Brief overview of dark matter direct detection experiments/R&D at Berkeley Lab

Aaron Manalaysay, on behalf of the group

15 March 2024

Berkeley Lab Group

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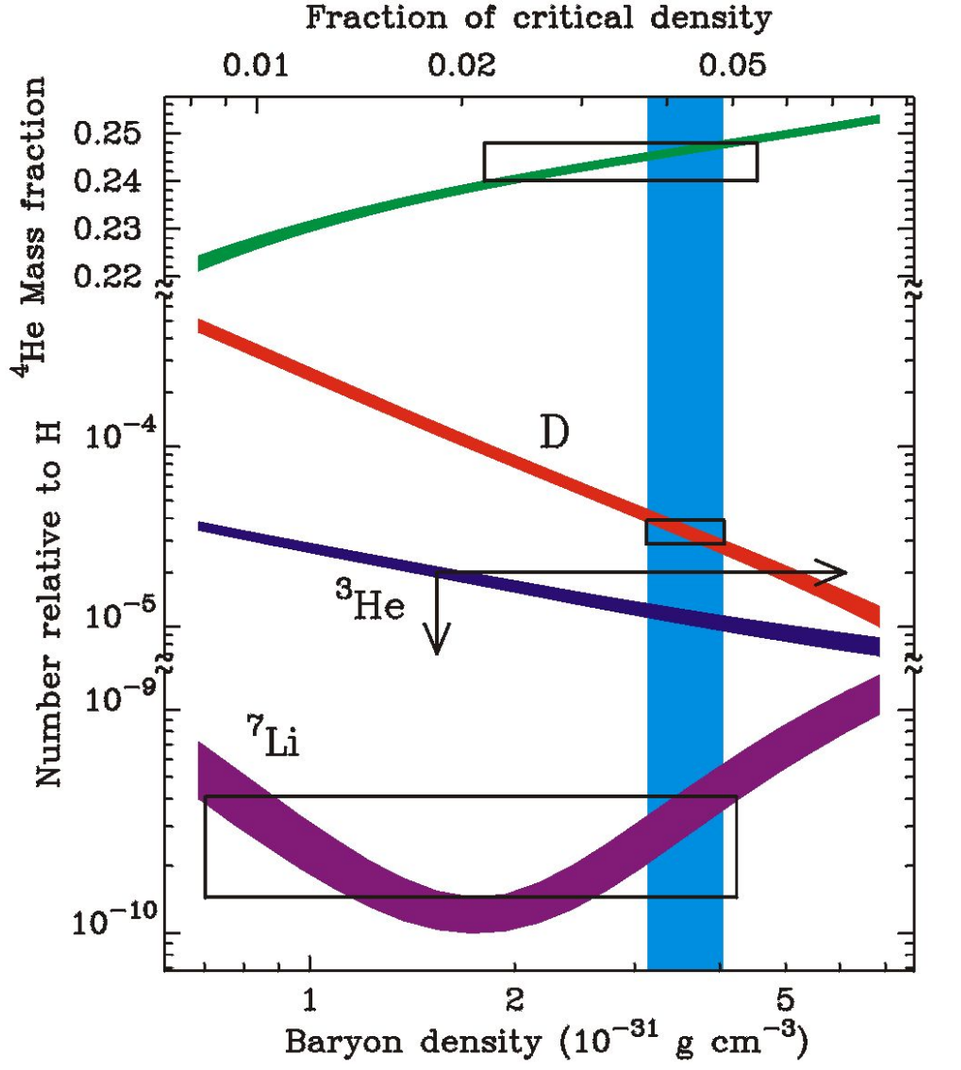
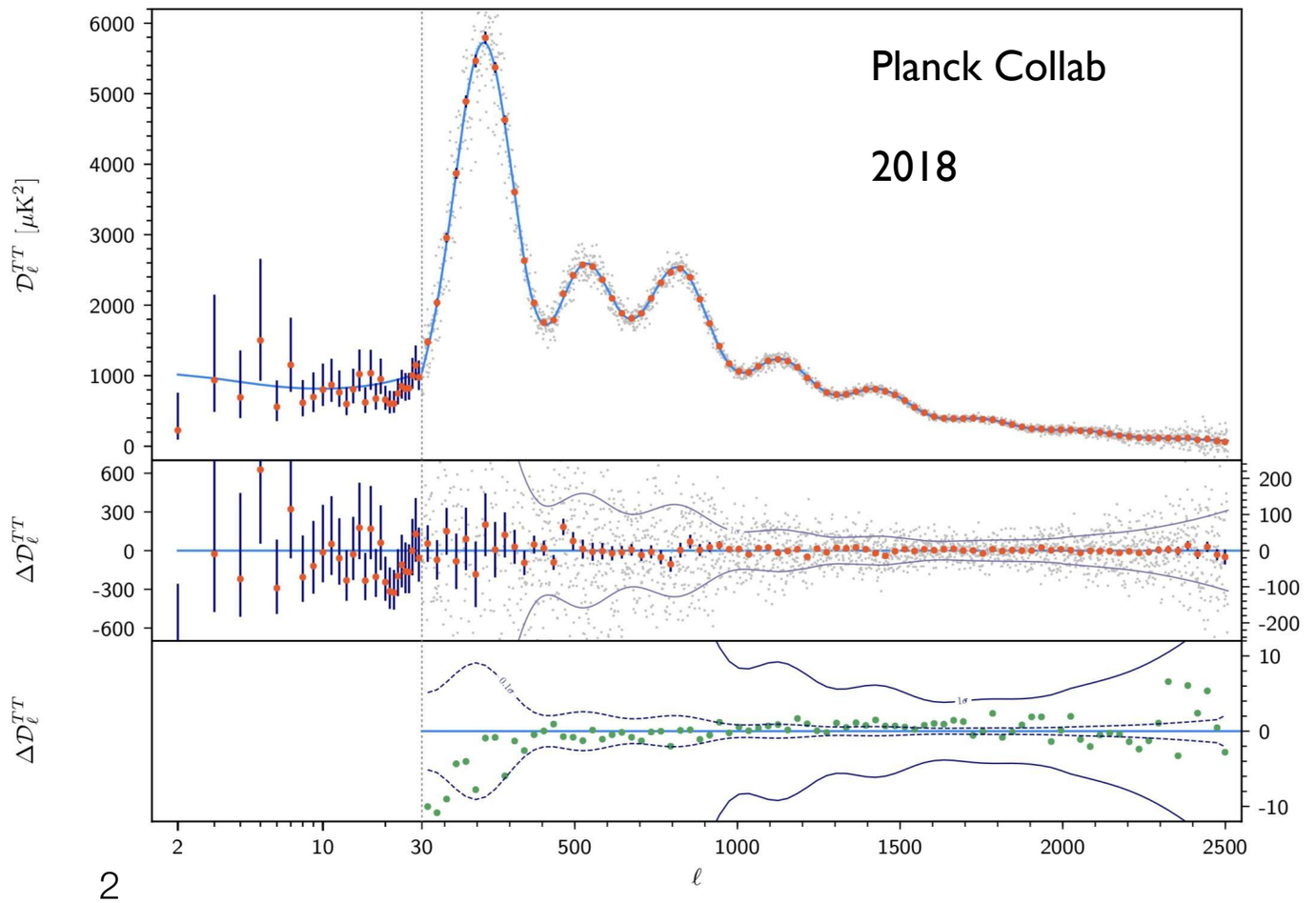
Direct Detection of Dark Matter

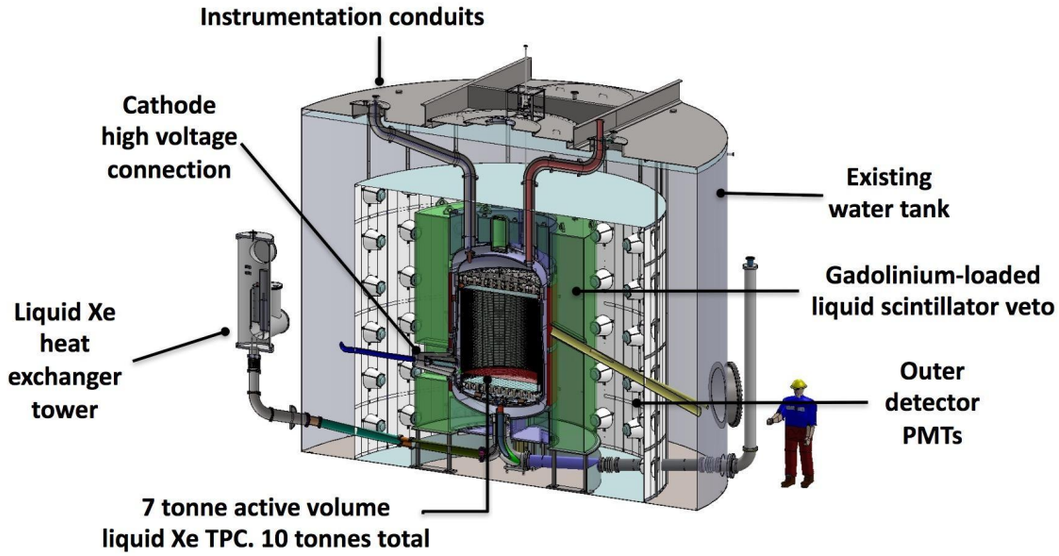
- We can "see" it and it isn't baryons
- Strongest evidence for physics beyond the Standard Model
- We would love to understand its particle nature (a P5 Science Driver)

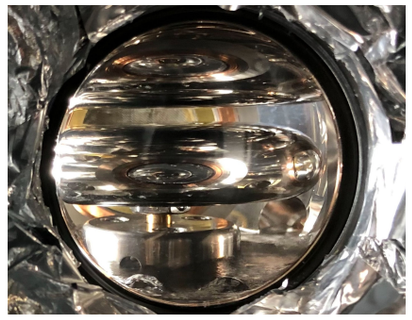


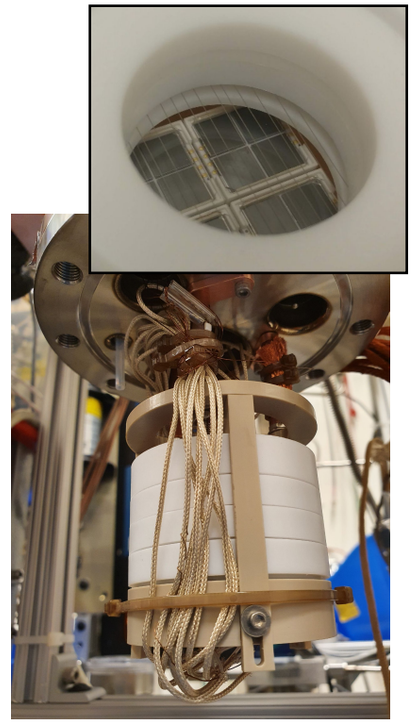


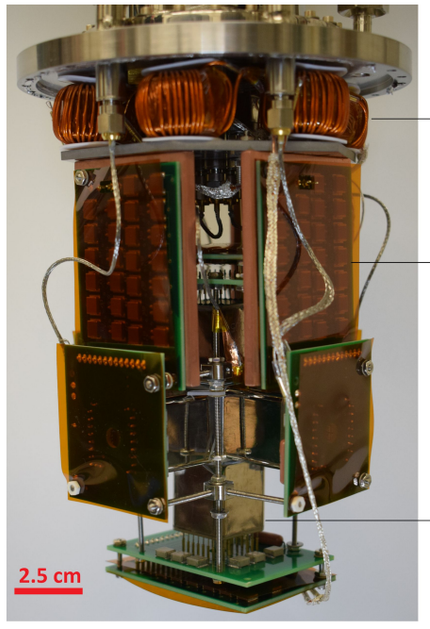
DM Group Focus next ~5 years

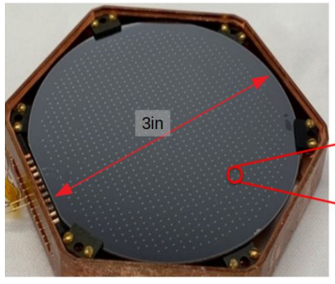
- LZ
  - Currently running, operations for 5+ years
- R&D towards possible LZ Upgrades
  - R&D towards optimizing/scaling xenon-target particle detectors
  - CrystaLiZe (DM mass ~10 GeV+)
  - HydroX (DM mass <10 GeV)
- TESSERACT
  - New detectors in pursuit of sub-GeV DM
- QIS detector R&D



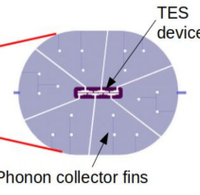








State of the art, lowest noise large area phonon detector. Used to set limits on low mass Dark Mater in ArXiv:2007.14289

