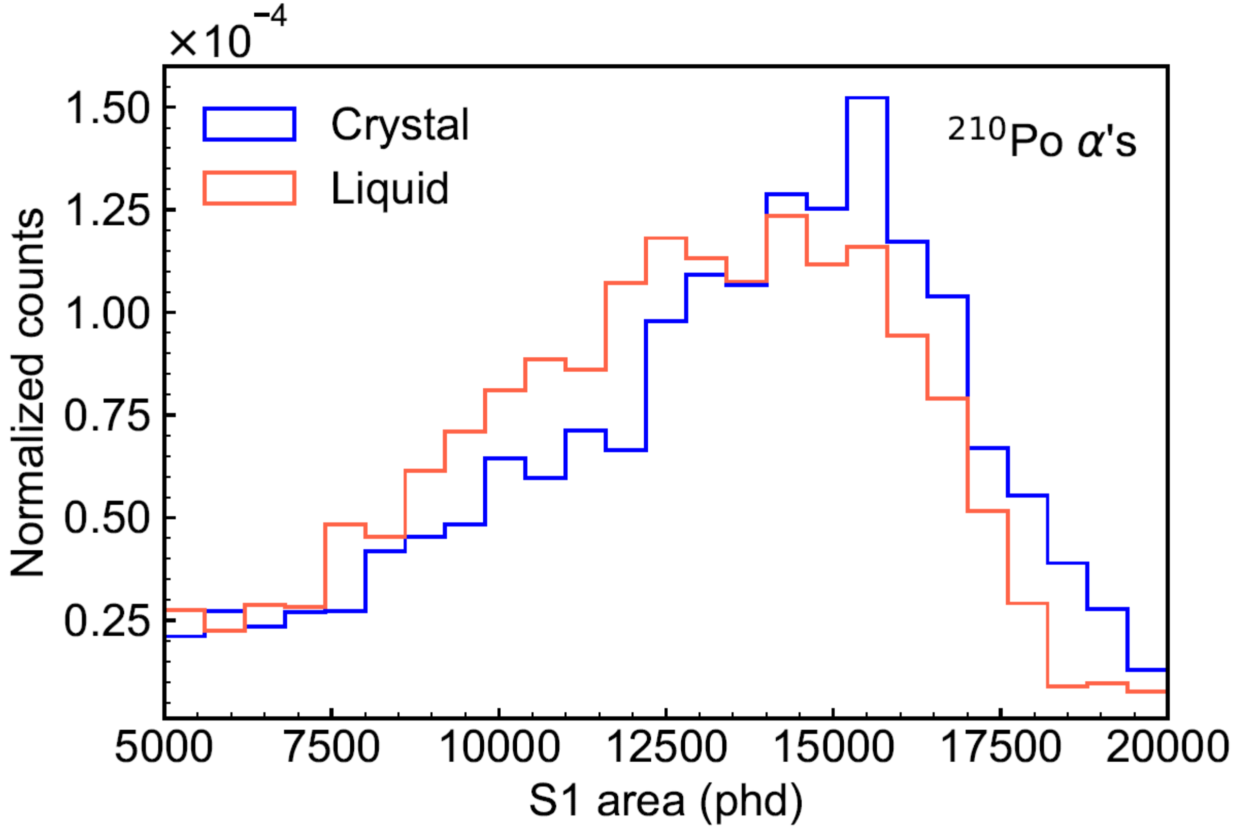
Functions just like its LXe cousin!



