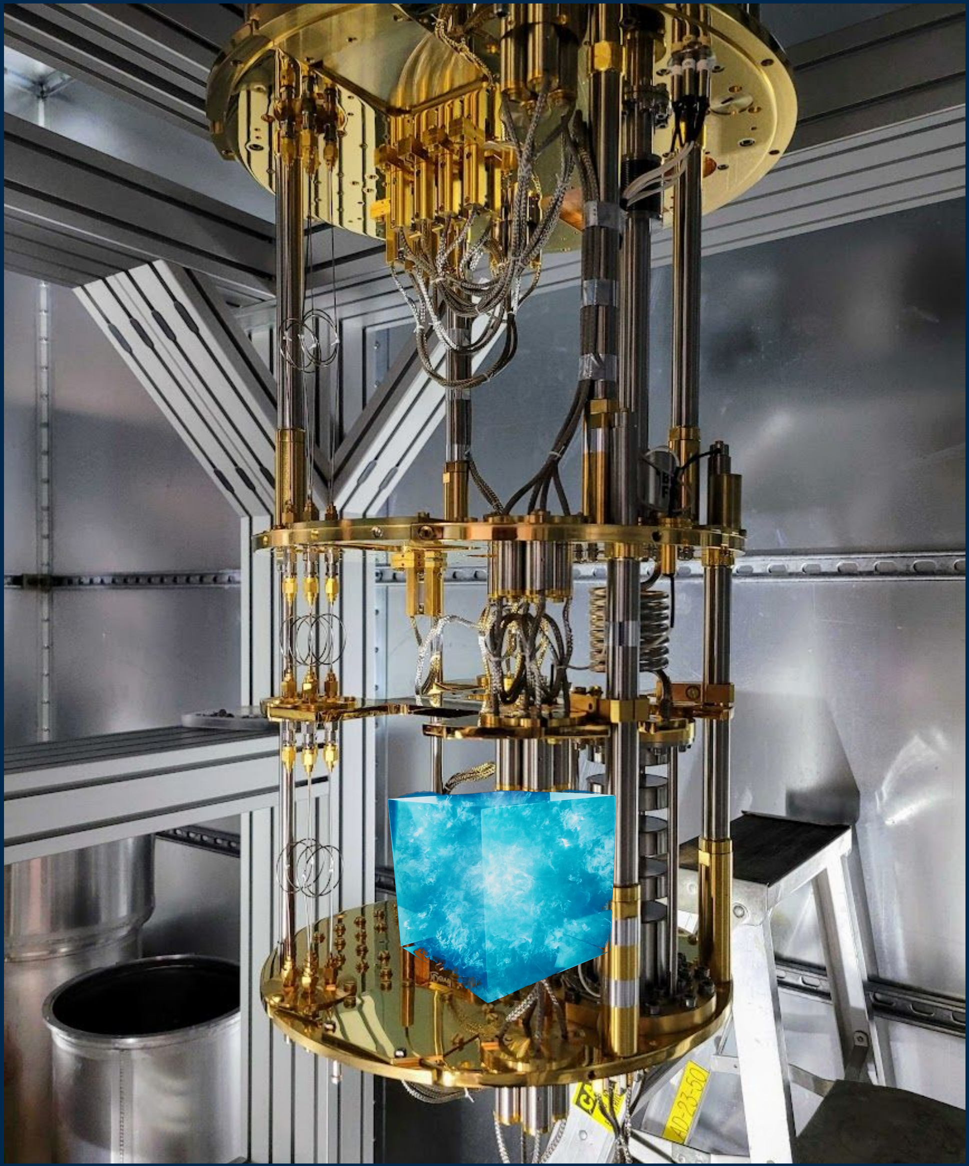
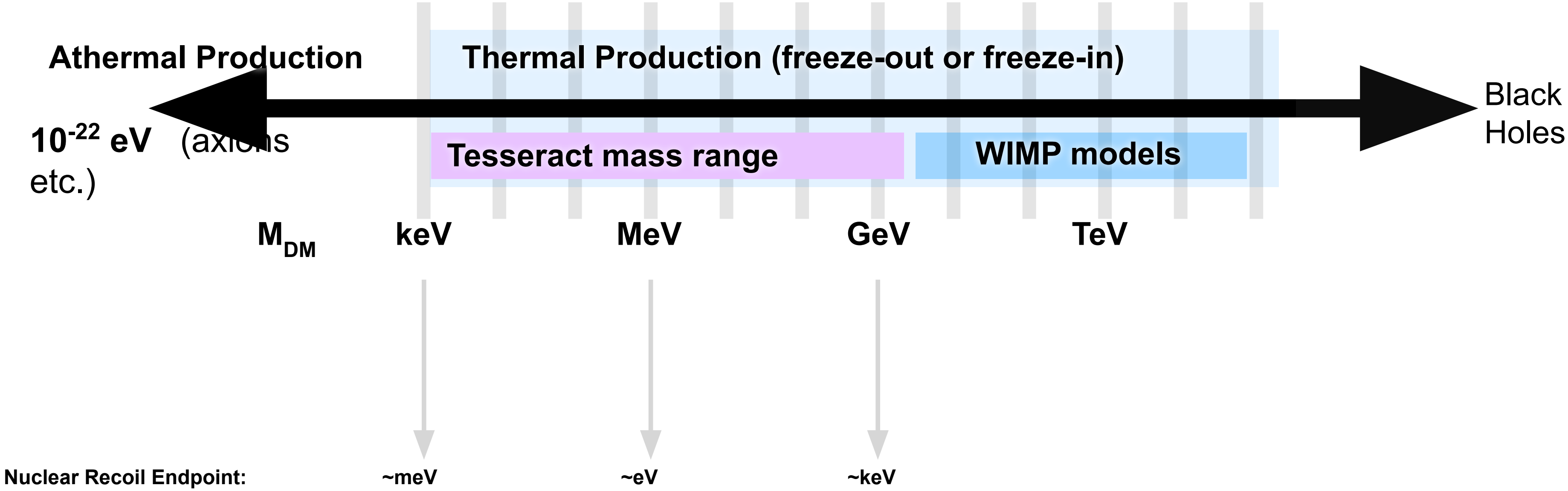
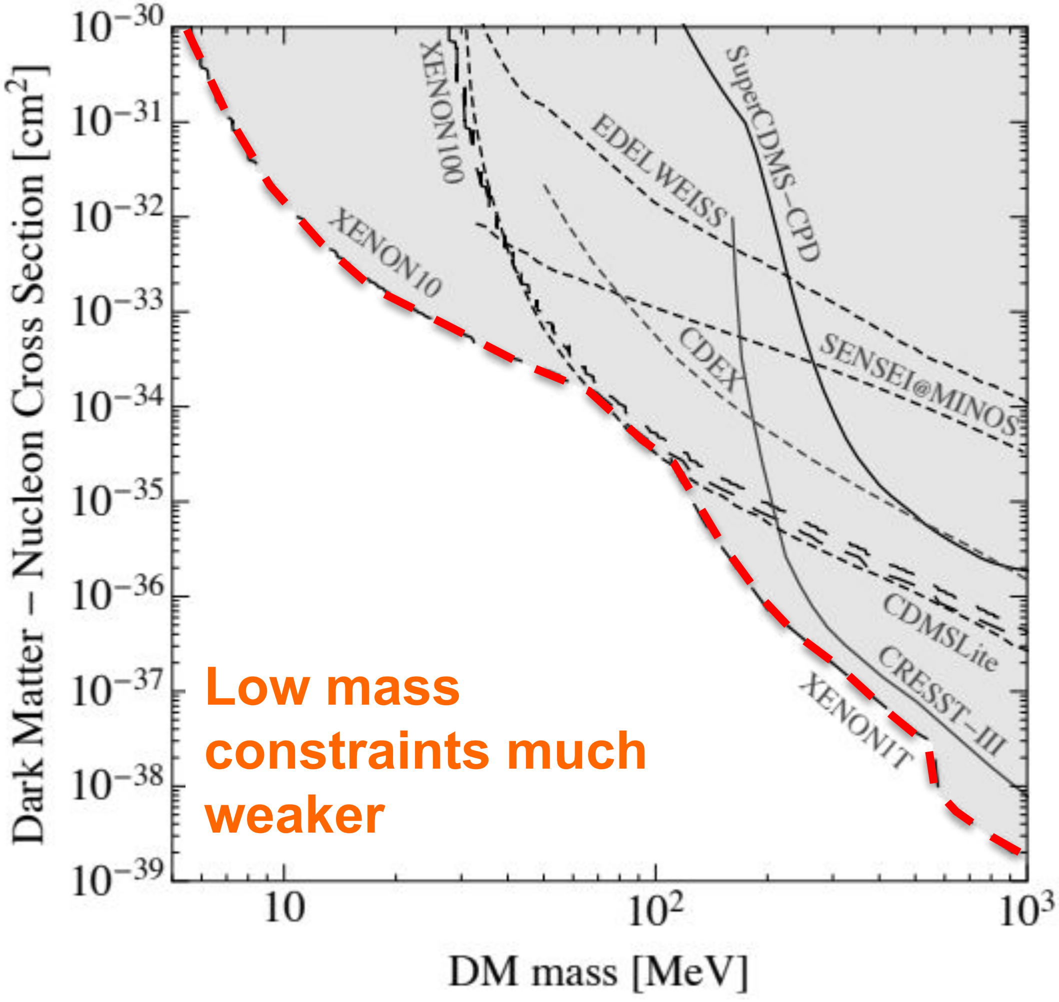