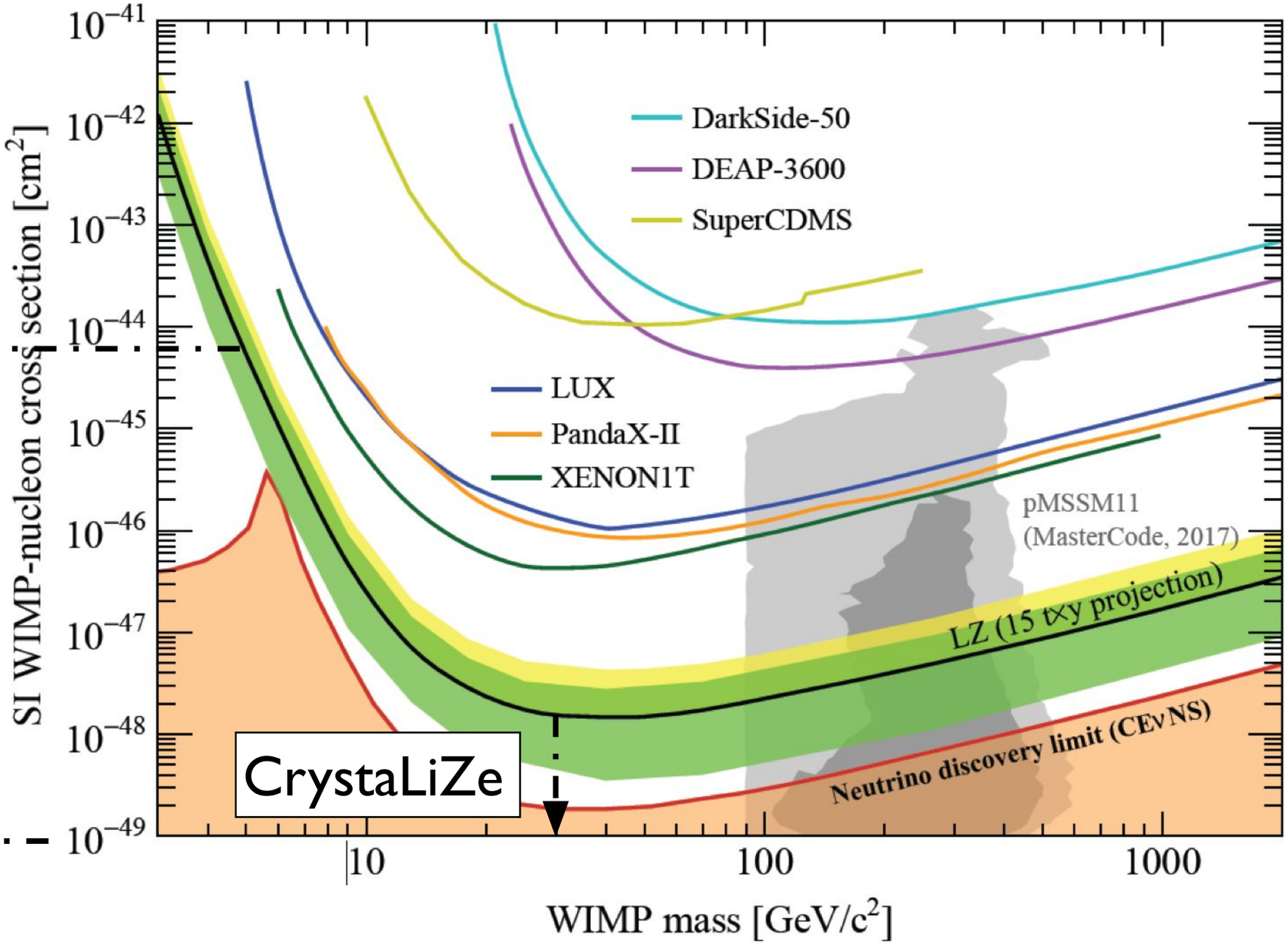


Roadmap

HydroX

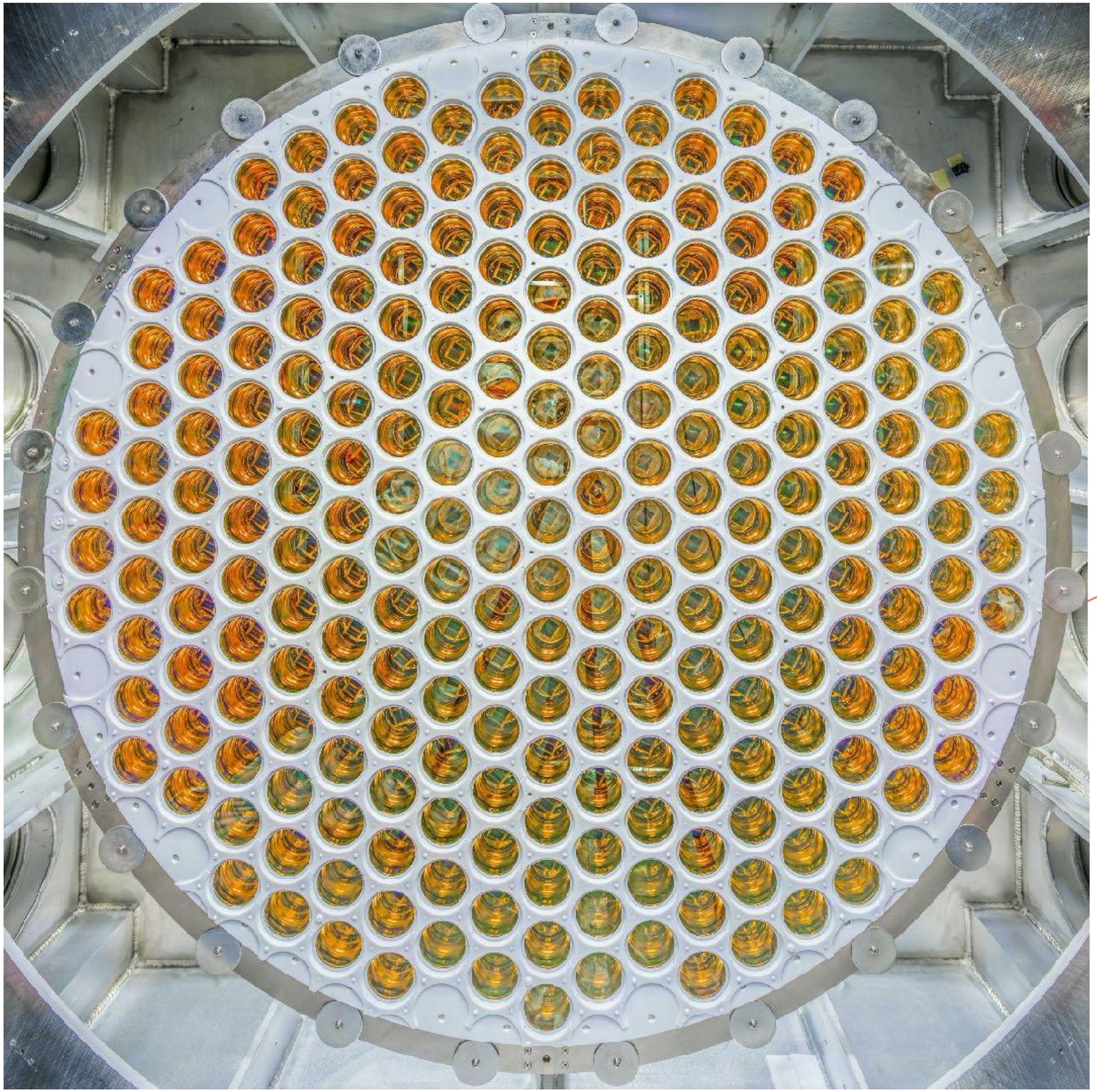
TESSERACT

QuantISED

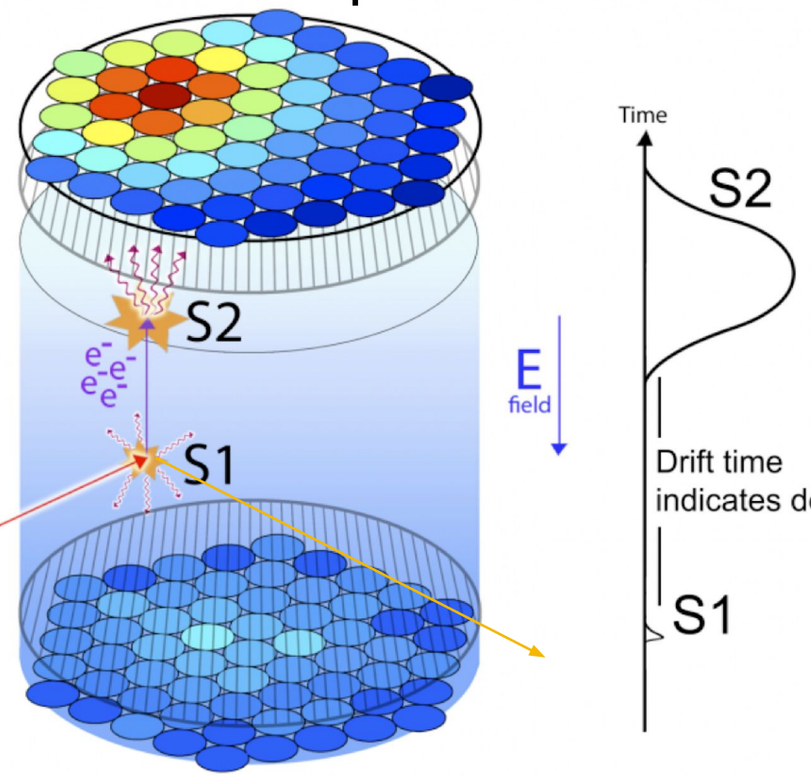


keV

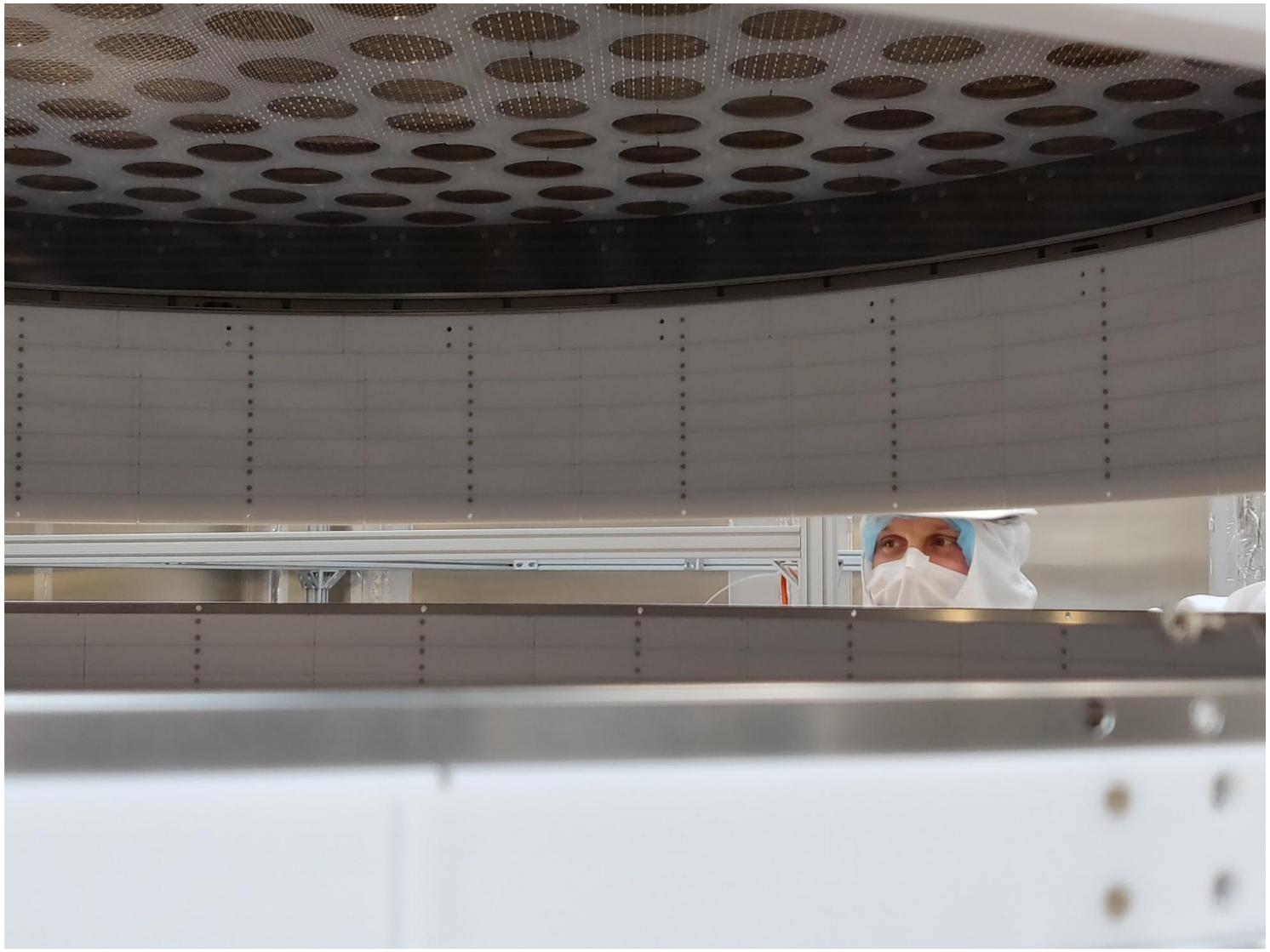
LZ: 494 primary eyes



LUX schematic: principle of operation

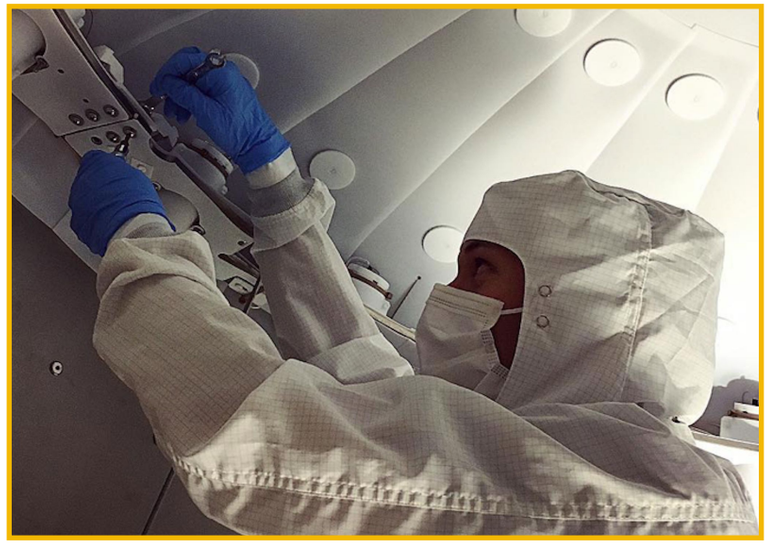


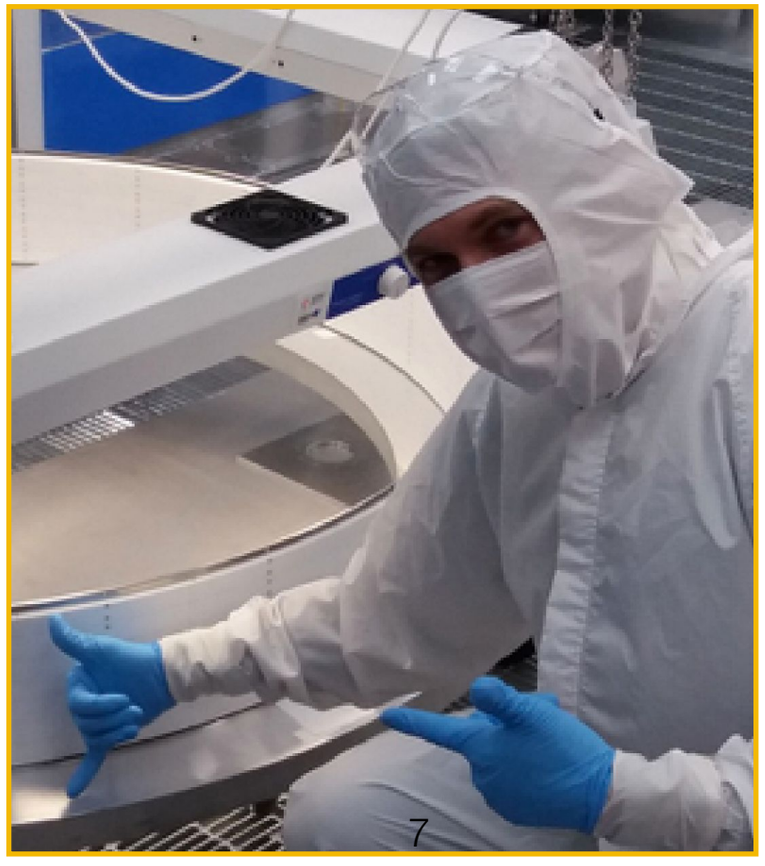
LZ



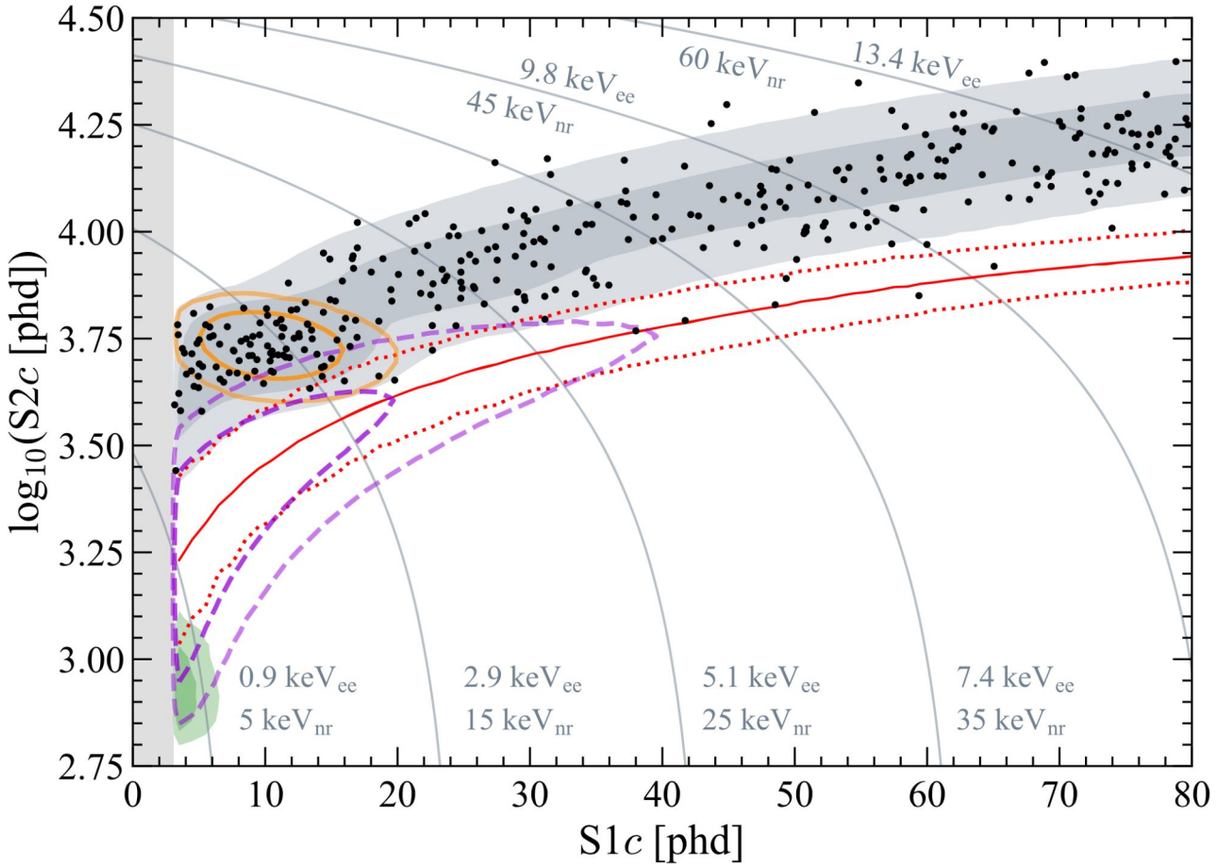
- LZ will improve direct detection sensitivity by an expected factor x40 (+discovery potential)
- Also sensitive to double beta decay, axion-like particles, neutrino magnetic moment, solar neutrinos
- On deck: operations (typical shift ~3 weeks), data, more data, analysis and publications

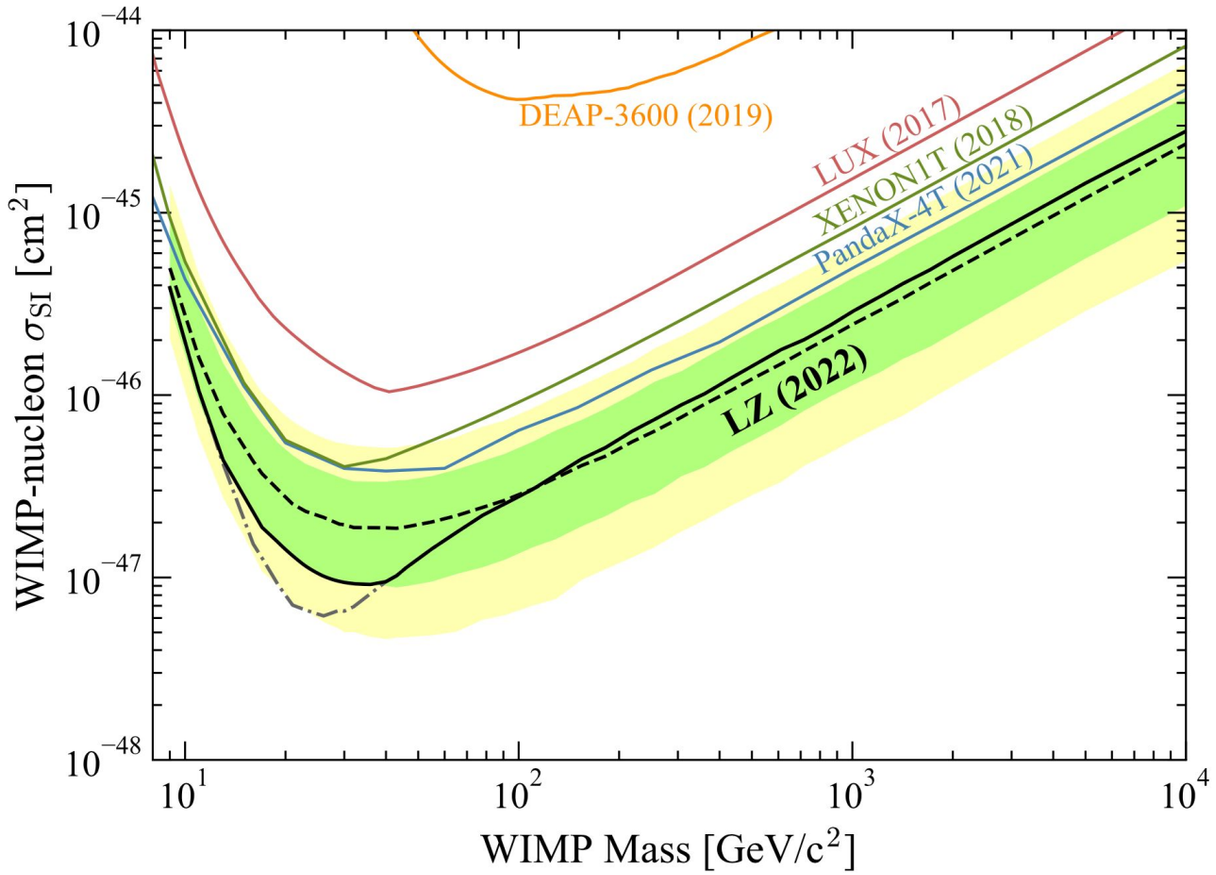