SCINTILLATION – MATCHES LXE

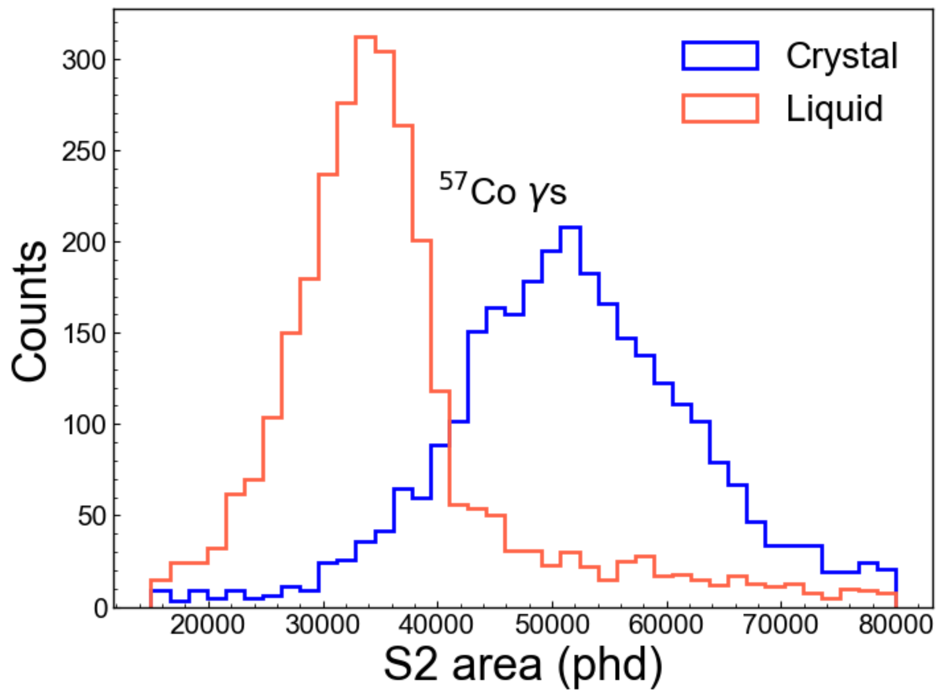
- Co **S1 size equal** for drift field ~270 V/cm
- Po S1 size equal or slightly larger at 0 field



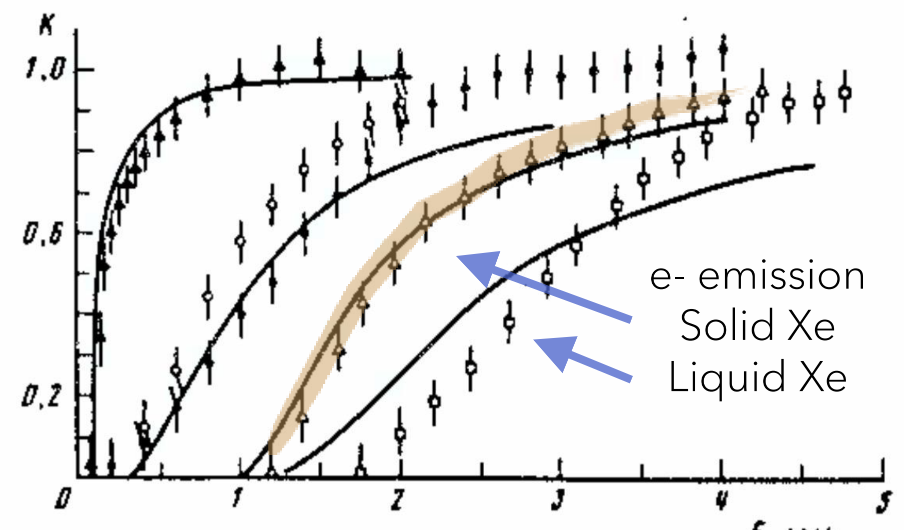


IONIZATION – READILY DETECTED

- No issues seeing S2s in crystal
- Raw yield measurement pending: gas gap may differ