# Tesseract

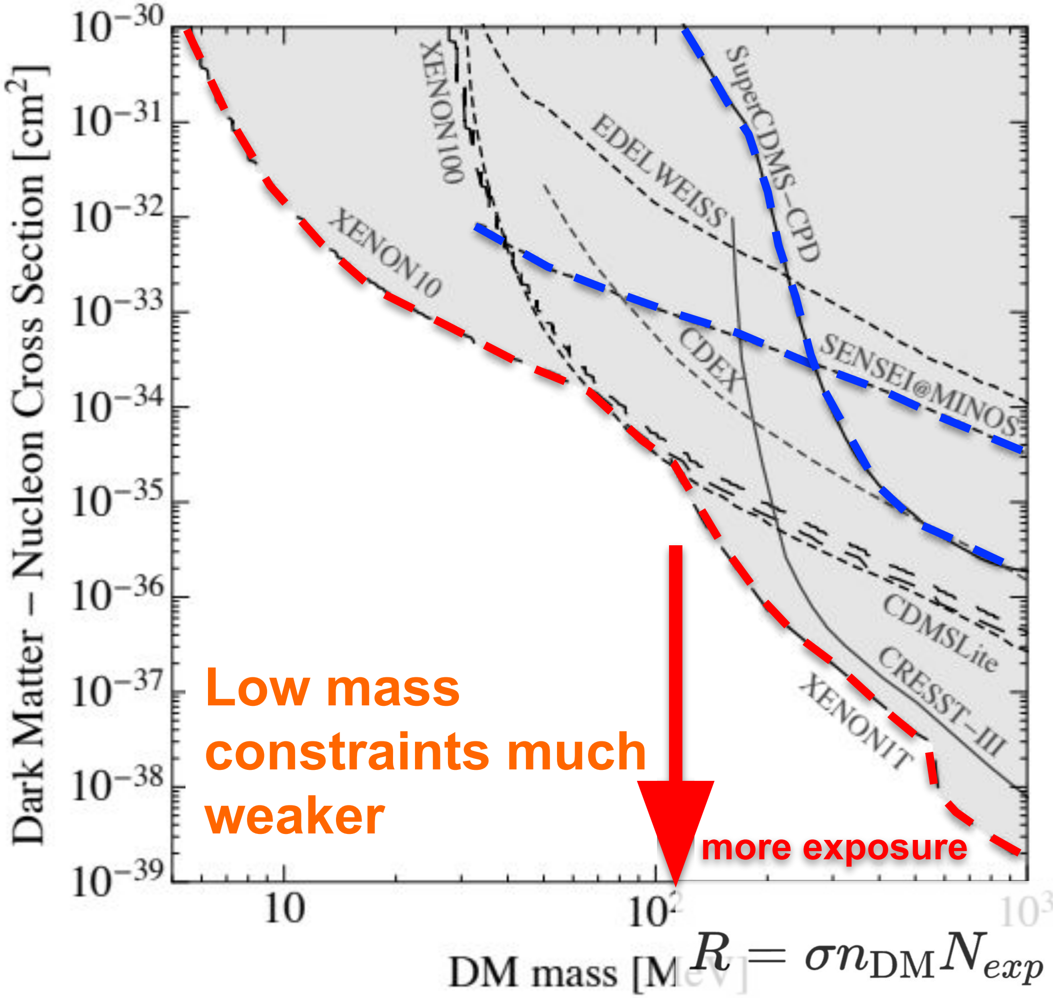
- Landscape & Design Choices
- Tesseract Overview
- Recent Progress




- **Low mass DM** (sub-GeV) consistent with simple thermal production after inflation (like other massive particles)
  - Typically require a new force mediator too, not just the DM particle.
- Direct detection searches via electron scattering or nuclear scattering
- **Tesseract**: New light DM experiment using multiple detection channels

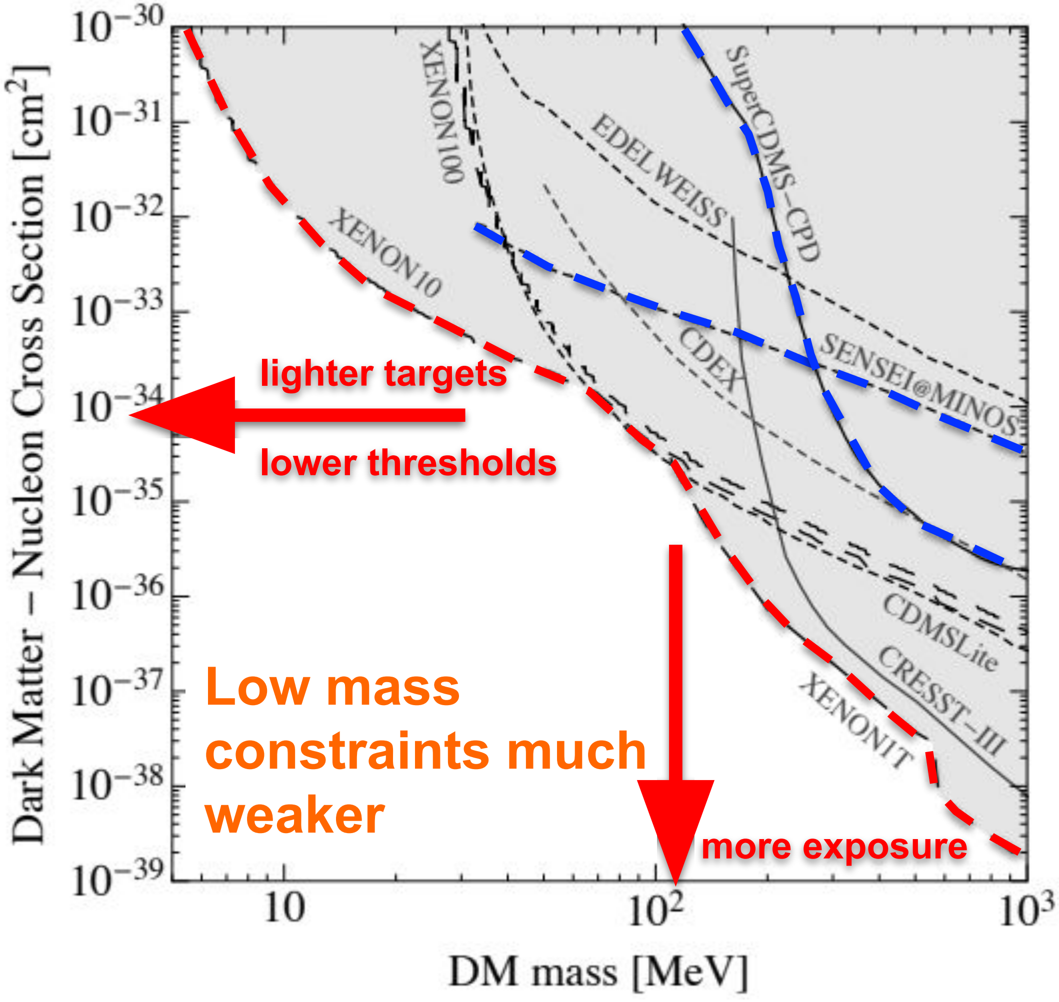



- We want to go **lower & deeper**!