Faces / LZ





LZ First Results - world's strongest constraints on WIMP dark matter



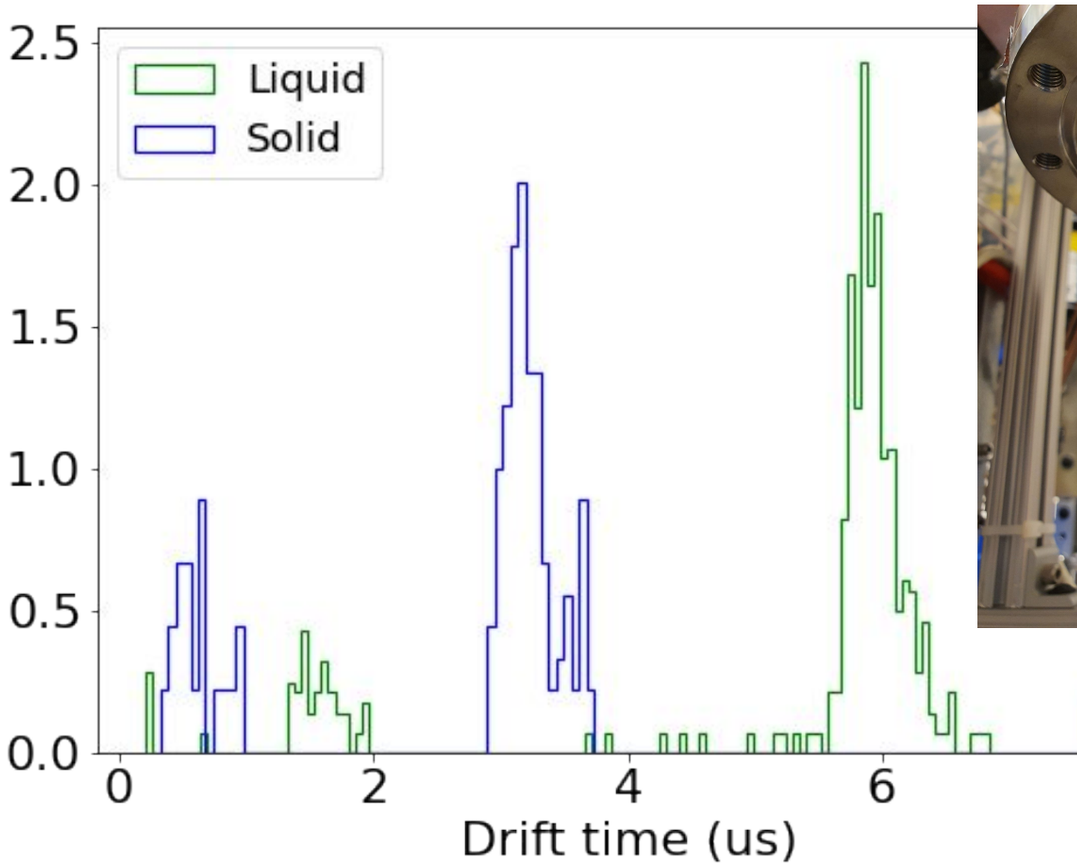


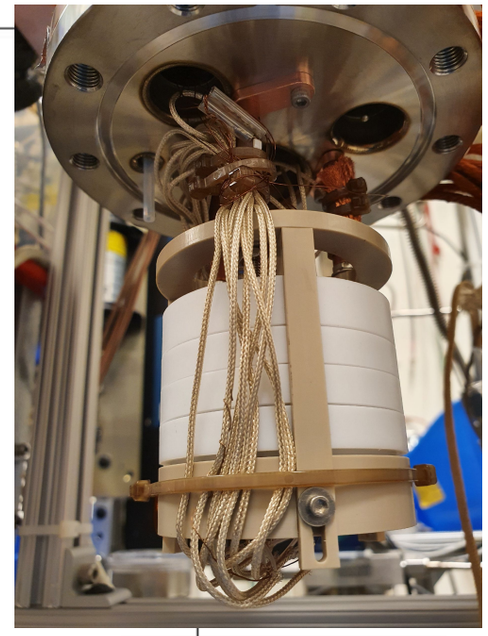
J. Aalbers et al., PRL 131, 041002 (2023)

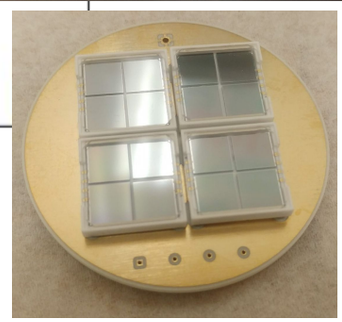
Instrumentation and detector R&D

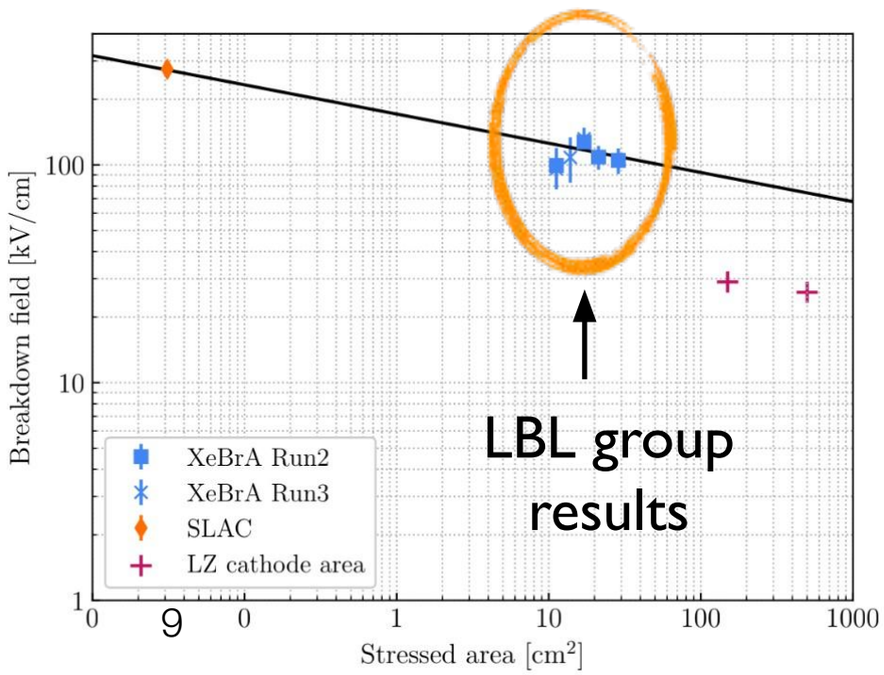
- crystaLiZe (LZ-upgrade concept): R&D on crystallizing liquid xenon TPC
    - Would allow nearly complete Rn-tagging, neutrino-limited search sensitivity
- HydroX (LZ-upgrade concept): helium-doping of LZ
    - Working towards first measurement of He recoils in liquid Xe using a novel degraded alpha source
- XeBrA (scaling laws study): high voltage delivery is critical to success of LZ and similar large TPCs