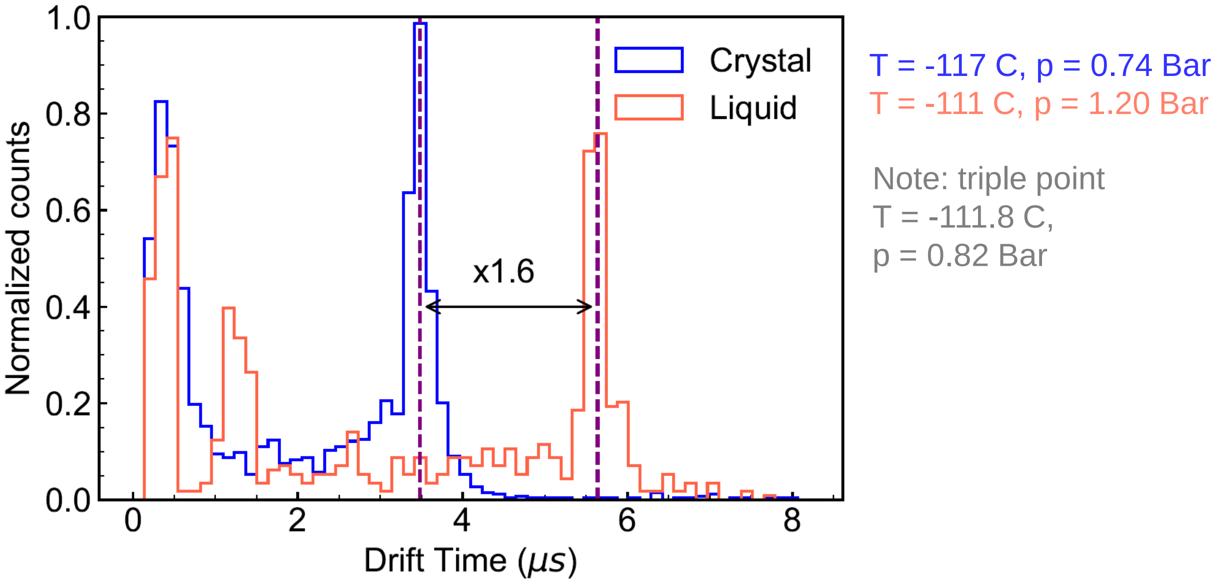
- **Higher e- extraction** for same field
- Bonus: smaller few-electron bkg from less trapping at surface?
- Potential application:
  dedicated low-mass DM experiment

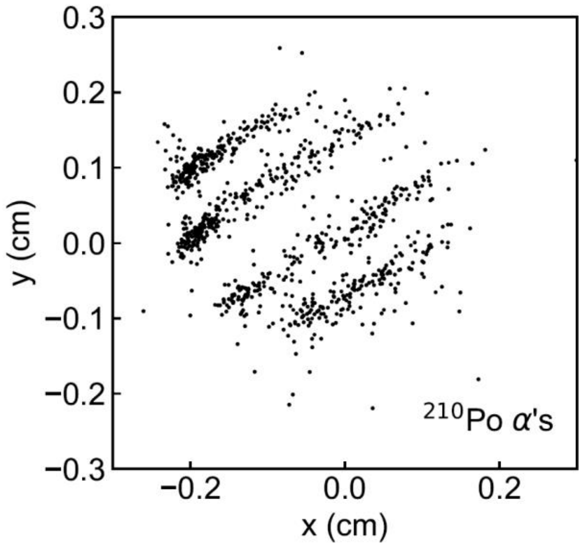


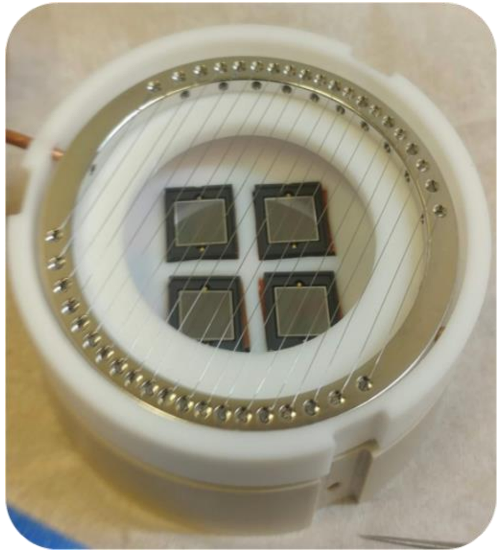
JETP 55 860 (1982)