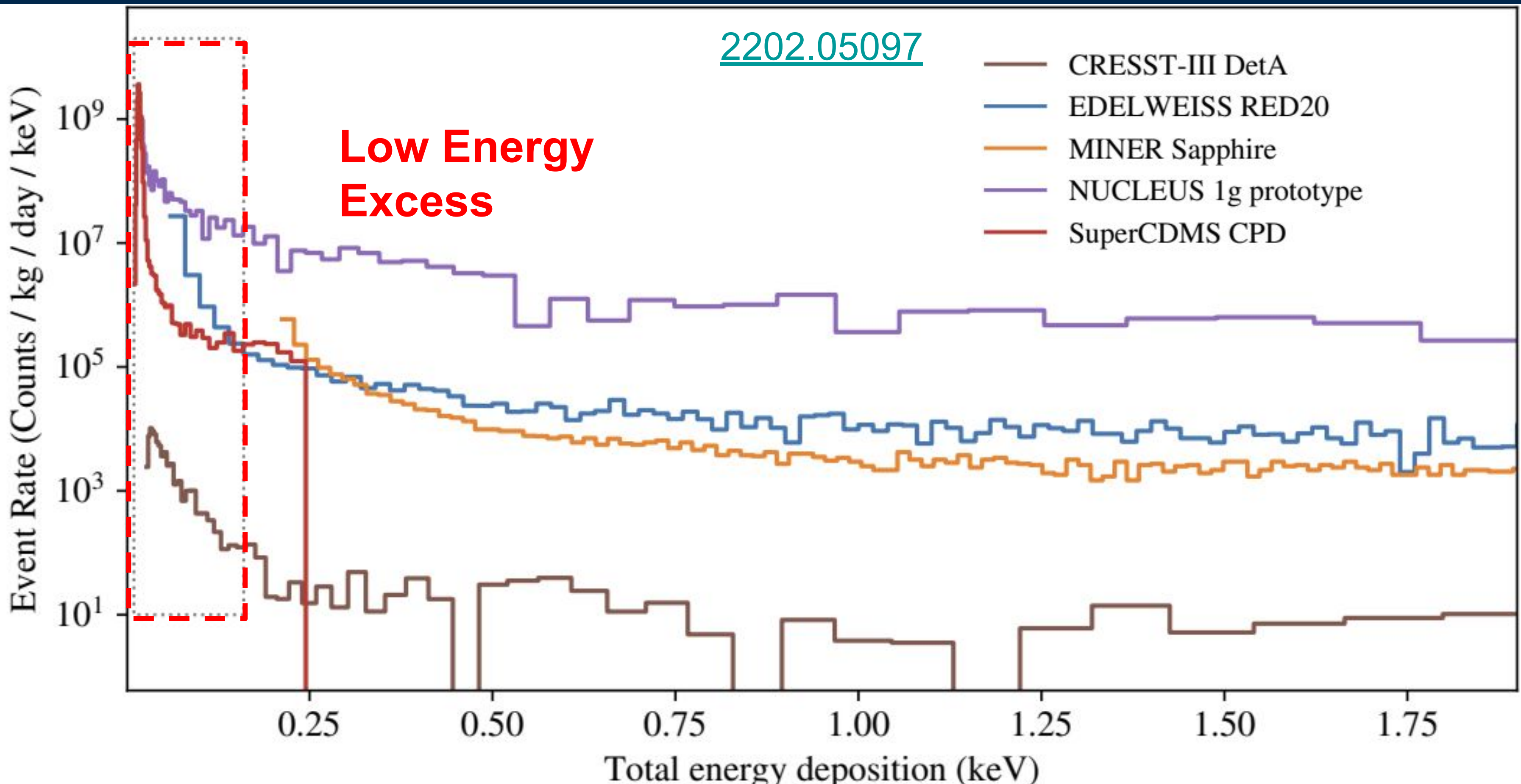

$$R = \sigma n_{\rm DM} N_{exp} = \sigma \frac{\rho_{\rm DM}}{m_{\rm DM}} N_{exp}$$

- **Exposure**: Rate scales inversely with dark matter mass
- Compare ton scale LXe with gram scale low mass DM experiments



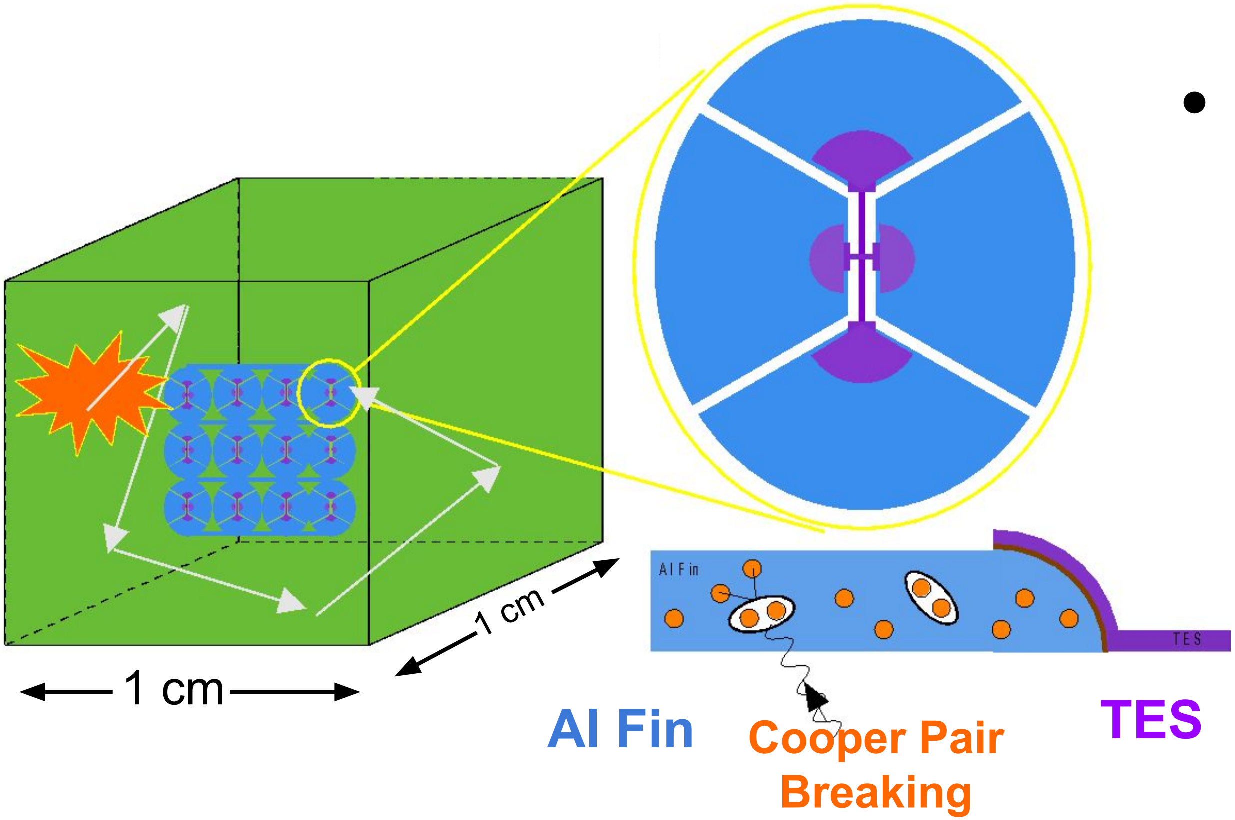

- Lower mass searches require **light targets** and **very low energy thresholds**

- Facing **new landscape**
- **Nuclear backgrounds**: Exists but less significant due to small ROI:
  - **γ down-scatter** to low E, can also **induce NR** via Thomas-Delbrück
  - Epithermal **neutrons**
- **Novel backgrounds**:
  - Sensors sensitive to **smallest energies**
  - **IR** backgrounds, **parasitic power**, **phonons**, **vibrations**, **transition radiation** etc
- New **calibrations** necessary
- We know some of the challenges we're facing, but **some cliffs** are probably still **hidden in the fog**




- Low energy excess, observed in many experiments: SuperCDMS, Edelweiss, Nucleus, DAMIC, SENSEI etc
  - Primary characteristic energy Scale: eV?
  - Probably more than one origin
- Design driver: Chose methods to reject LEE

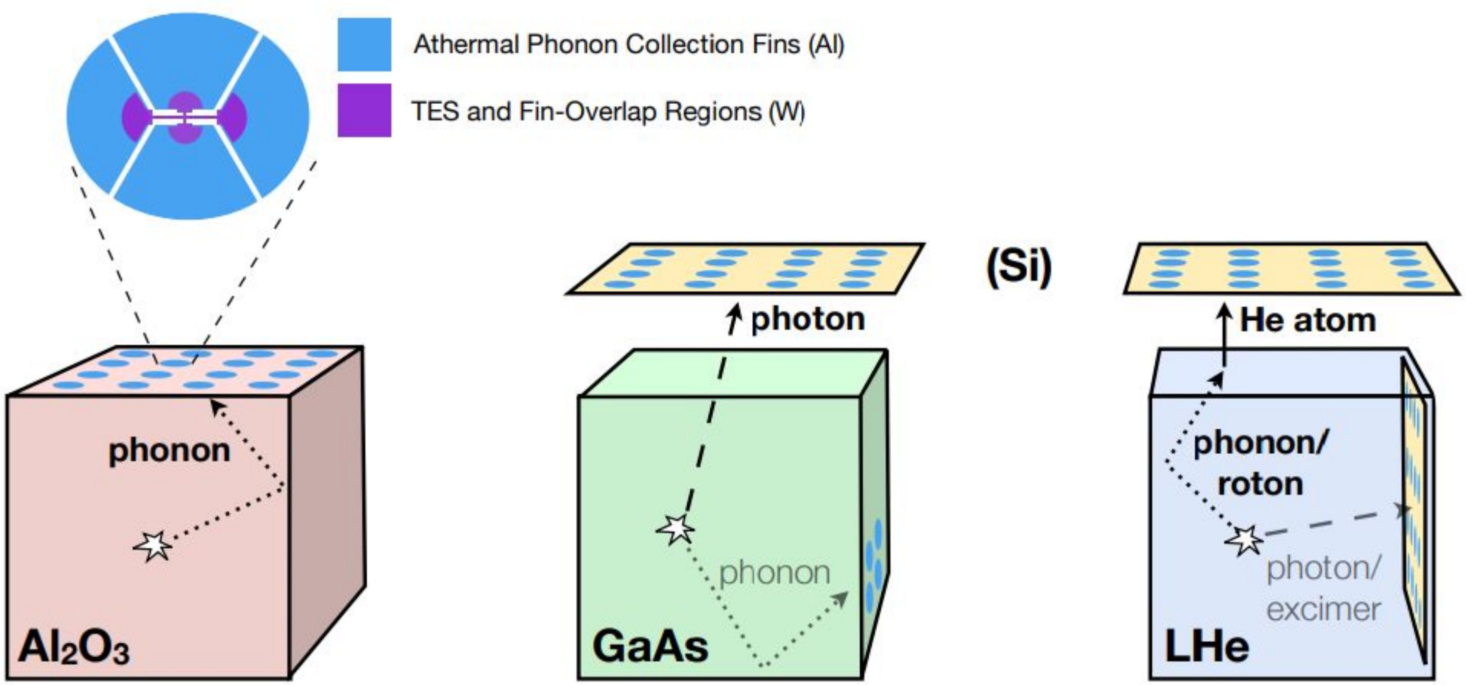
- Our goals
  - Low energy threshold
  - Scalable
  - Minimize backgrounds
  - Ability to discriminate and understand remaining and novel backgrounds