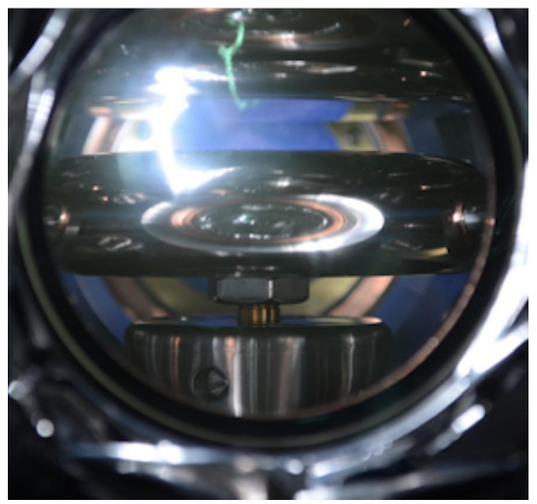
Xe crystal growth tracking via e- drift time



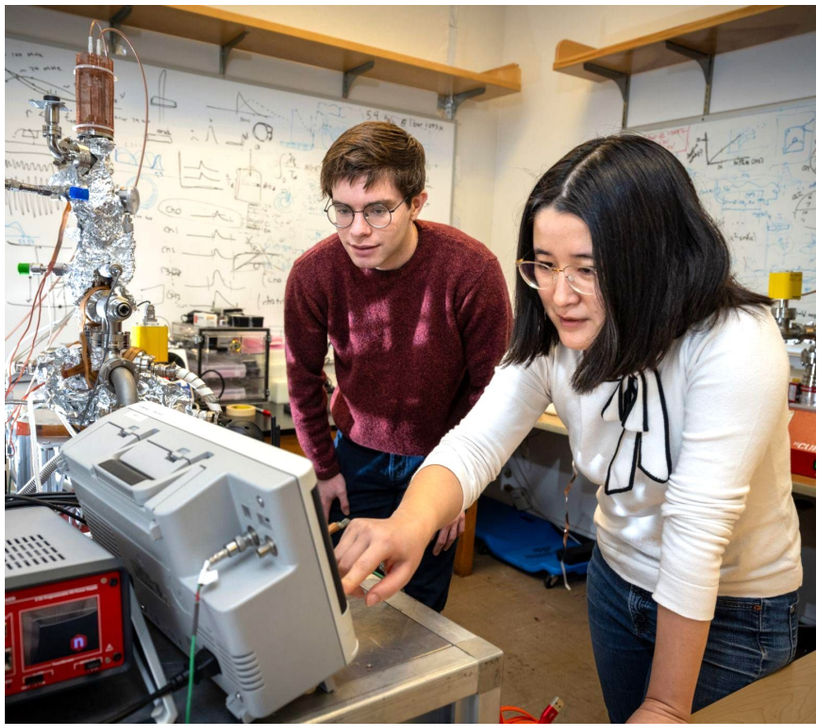


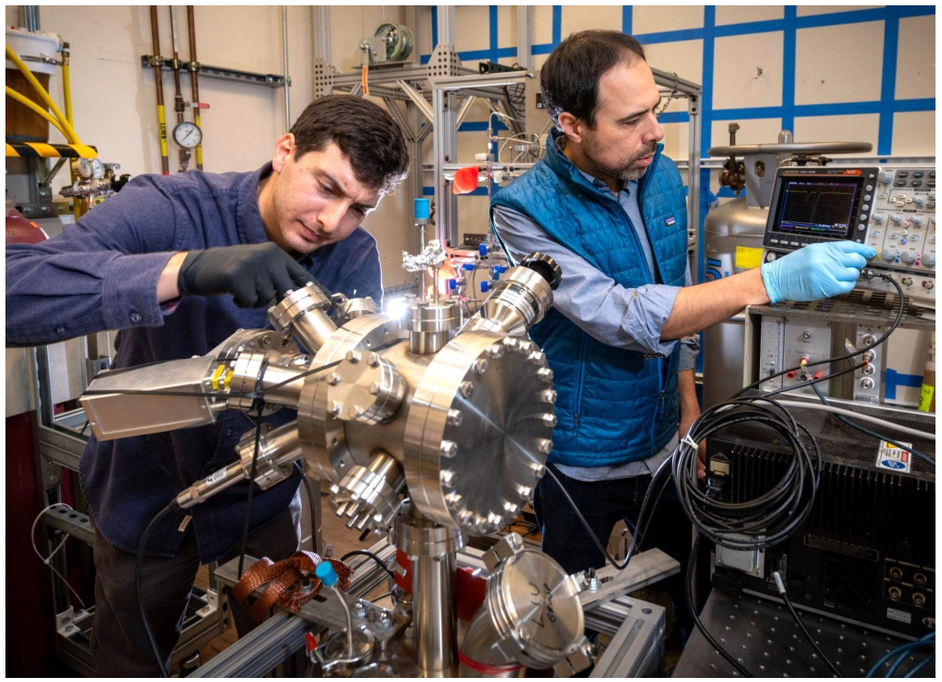


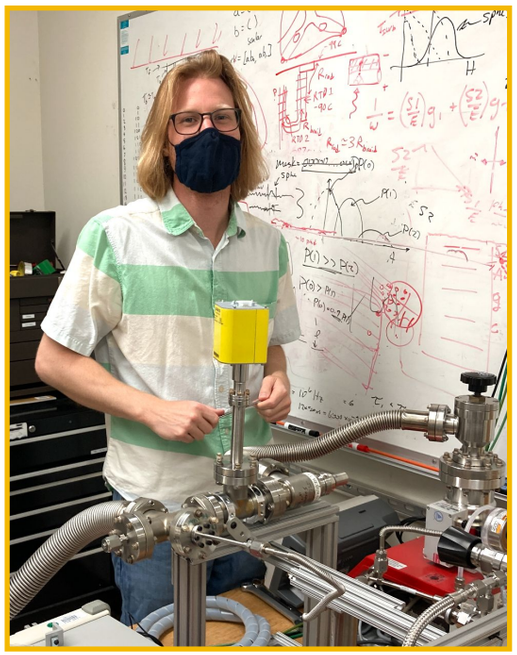


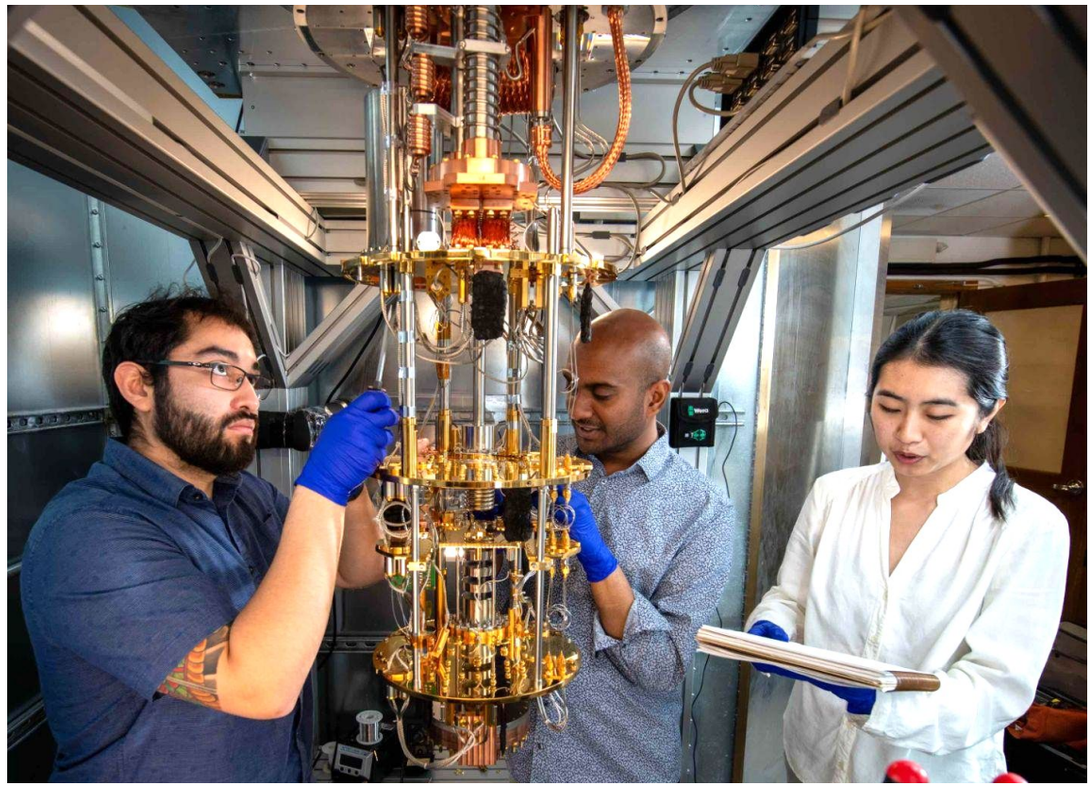


Faces / lab

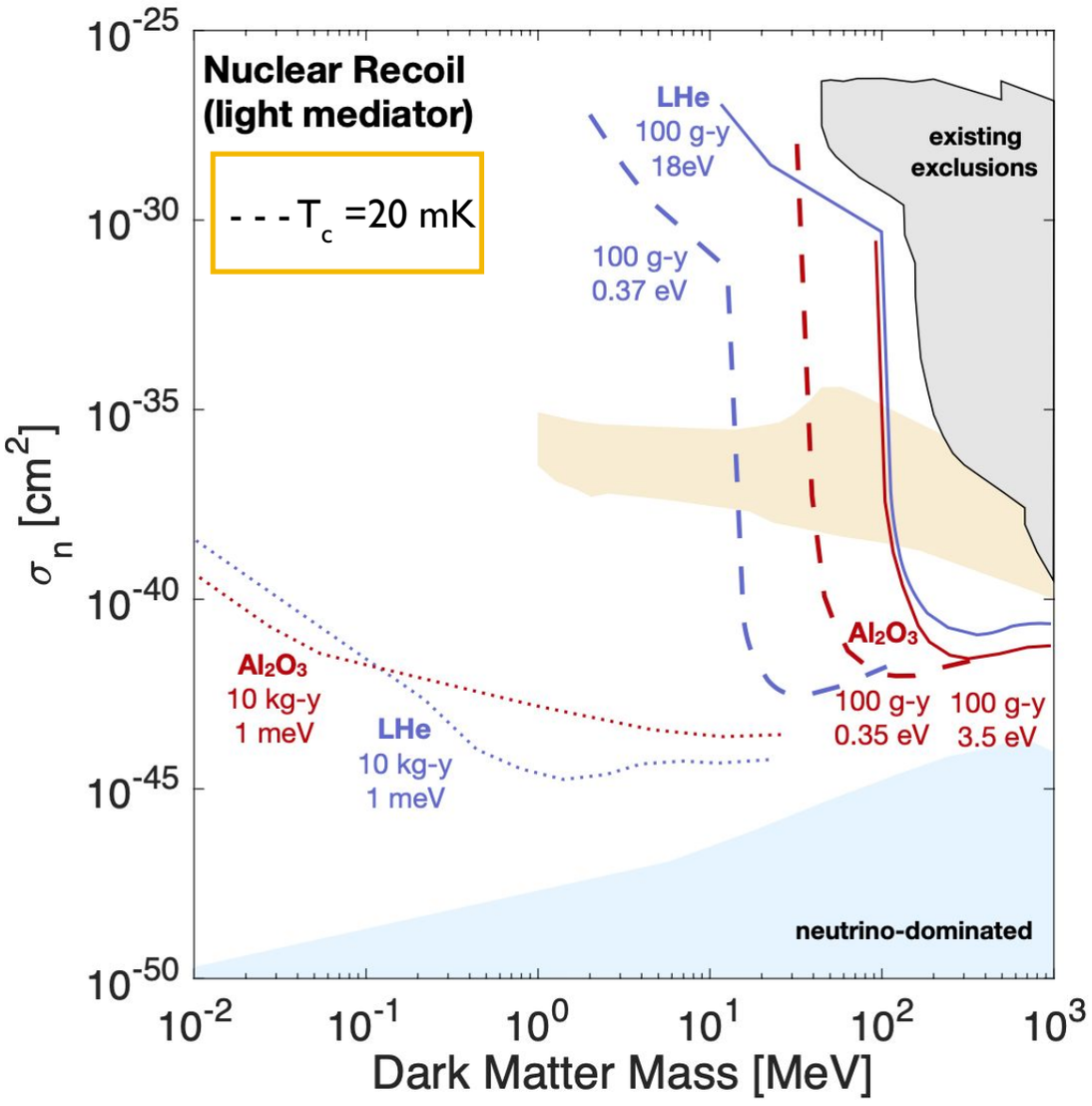


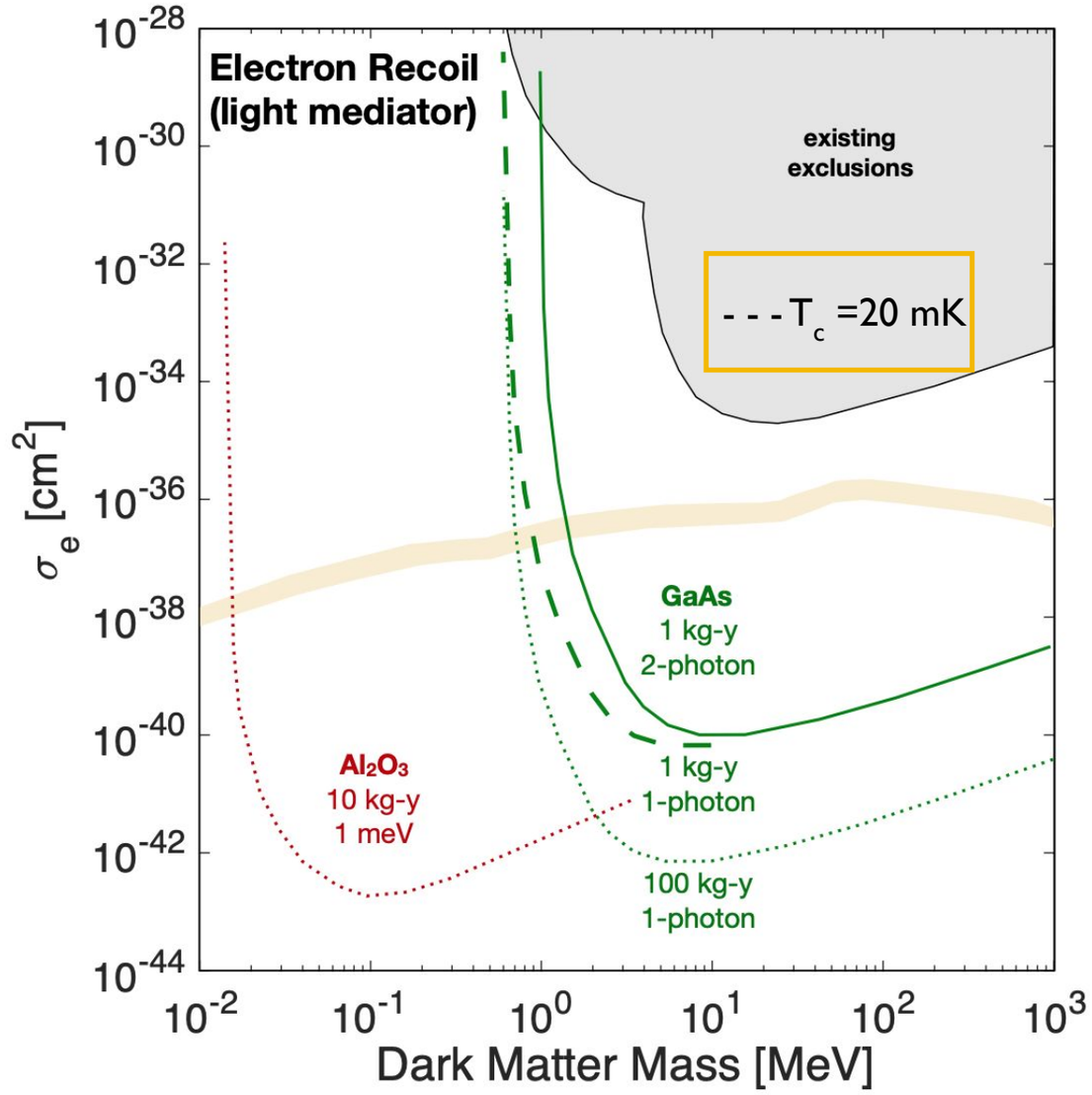






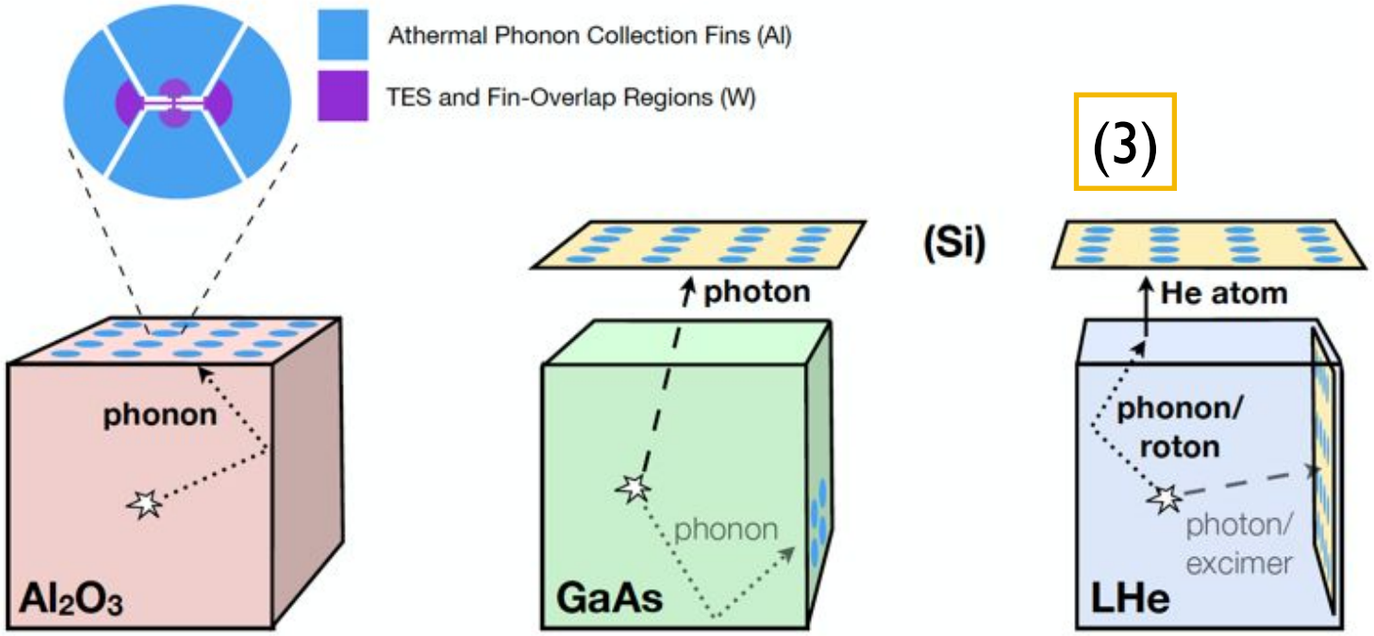
TESSERACT

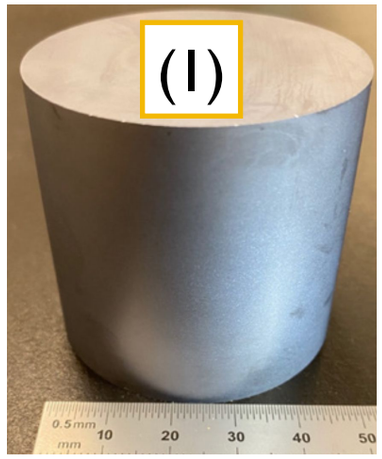


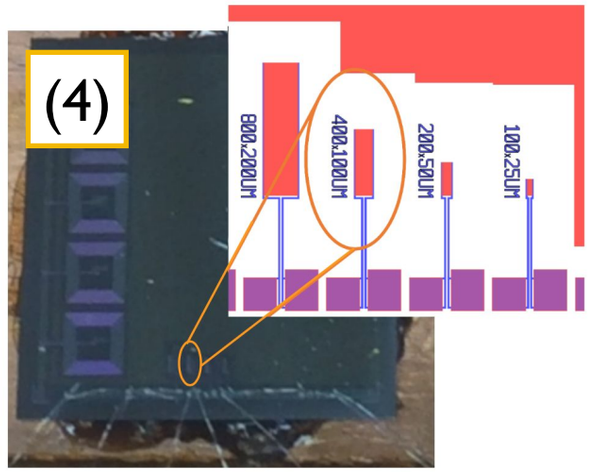


- Multiple detector targets (LHe, GaAs, Al_2O_3)
- Multiple DM candidates (Asymmetric, Hidden Sector …)
- Multiple signal modes (scintillation, phonon, roton, quantum evaporation)
- No dark counts

TESSERACT





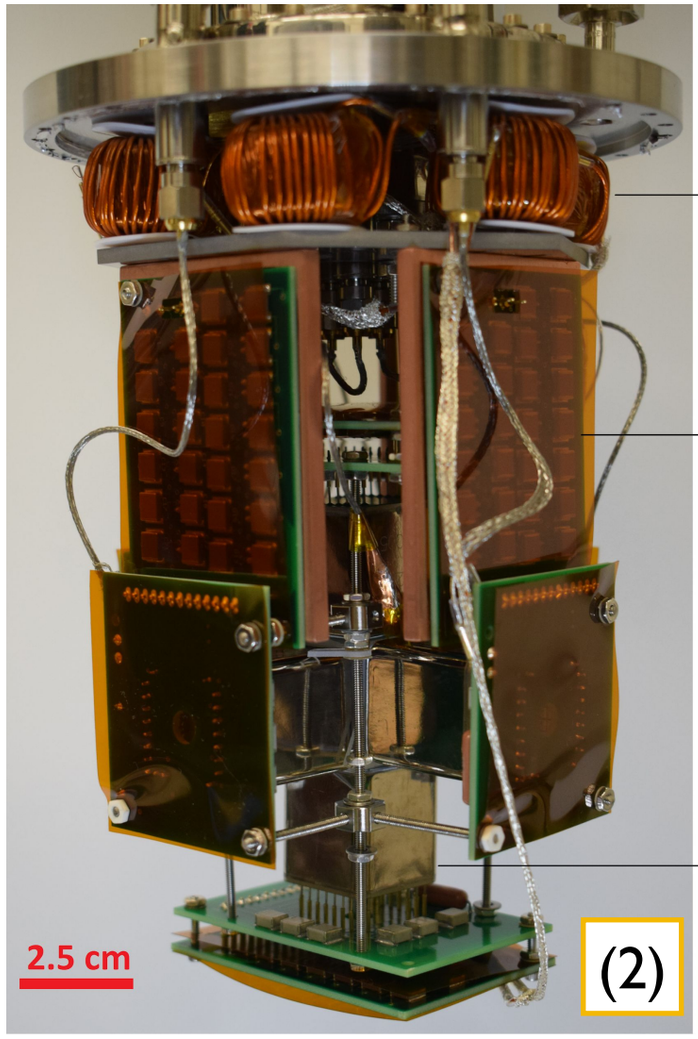