ELECTRON MOBILITY – HIGHER

- Drift speed ~1.6-2x faster in crystal
  (consistent w/ Fermilab arXiv:1410.6496 and Phys Rev B 10 4464 (1974))
- Bonus: less pileup, **fewer accidental coincidences**; less time for electron diffusion

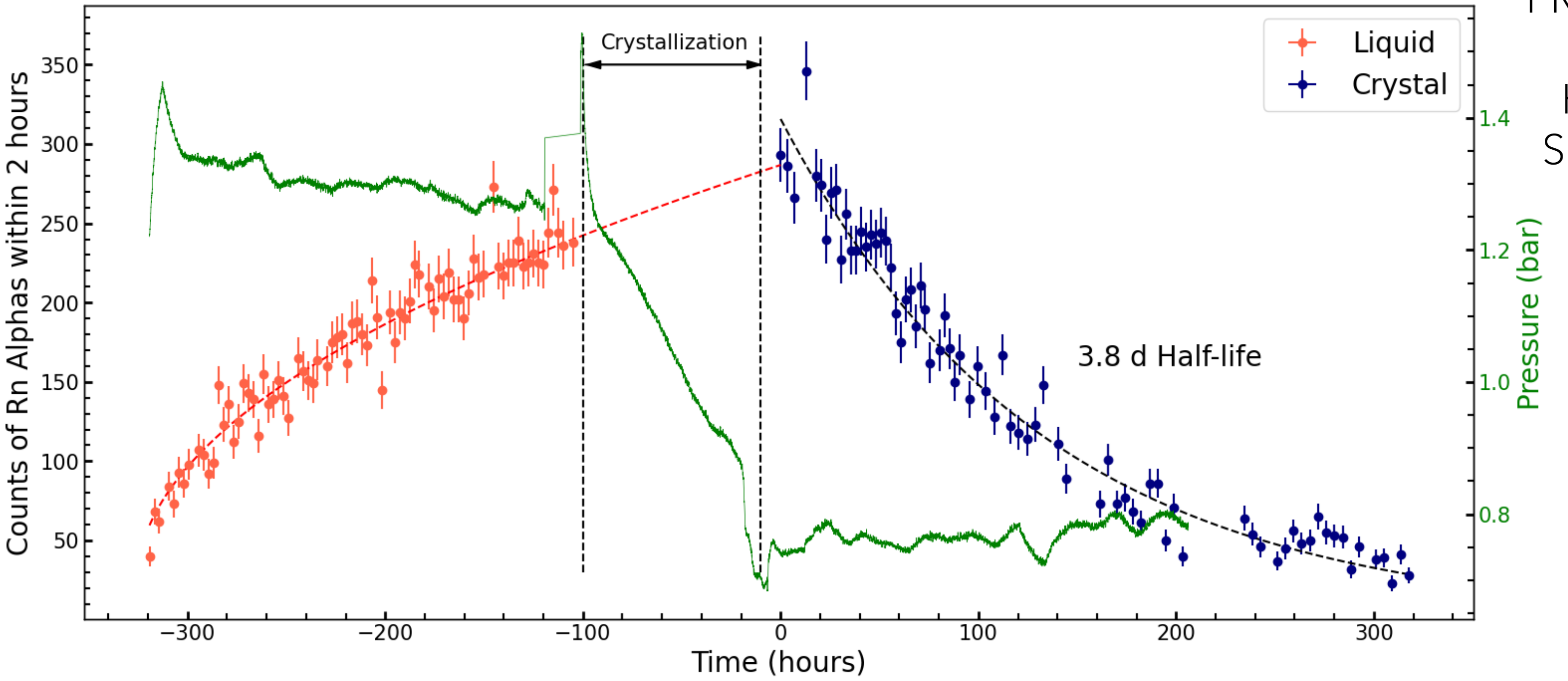






RADON DECAY IN CRYSTAL

- Test: continuous Xe flow past ^{222}Rn source (fixed flow throughout full test)
- Radon exclusion of ~>10x (limited by time needed for ^{222}Rn decay)