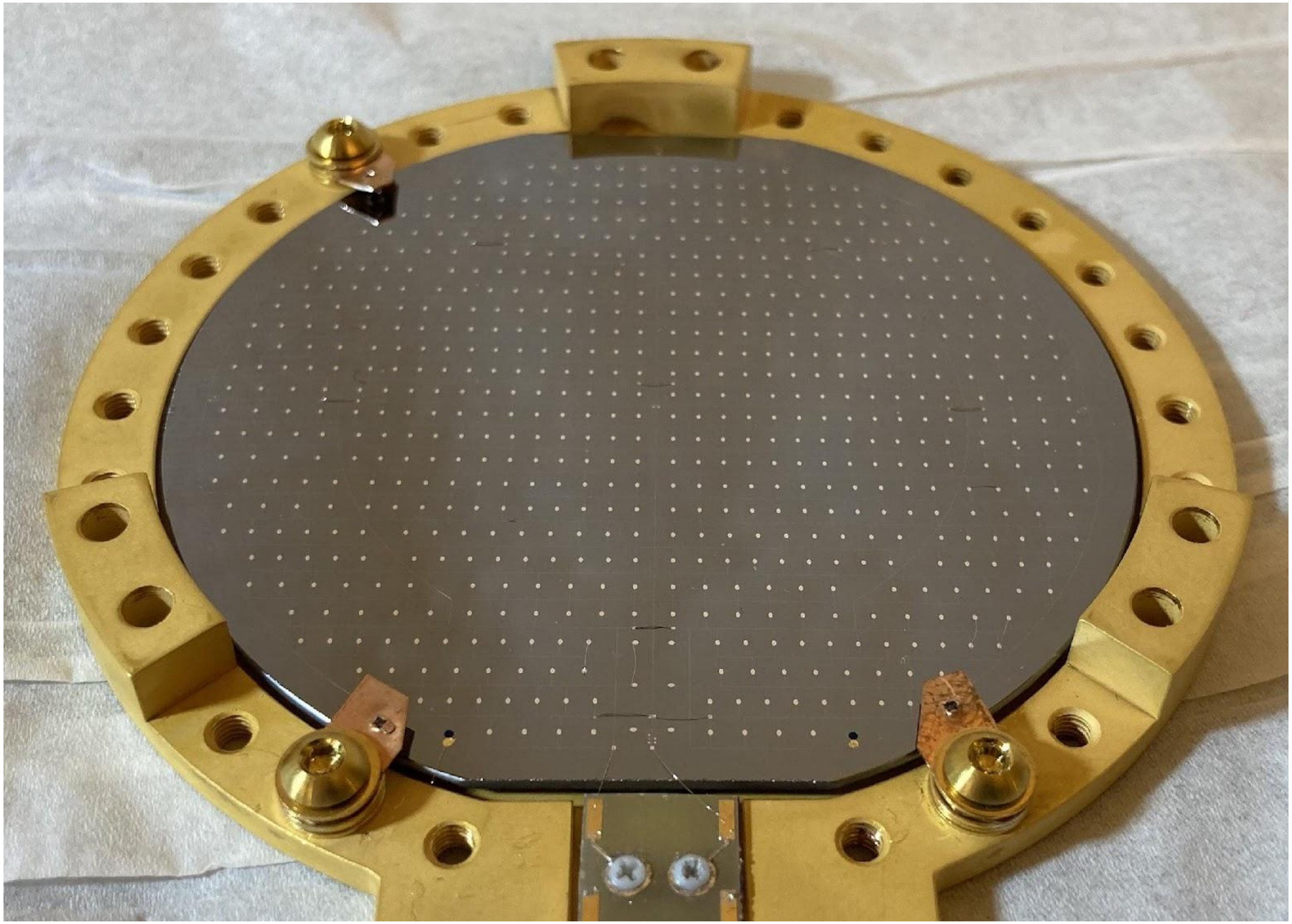



- Collect and concentrate athermal phonon energy into Al fins
  - Phonons break Al cooper pairs
  - Quasiparticles are absorbed by W TES connected to Al fin

- Large collection area without the drawback of the heat capacity of a large sensor
  - Signal is degraded by phonon collection efficiency factor (~20%)
- **Readout of all targets identical** except the substrate
- More **DM science doesn't increase cost** significantly!

- **Energy sensitivity** is primary driver for low mass DM
- All detectors use TES readouts
  - Zero E-field → **no dark-currents**
  - Already achieve very low E threshold → Goal: 100 meV-ish
- **Targets**: SPICE (polar crystals) & HeRALD (superfluid helium).





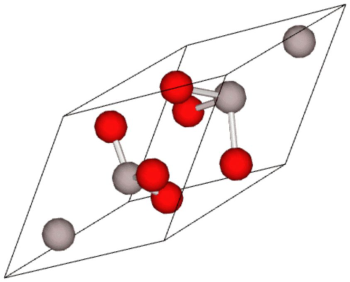
- Array of tungsten TESs: $T_c$ = 55mK,  about 2.26 eV resolution (σ)

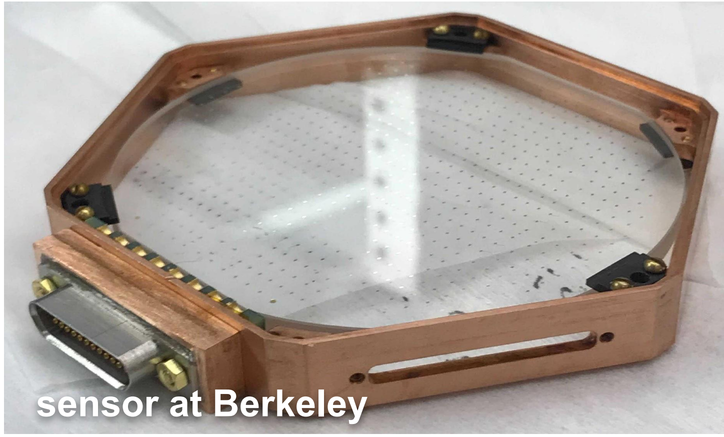
# Complementarity

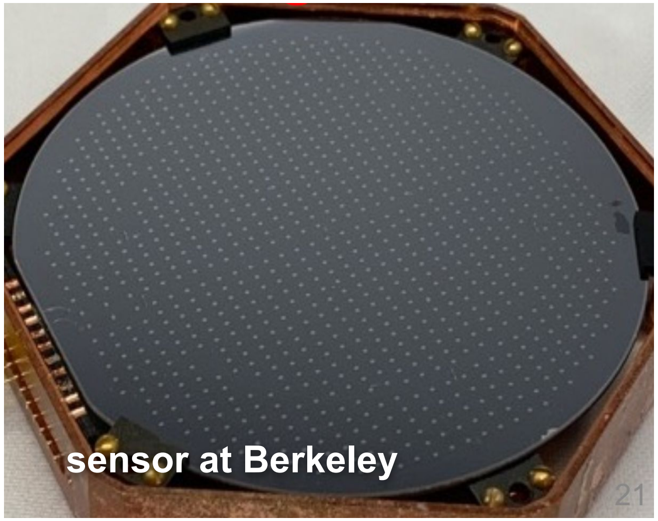
| Target | NRDM | ERDM (> 1 MeV) | ERDM (keV - MeV) | Absorption | Background rejection |
|---|---|---|---|---|---|
| Al2O3/SiO2 | | | | | |
| GaAs | | | | | |
| Superfluid helium | | | | | |

- Targets relatively cheap, hence we consider several
- **$Al_2O_3$** sensitivity across the board.
  - One type of signal (phonon), multiple readouts to reduce instrumental background
- **GaAs** and **superfluid helium**
  - Advantages in background rejection: multiple signal channels and multipixel coincidence-based instrumental background rejection

- **Sapphire** ($Al_2O_3$):
  - **Sapphire** supports many optical phonon modes.
  - DM recoiling recoiling off the lattice, ‘exciting a **phonon’**
  - **Optical phonons** kinematically well-matched to low-mass DM → effective energy transfer
  - Coupling to E&M-like inputs due to electric dipole → **dark photon sensitivity**