(1) Developing and characterizing GaAs vs dopant species and concentration

(2) Superfluid helium light yield (campus)

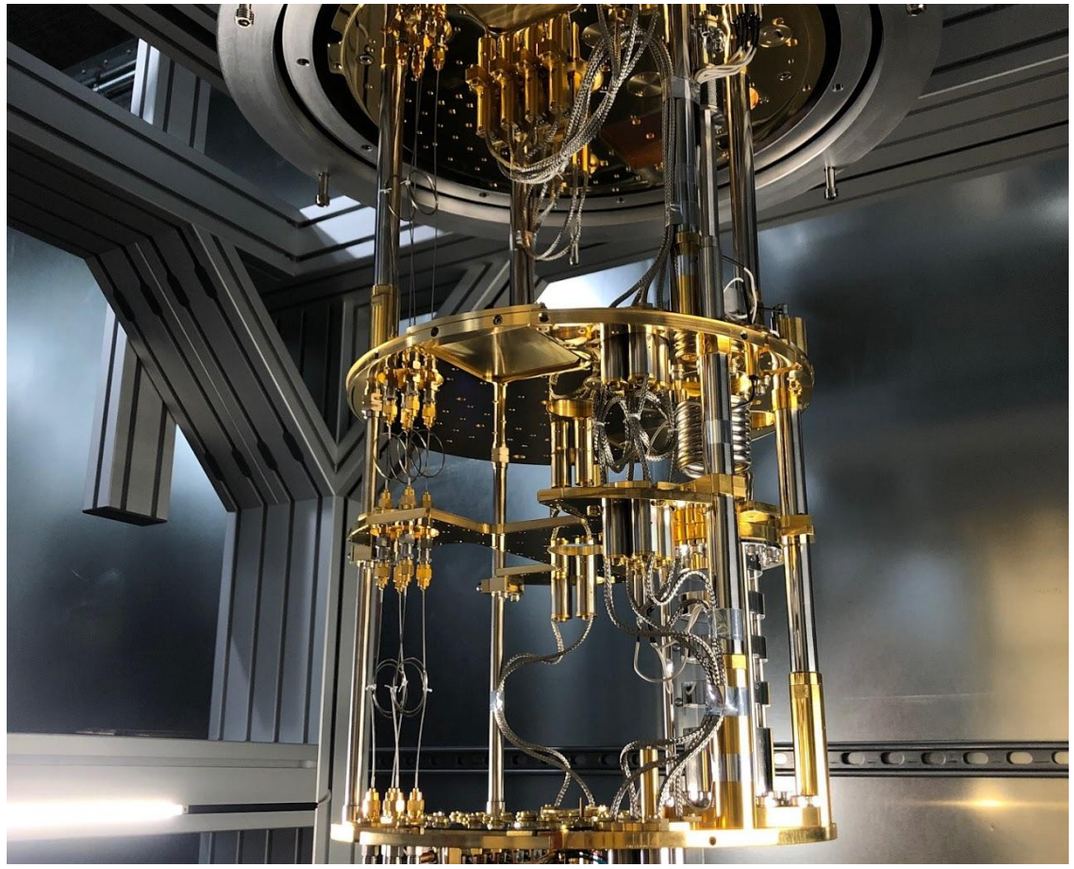
(3) To be read-out by novel transition-edge sensor (TES) IR photon detectors

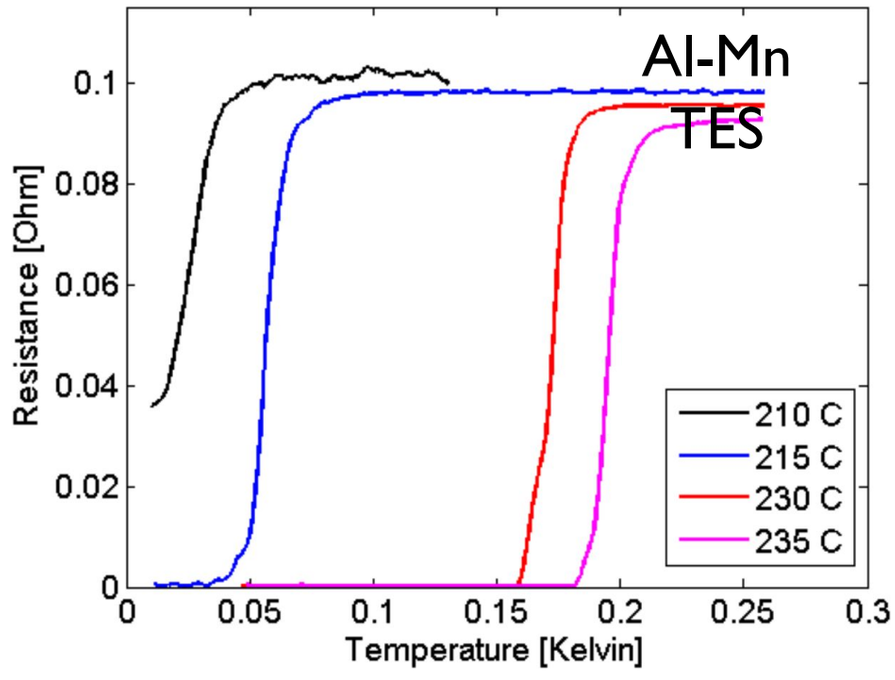
(4) TES testing underway at LBL



QuantISED

- Broad collaboration with Caltech, JPL, Princeton, U Mass, UCB, Yale
    - (theory => experiment)
- A primary goal is to develop next-gen sensor technology to reach 1 meV threshold with no dark counts
    - TES (would like T_c < 20 mK)
    - KIDS (can they compete with TES?)
    - SNSPD
- Also to identify and produce new quantum materials for DM detection targets (e.g. Si-, B-doped GaAs)
- Develop quantum evaporation of He as an amplifier for phonon excitations