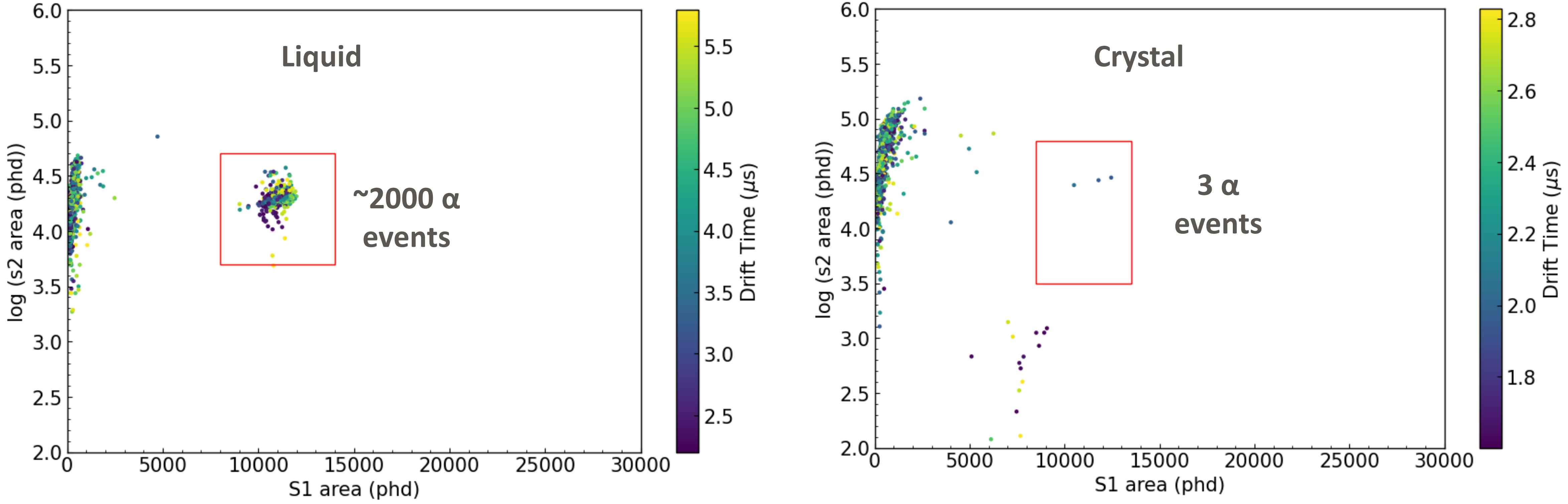


PRD 109 (2024) L071102
[arXiv 2312.15082]
H. Chen, R. Gibbons, S.J. Haselschwardt, S.K. Q. Xia, P. Sorensen

RADON EXCLUSION FACTOR

- Test: flow ^{220}Rn for hours in liquid (left) or after crystallization (right)
- ~2000 Rn chain alphas in liquid, only 3 in crystal
- Exclusion factor of >600x

- Crystal alphas are unlikely to be from diffusion through crystal:
  - In center (vertically)
  - Rate consistent w/ pre-existing ^{222}Rn background