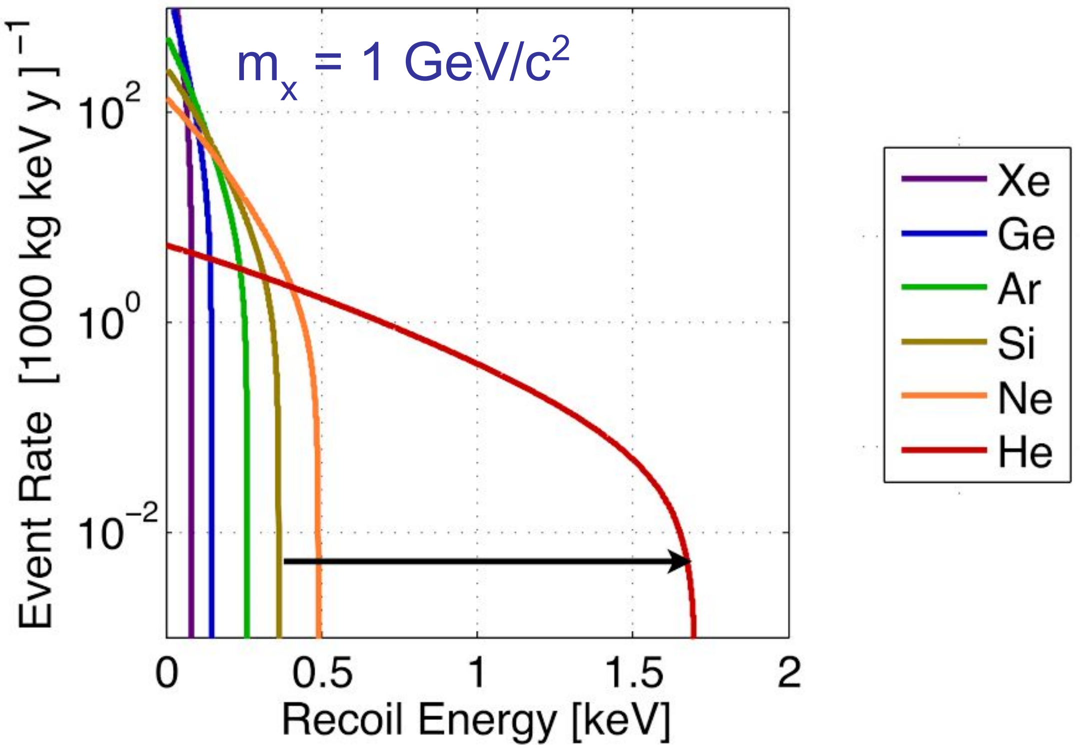





See Tongyan’s talk Thursday for more info

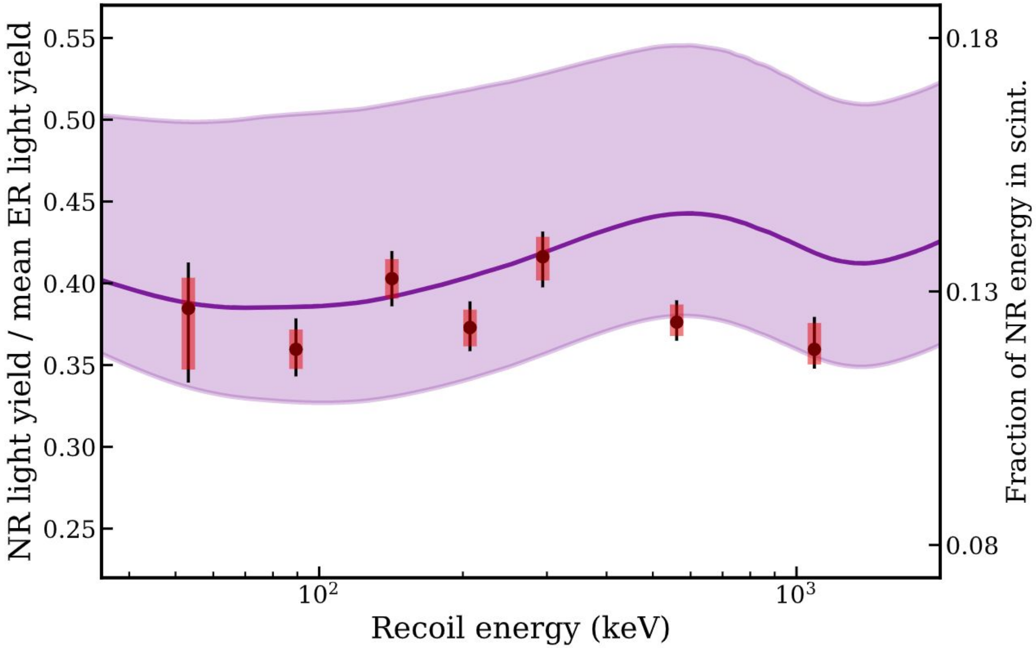
- **GaAs**:
  - **Polar crystal** & **bandgap** well matched to kinematic region of low mass DM
  - **Background discrimination** using phonon/photon ratio
  - Photon-photon and phonon-phonon coincidence can reduce instrumental bkgds
  - High light yield (125 ph/keV, 1904.09362)

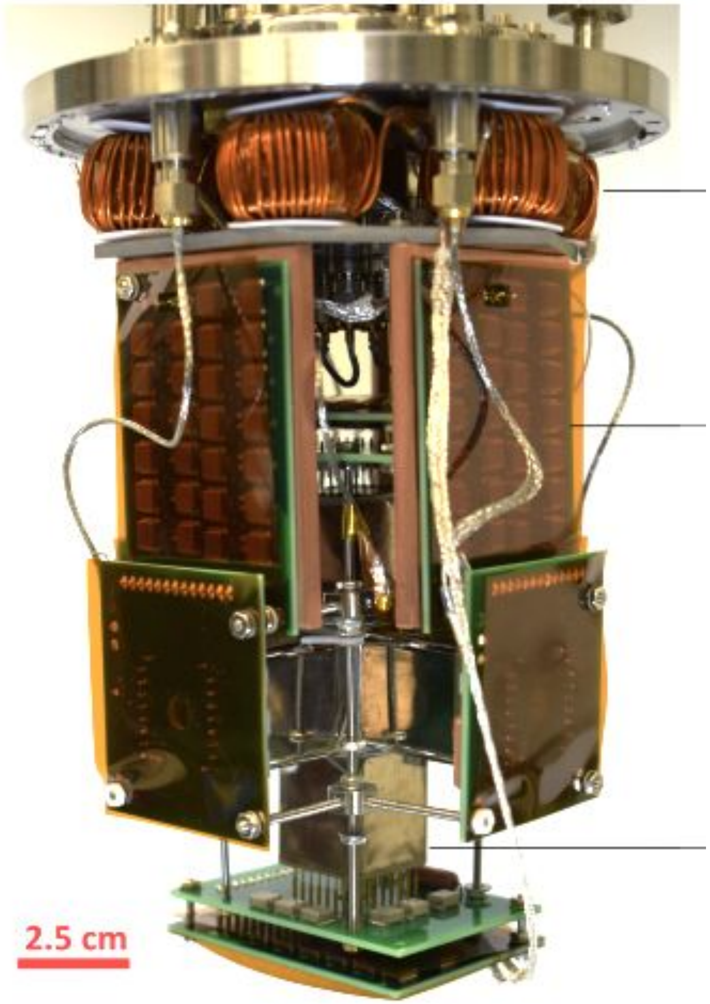




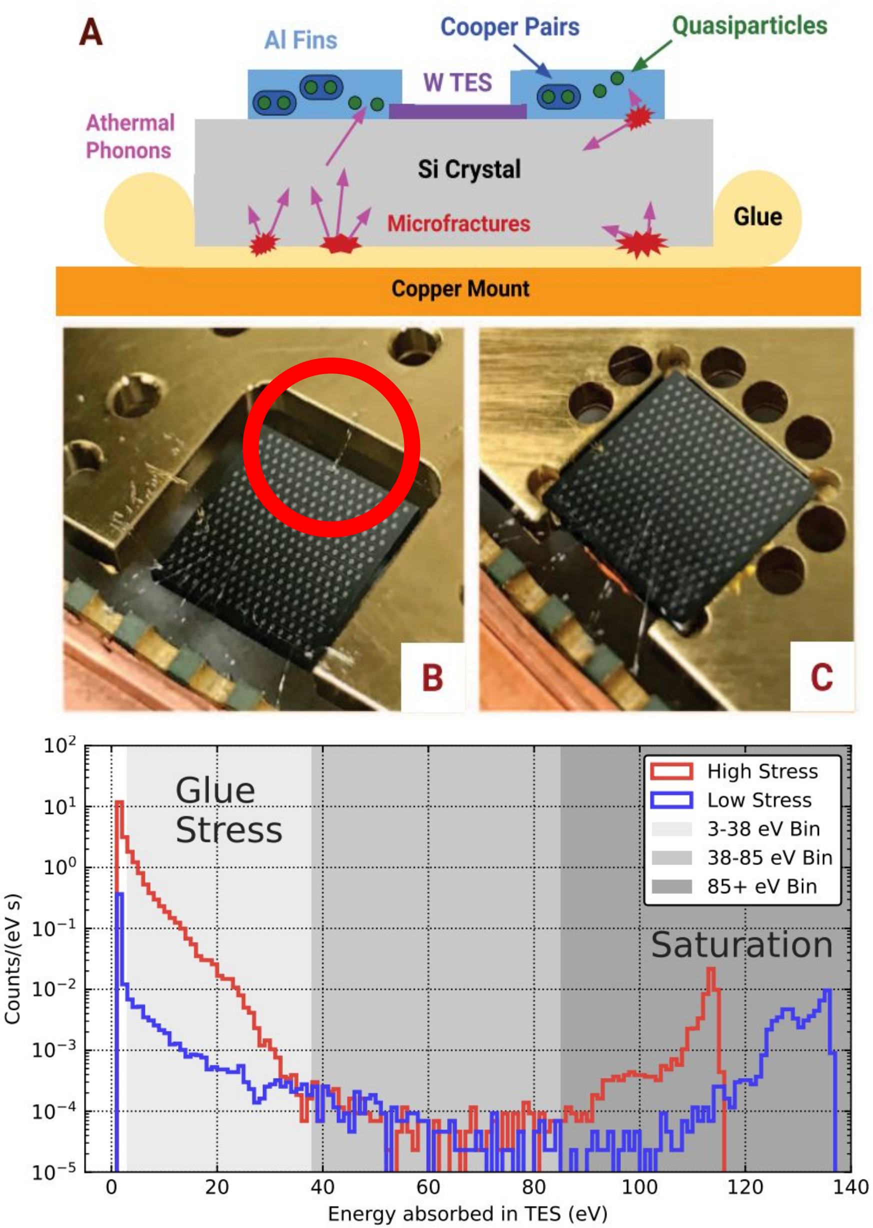
- **Superfluid helium** has significant additional advantages:
  - Quantum evaporation signal gain
  - **Multiple signal channels** (rotons, phonons, scintillation, triplet excimers)
  - Background rejection by requiring coincidence
  - Superfluid Helium: no LEE due due stress microfractures since it is a liquid
- See **Scott Hertel's** talk (next)