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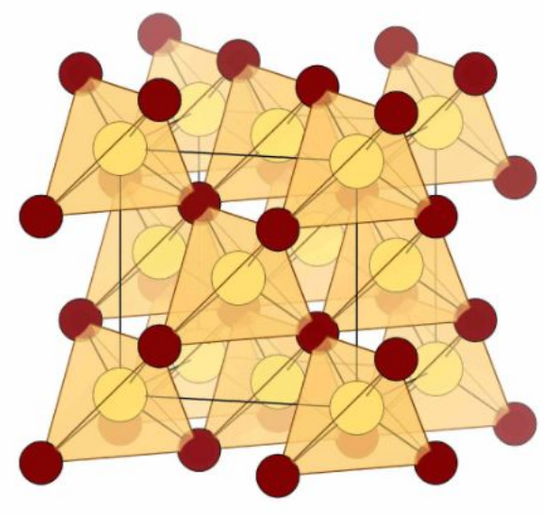
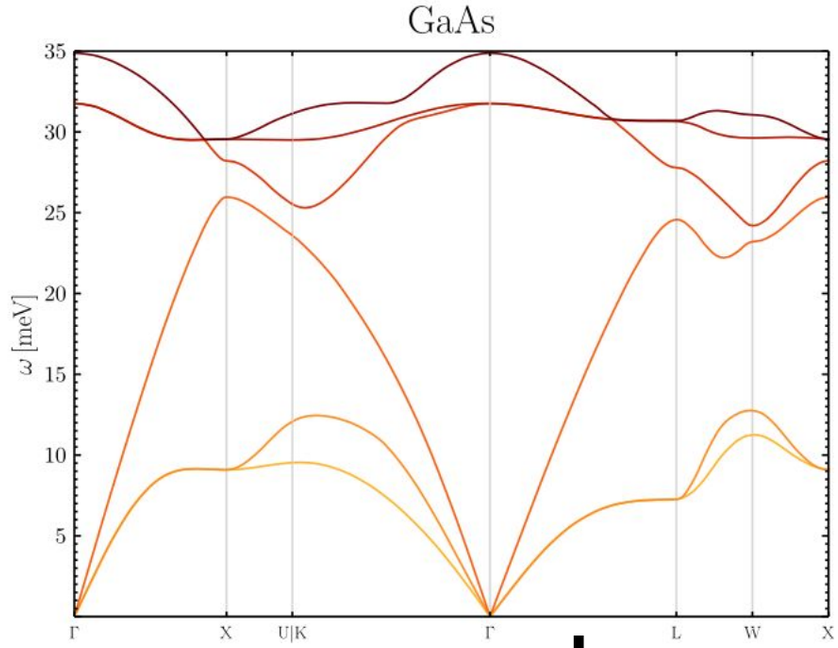
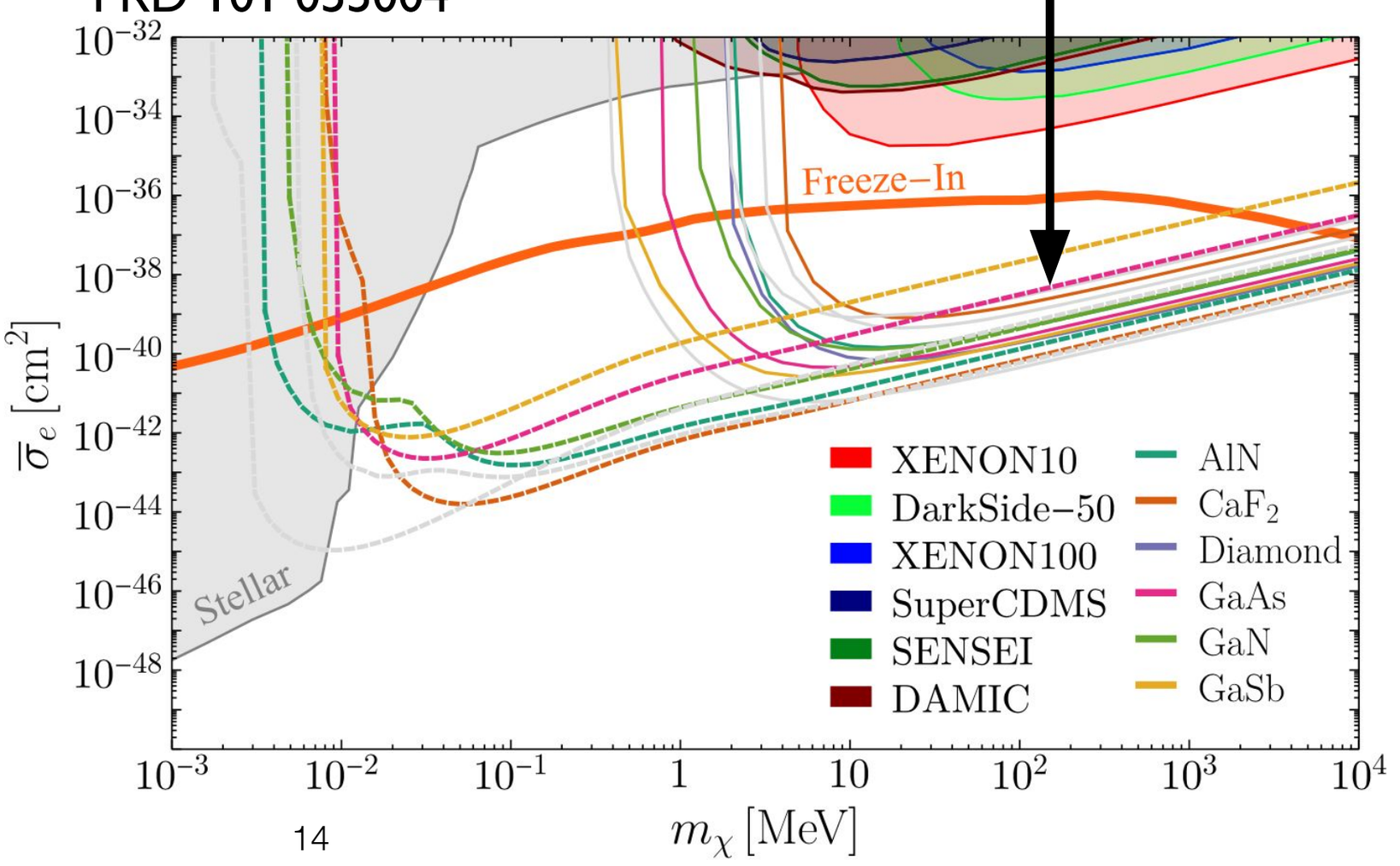


(b) Zincblende: ZnS, GaAs, InSb, GaSb. Same arrangement as diamond cubic, but with two atom types, each occupying one of the face centered cubic lattices.



PRD 101 055004



Summary

- Berkeley Lab dark matter direct detection group maintains an exciting, multi-faceted experimental program with singular aim of directly detecting dark matter

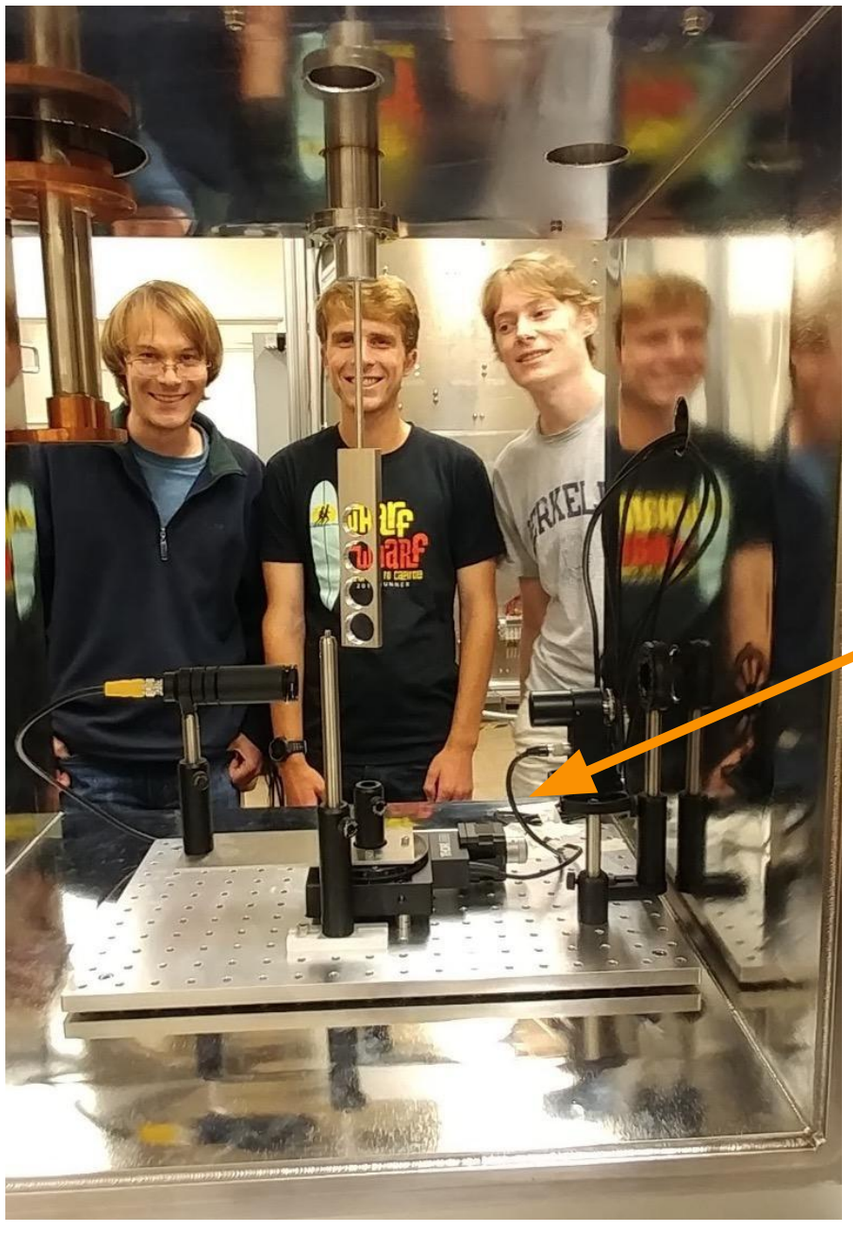
- In addition to UCB campus connection, Berkeley Lab offers significant expertise/resources/collaboration from its other divisions

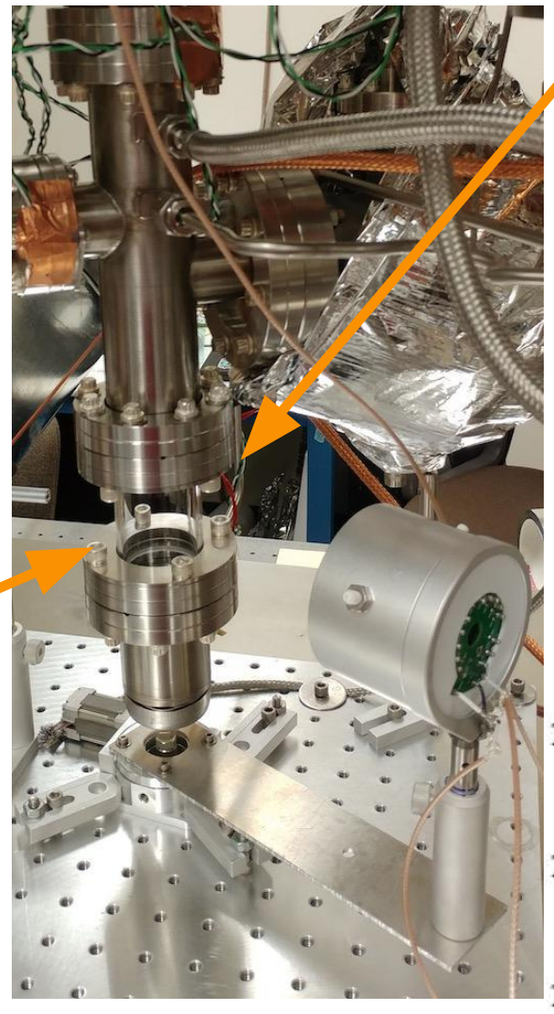
- Graduate students will find broad training in HEP / instrumentation / analysis / AI-ML / “big data” / etc

Extra Material Follows

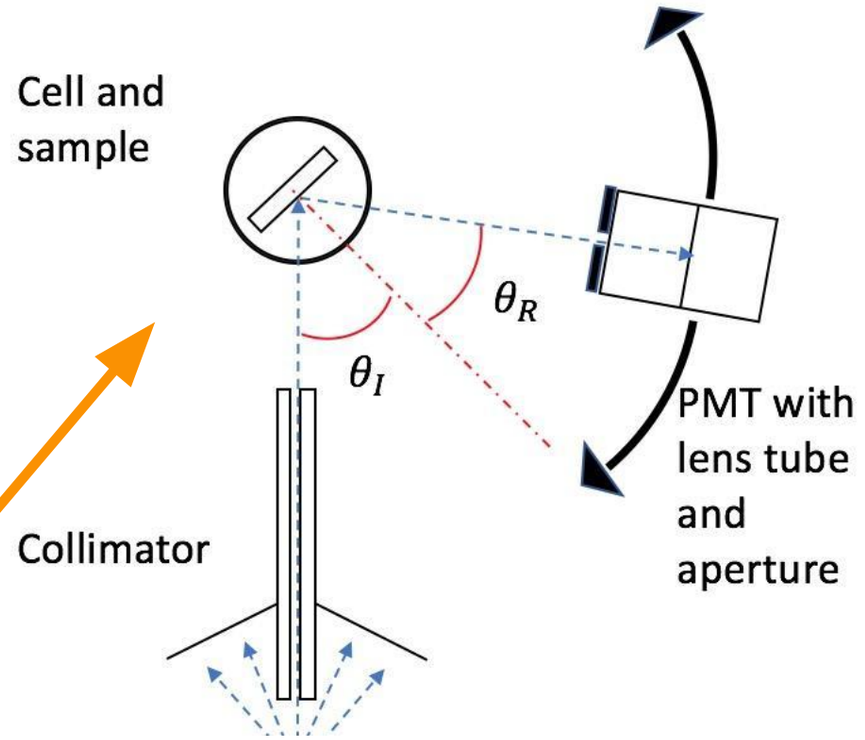
“Completed” R&D

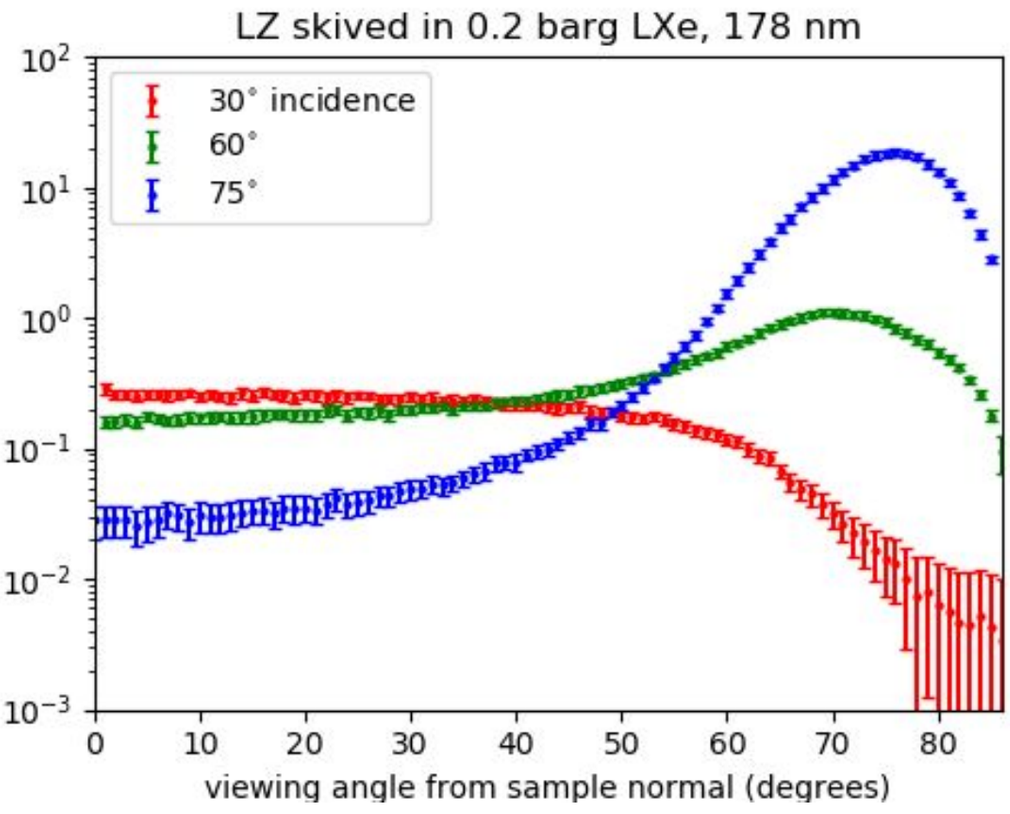
- **Measure/model Teflon reflectivity to Xe scintillation light as a function of angle**
- Informs Xe-based dark matter searches like LZ: Teflon reflectors collect light