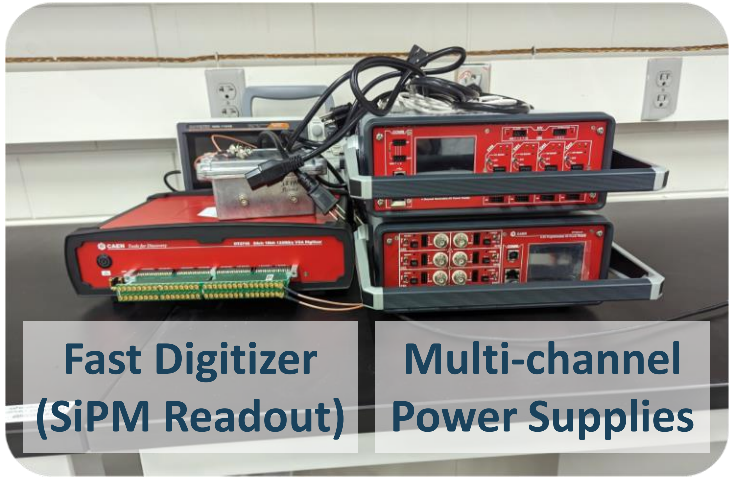


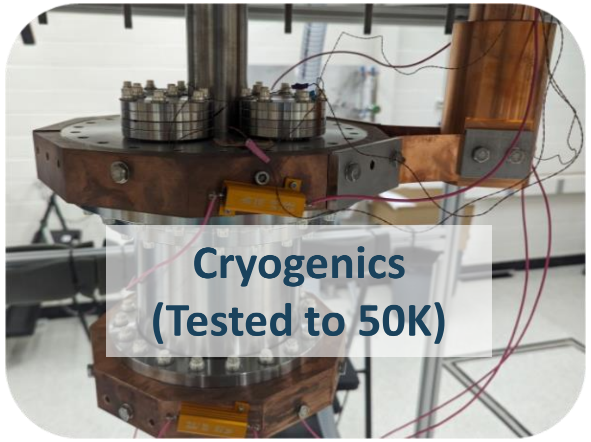
NEW EFFORTS AT UT AUSTIN

- Key question:

  Does this scale up from 700 g to 7 tonnes?

- UT Austin apparatus being built for ~20 kg tests
  - Scaling of crystallization time vs mass
  - Studies of crystal transparency

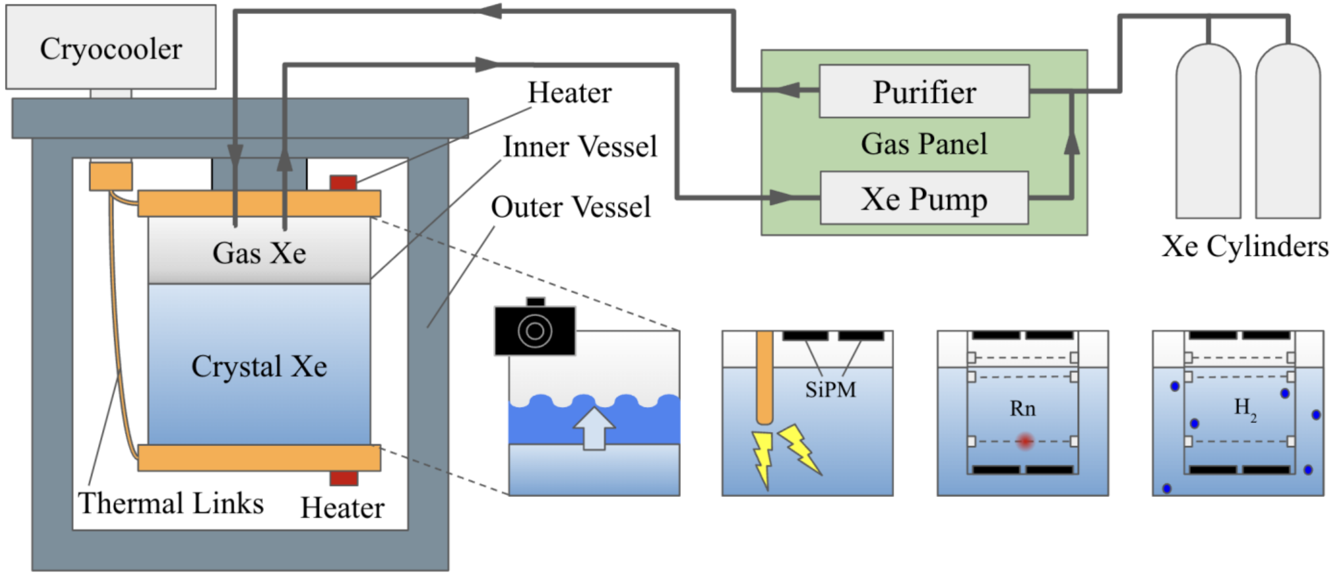




CHALLENGES AND OPPORTUNITIES

- ER/NR discrimination: might it be better in crystal?
- Do PMTs work in crystal (vs SiPMs)?
- How stable are Xe crystals over time?
- What is the IR scintillation response in crystal?
- Can we scale up from 700 g to 7 tonnes?
- How does crystallization rate affect yields? Crystal surface shape?
- Can we achieve the needed HV?
  - Quantify S2 response
  - Possible application: single phase, charge amplification in crystal