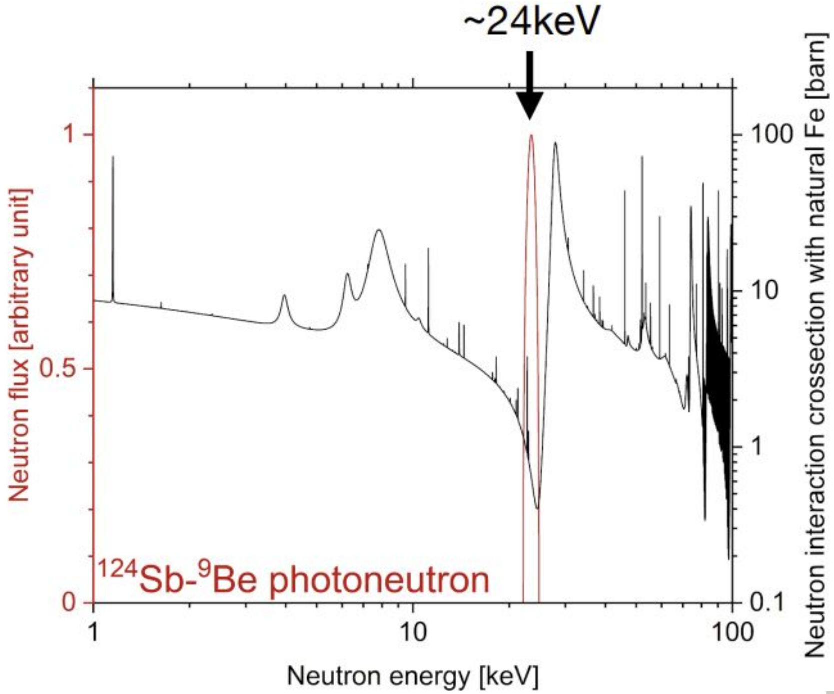
- Measurement of $^{4}He$ light yield of ER and NR
  - arXiv:2108.02176
- Good **agreement** with an **empirical model**
- High **NR light yield**
- Offers **ER/NR discrimination** via photon/roton ratio



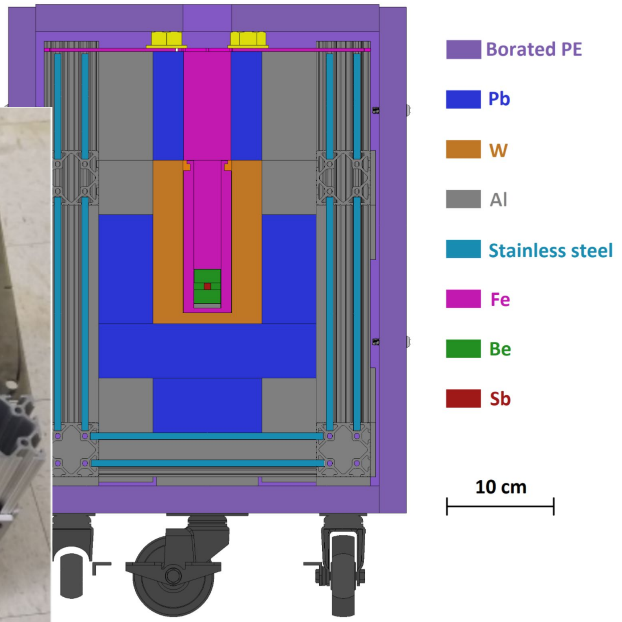



- Two **identical detectors** (as possible)
  - One glued
  - One suspended from wire bonds
- **TES based readout** measures athermal phonon pulses in substrate
- Successful mitigation of mounting stress
  - **Two orders** of magnitude difference in rate → stress is major source of LEE
- **Investigating** other sources: stress from sensor films, crystal and IR leakage
- See arXiv:2208.02790



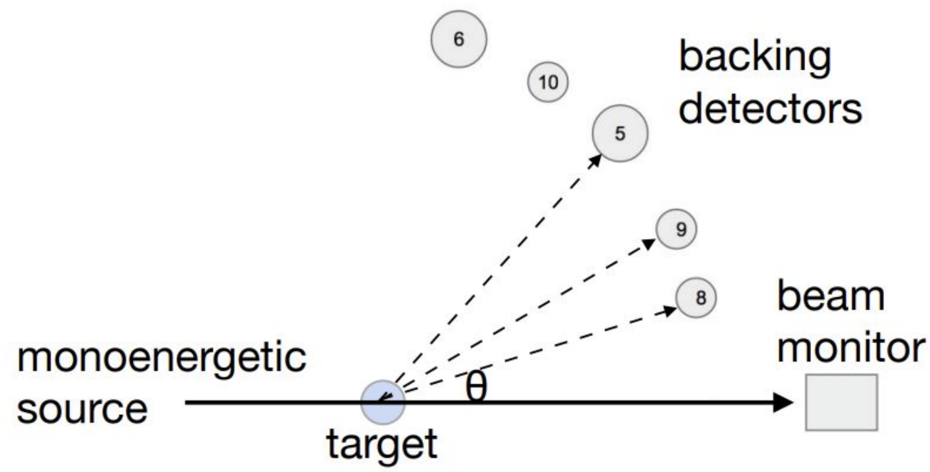


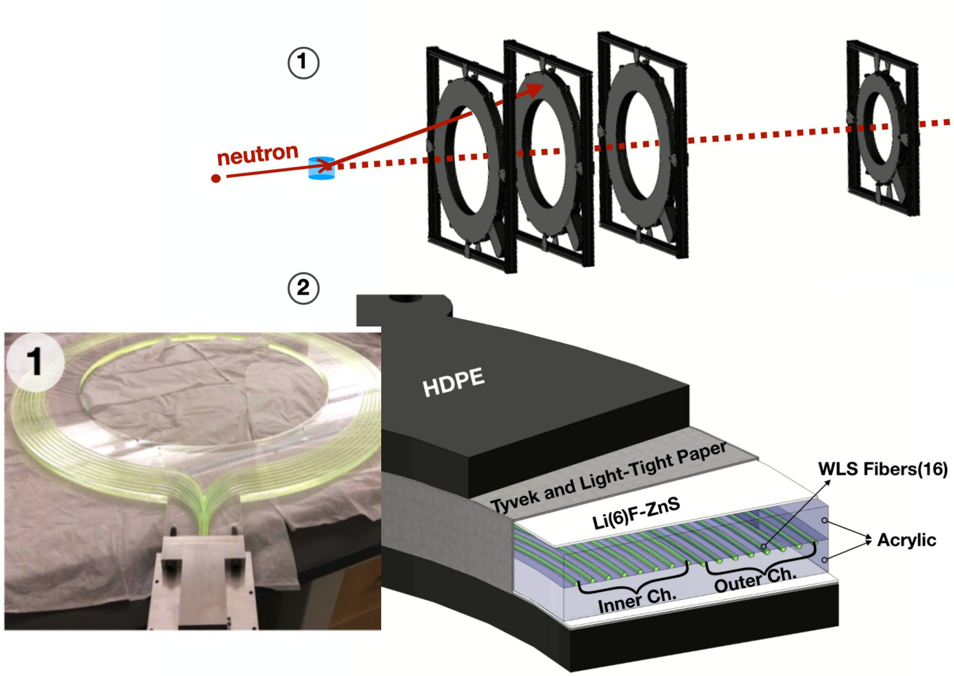

- **SbBe photoneutron + Fe** shield
- Remarkable coincidence:
  - $^{124}$SbBe **neutron energy**: 23.47 keV
  - Fe n-**transmission resonance**:24.54 keV
- Fe transparent to neutron, serves as collimator and very efficient gamma shield


- Source built & works
- Favorable **n flux**: ~5 $cm^{-2}s^{-1}$
- Portable, ideal for **CE*ν*NS** and **light DM** experiments
- See arXiv:2302.03869

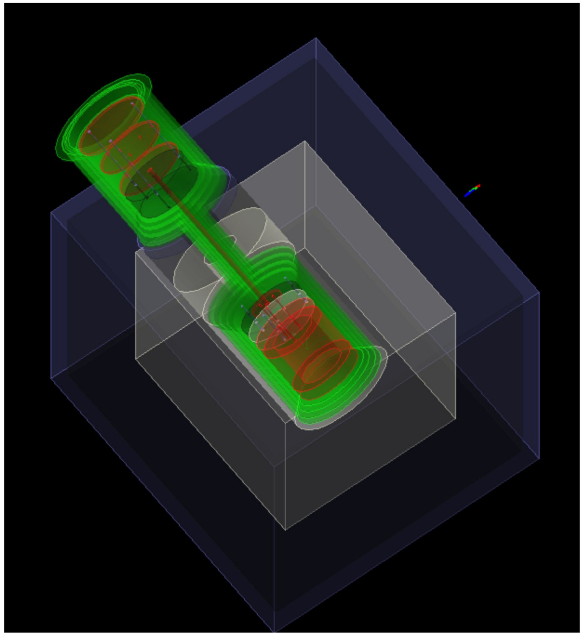
- Have now a low energy neutron source
- Primary strategy: Have a neutron of known energy, tag its scattering angle
- Large arge **keV Neutron backing** detector for low energy NR calibrations