B70A 2263 (Liquid Xenon Lab)

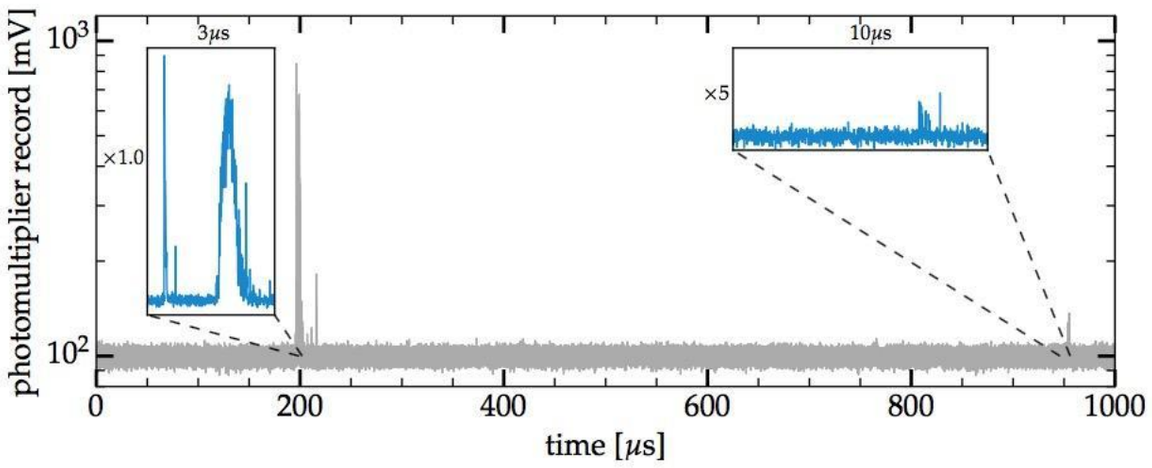


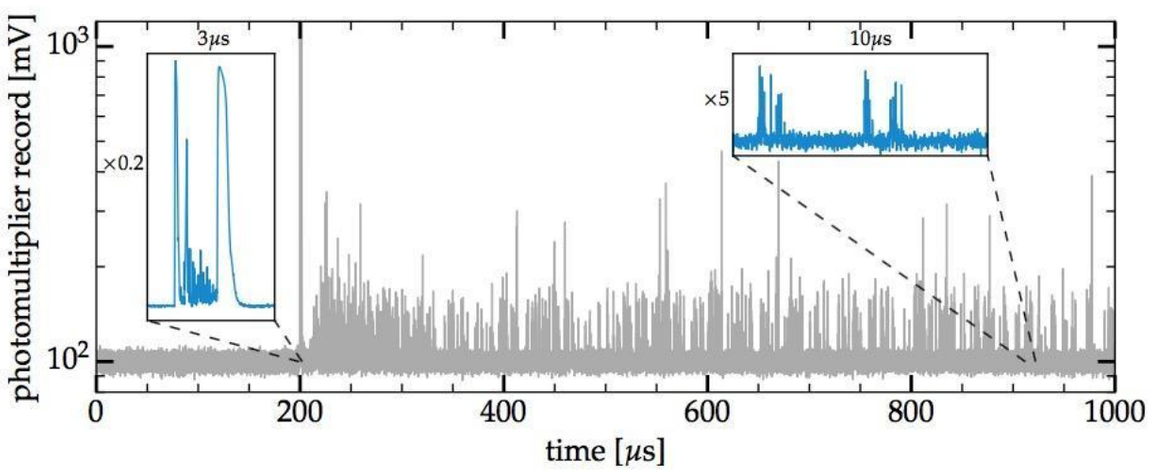


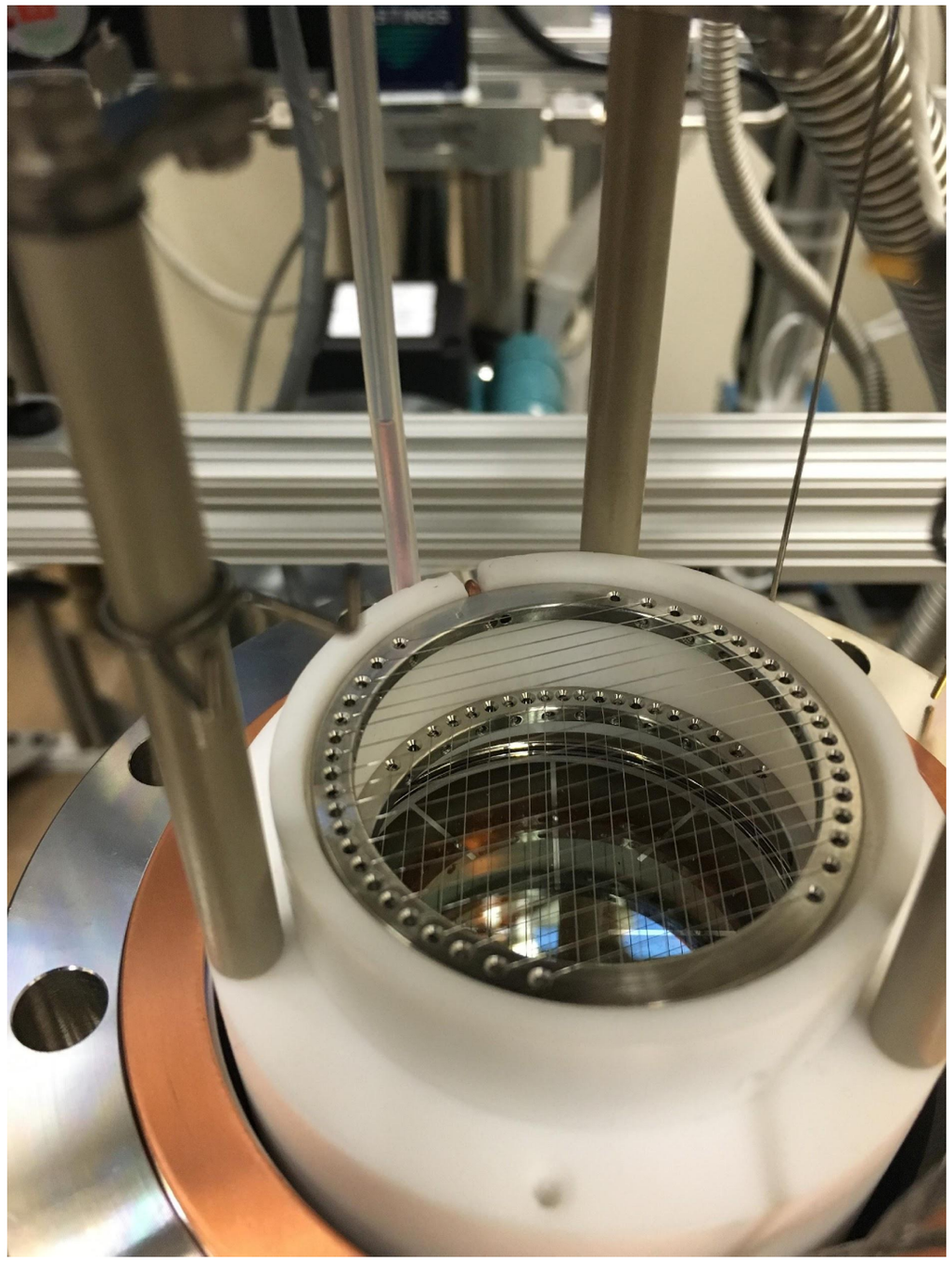
“Completed” R&D

B70A 2263 (Liquid Xenon Lab)

- **Measure delayed electron noise in liquid Xe TPC (a mini-LZ) as a function of applied electric field**
- Informs analysis of small S2 signals, especially in the absence of S1
- First results just published in JINST 13 P02032

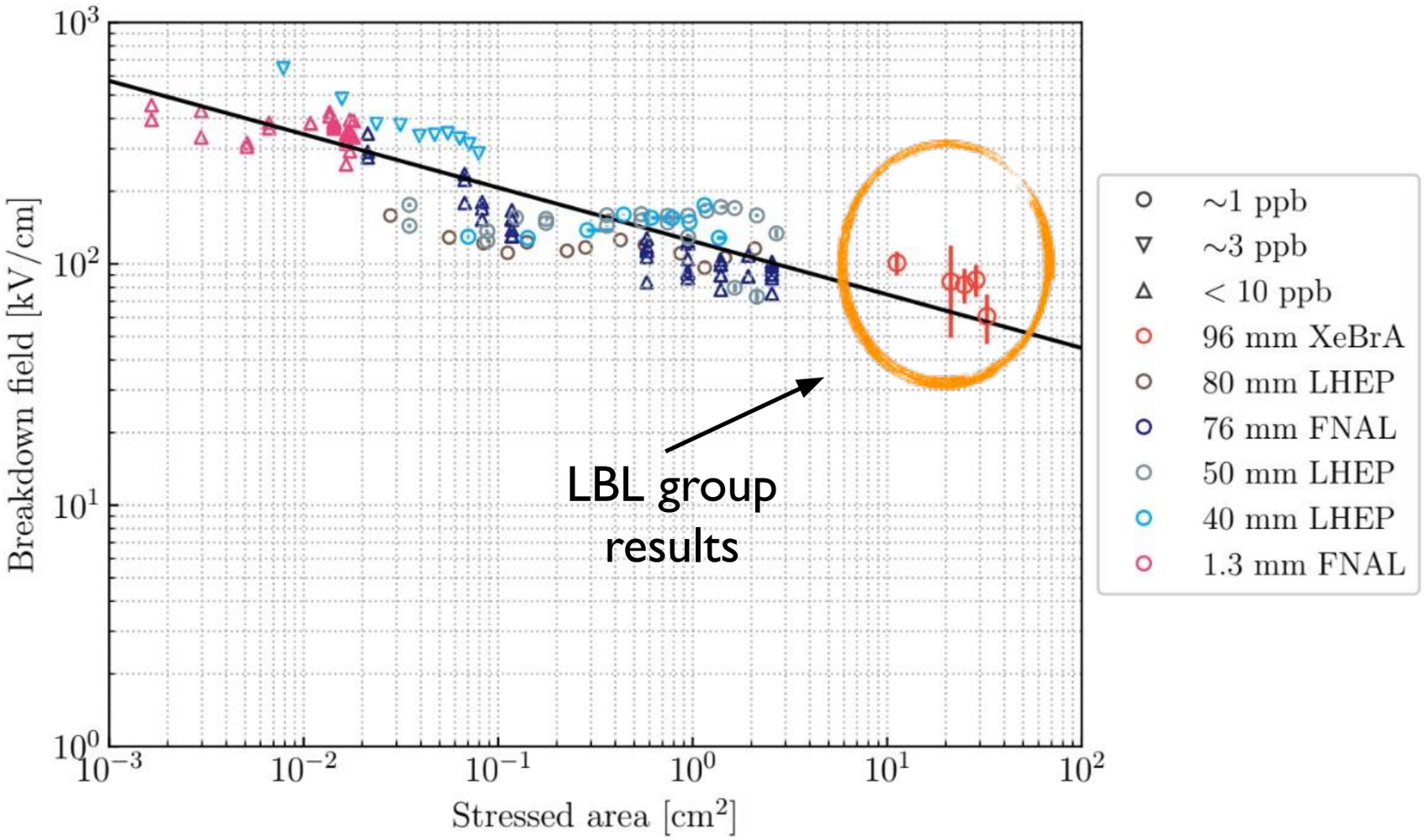






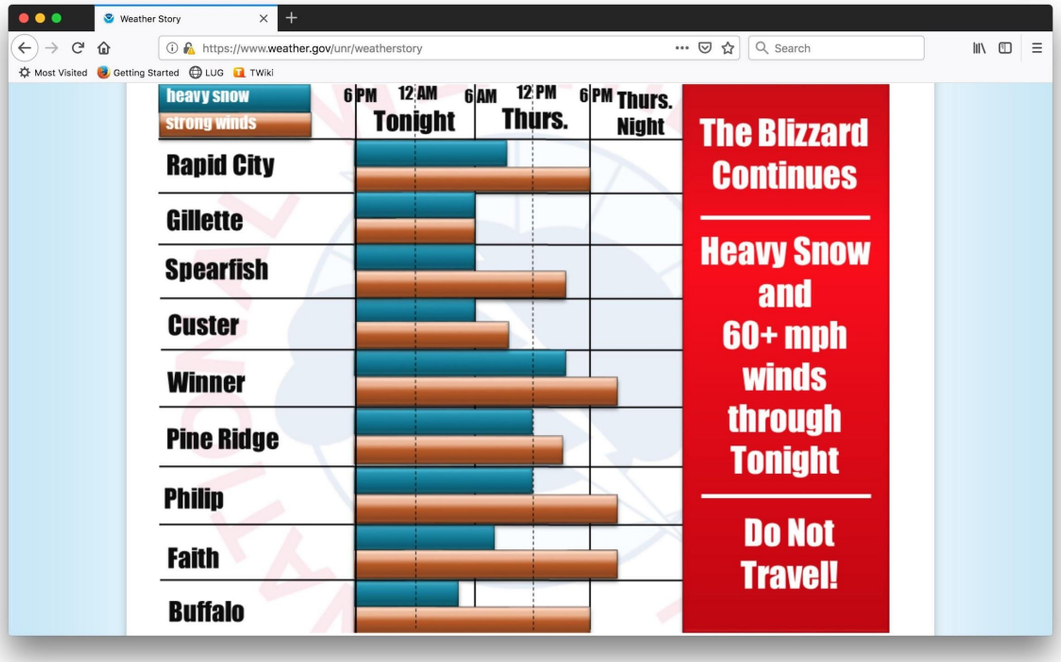
"Completed" R&D

- **Measure effects of very high electric field ad breakdown in in liquid Xe**
- scaling laws Inform behavior and performance of operating detectors