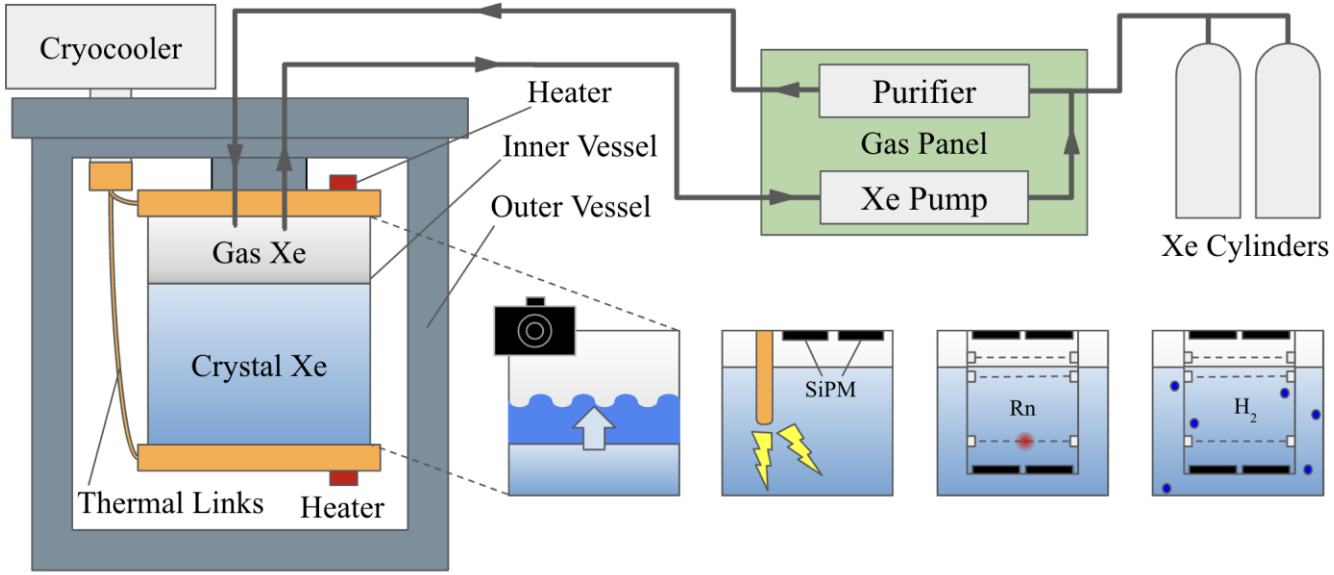
LBNL future work
New UT Austin apparatus



CHALLENGES AND OPPORTUNITIES

- What are the diffusion rates in crystal?
  - Radon and electrons
  - Possible application: Neutrinoless double beta decay
    - Largest bkg in LXe is cathode plate-out of Rn daughters
    - Less diffusion = better position, energy resolution
- Is crystaLiZe compatible with HydroX (hydrogen doping of xenon) for low-mass / spin-dependent WIMP searches?
  - Crystal solves: need for re-purifying / re-doping H; possible concerns about S2 quenching of from H in vapor

LBNL future work
New UT Austin apparatus



FIT TO RDC STRUCTURE

- Current research is at LBNL + UT Austin
- **Looking for broader collaboration**
  - New applications are likely w/ proper study
  - Example: sub-Kelvin crystal xenon bolometry
- Further studies
  - Calibration techniques
  - Maintaining purity during crystallization
  - Extending to tonne-scale likely requires coordination of a larger team of research groups
- **Goals are "blue sky":** develop into a mature technology that has the potential for wide applicability in particle physics