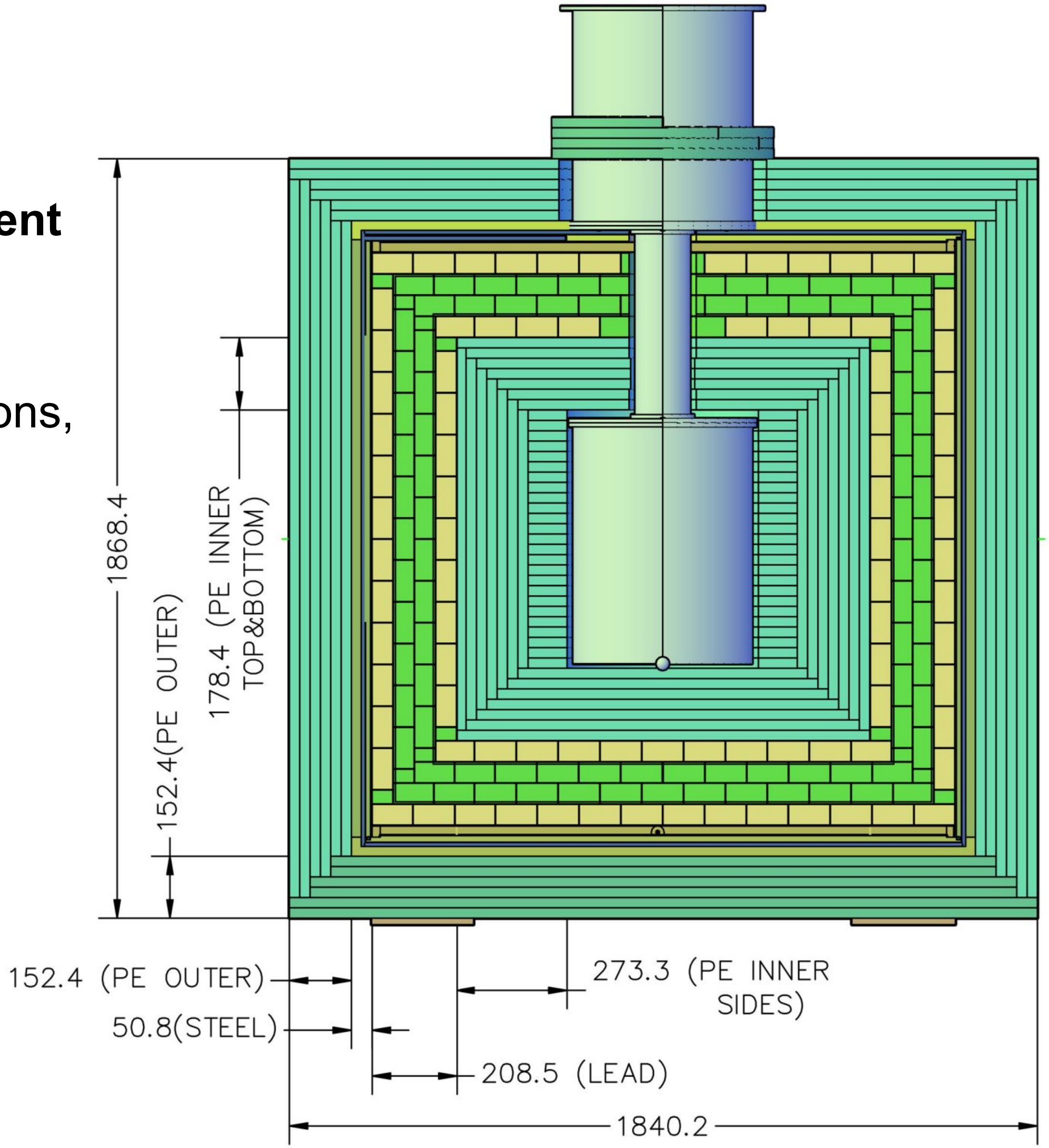


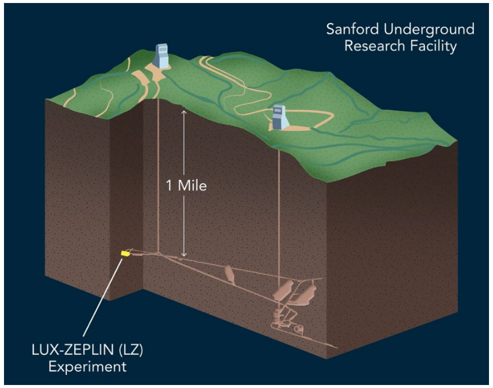



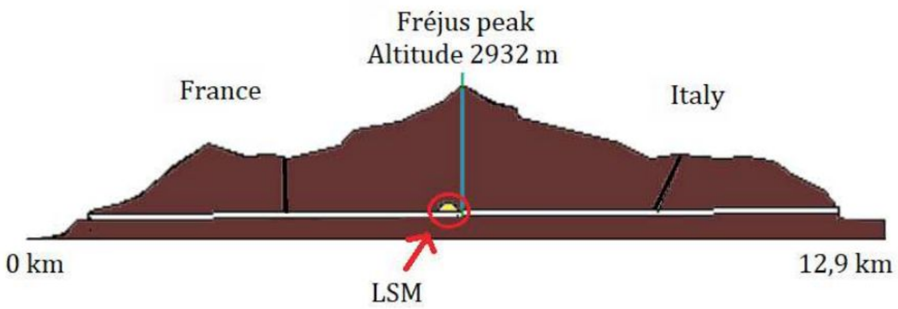

- $^{6}Li$ + Scintillator + Reflector + WS fiber + SiPM
- Eff: 25% eff. & affordable
- See [arXiv:2203.04896]

- Developed a novel shielding concept: **Tesseract Design**
    - **1.2 DRU** at 1 keV
    - About **0.75 DRU** with **ancient lead**
- **Advanced design** considering fabrication, installation, operations, budgeting & underground constraints