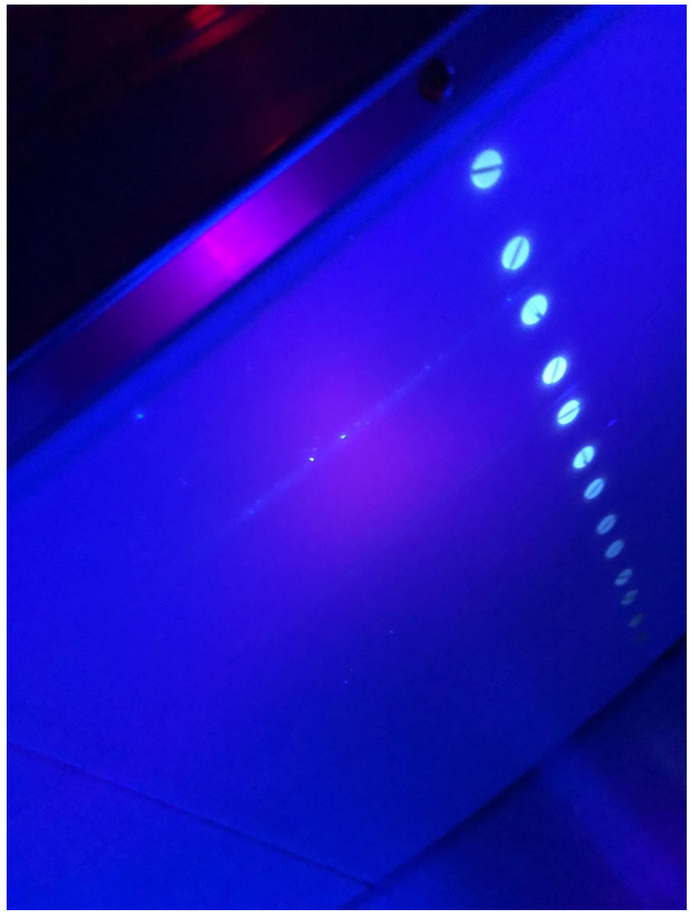


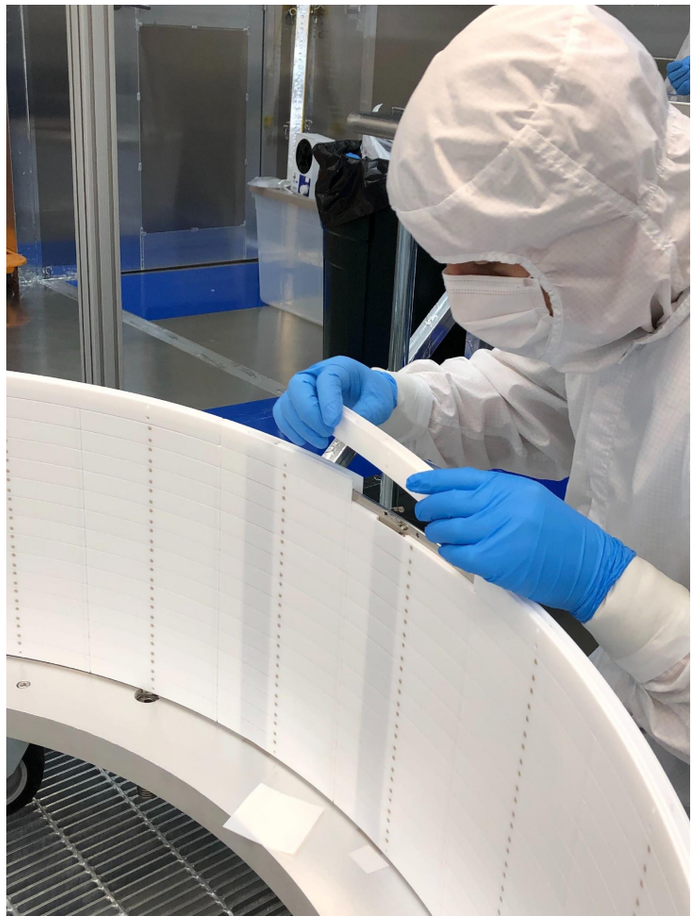
B70A 2263 (Liquid Xenon Lab)

Typical February Fun at SURF



Building LZ

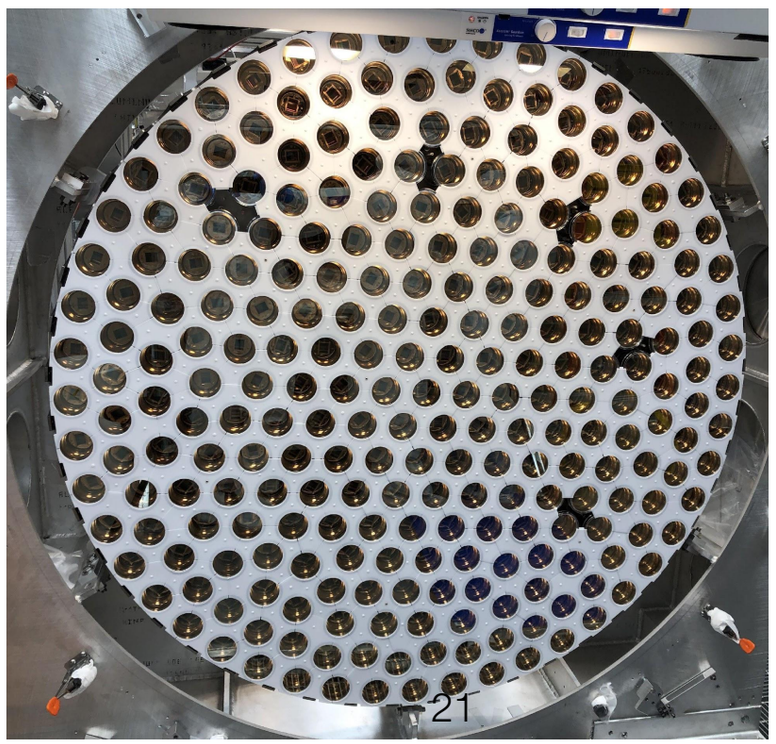


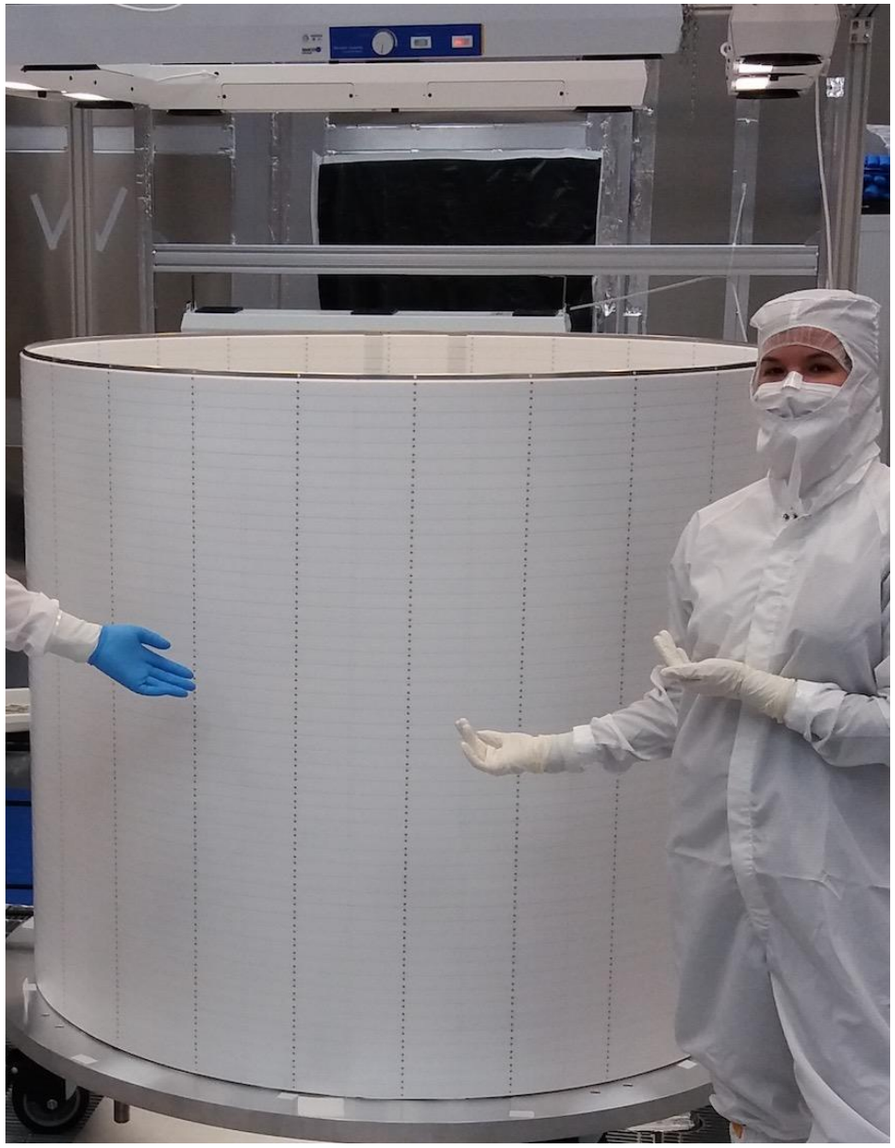


SOPHIA CHEN SCIENCE 01.11.18 08:00 AM

WIRED

HOW DARK MATTER PHYSICISTS SCORE DEALS ON LIQUID XENON

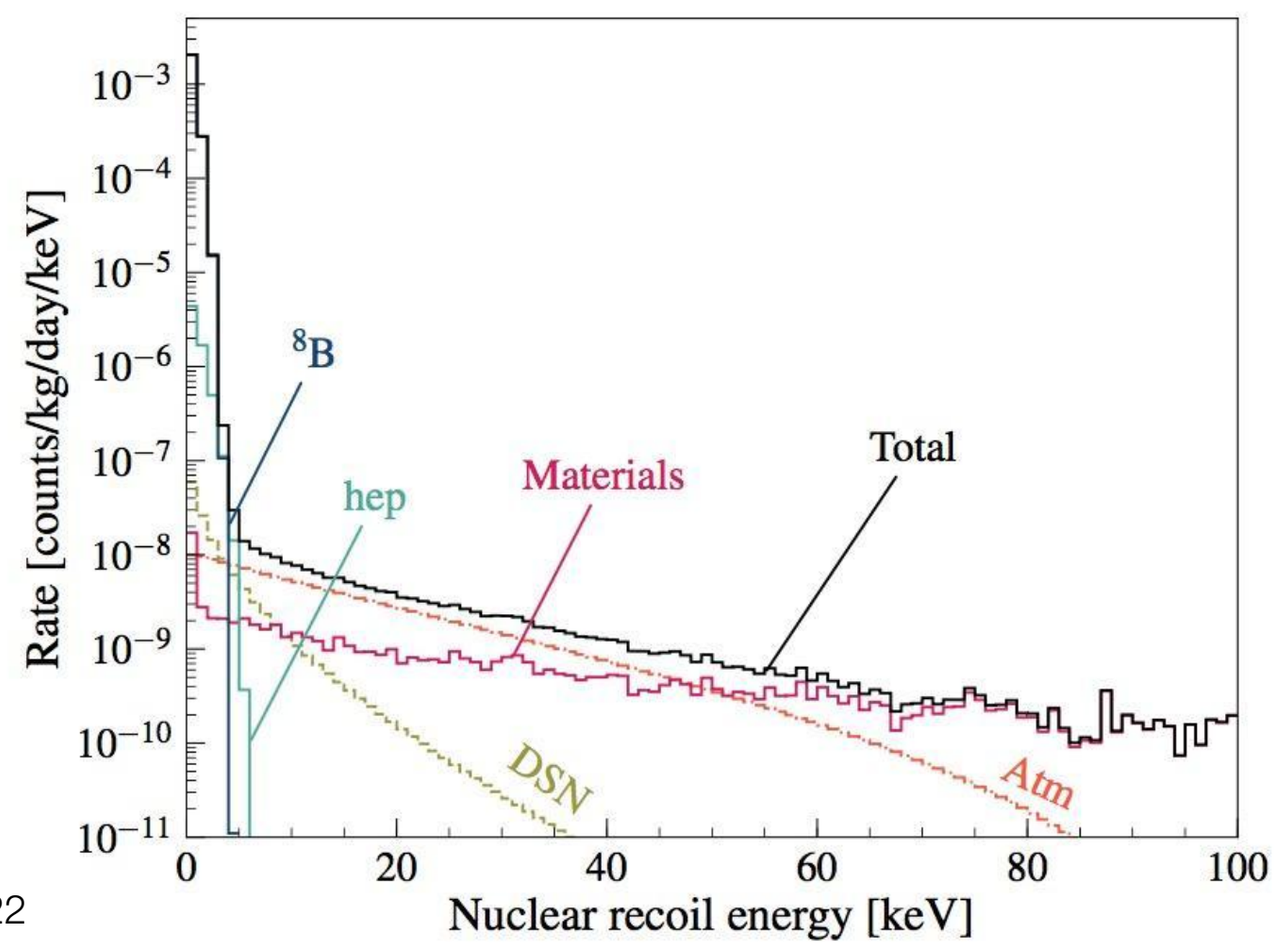




BLBF

down the corridor from the Davis Campus*

- **Measure the radio purity of every last component that we will use to build LZ**
- Informs shape and normalization of the "material" histogram with respect to the signals we are chasing
- Plot from LZ sensitivity paper



* started by Al Smith @ LBL 1960, moved to Oroville Dam 1985