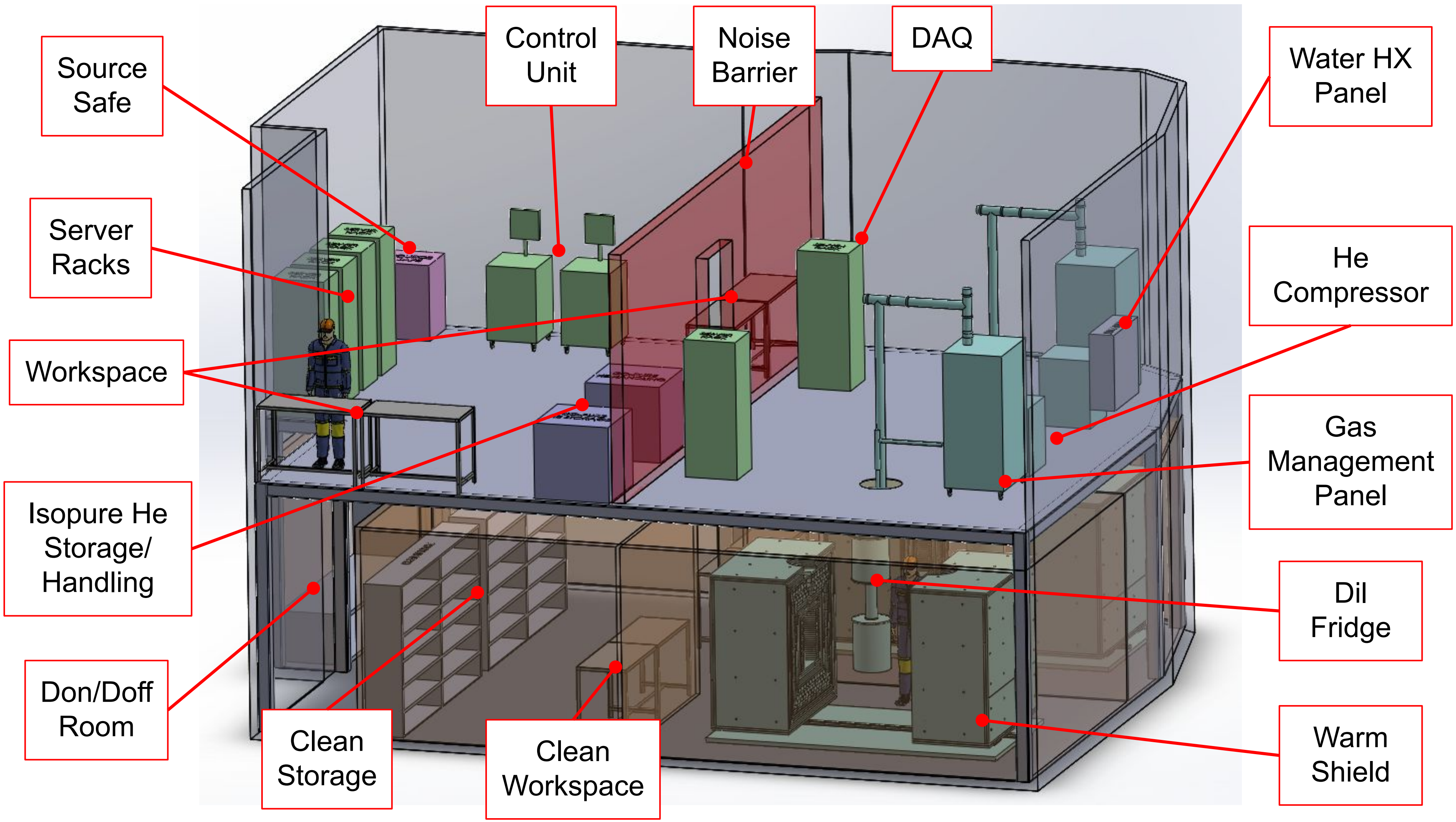




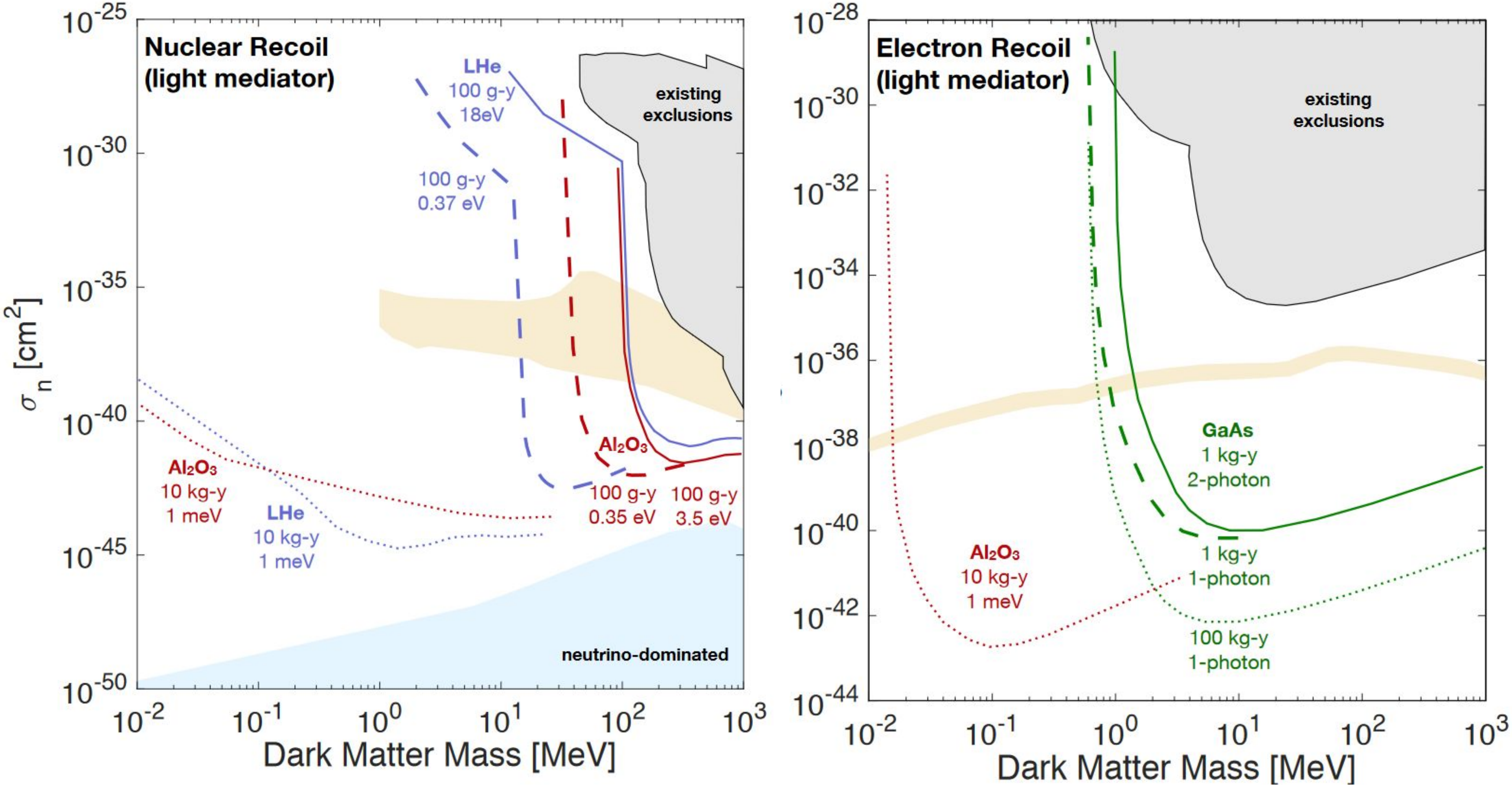





Maps are on the same scale!



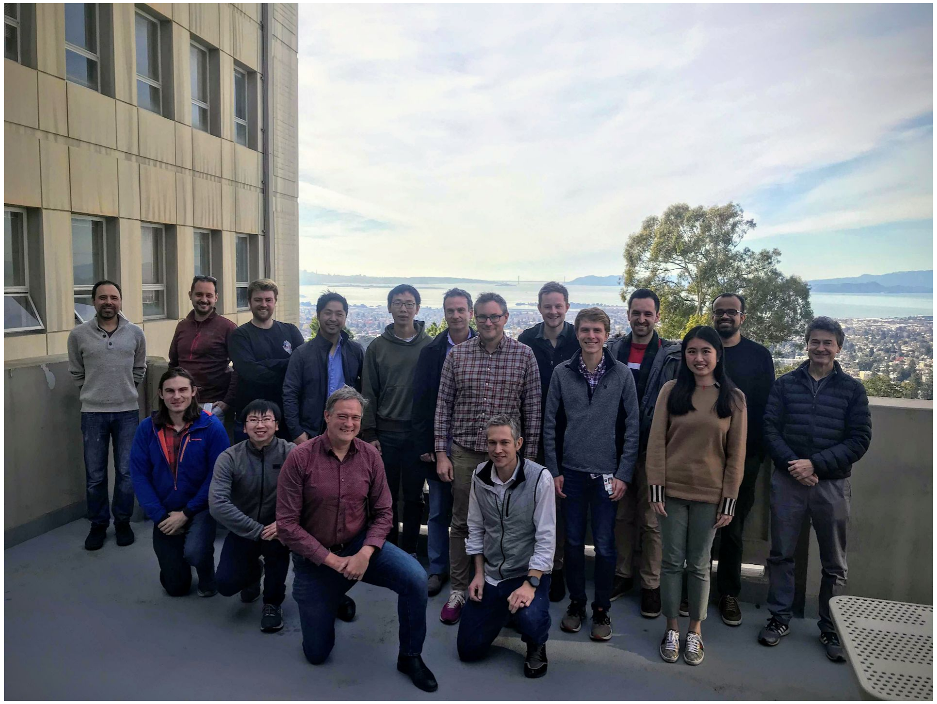

- Potential layout in Modane




- Tesseract will **probe multiple unexplored DM parameter spaces**
  - A discovery could come at any point

Snowmass LoI

- **Tesseract** is:
  - Two detectors: **Spice** & **Herald**
    - Sensitive to wide variety of models
    - Discriminate & understand backgrounds
    - Discover DM!
  - TES and calibration R&D
  - Engineering
  - Underground facility
  - Project management
- **Progress** in all of those topics
- Start **construction 2026**



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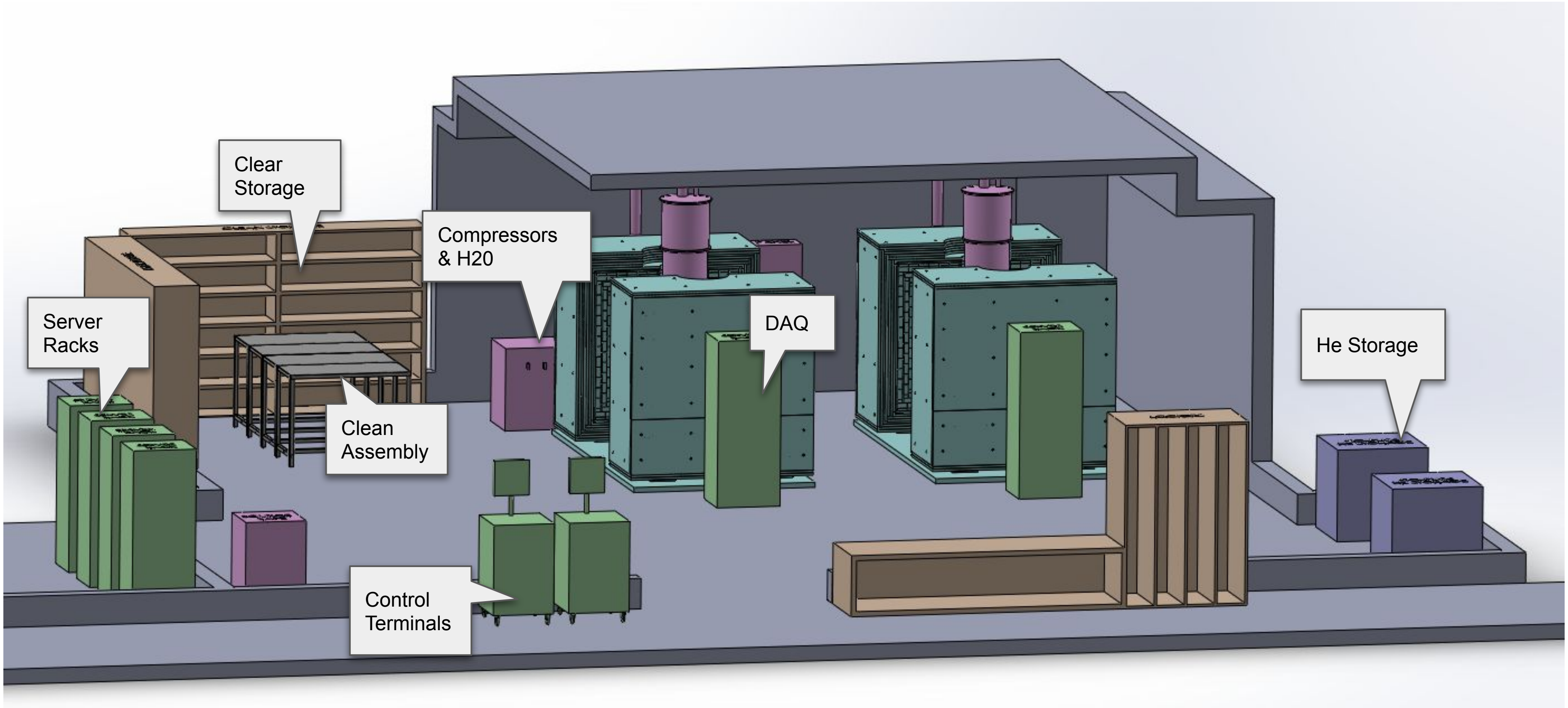
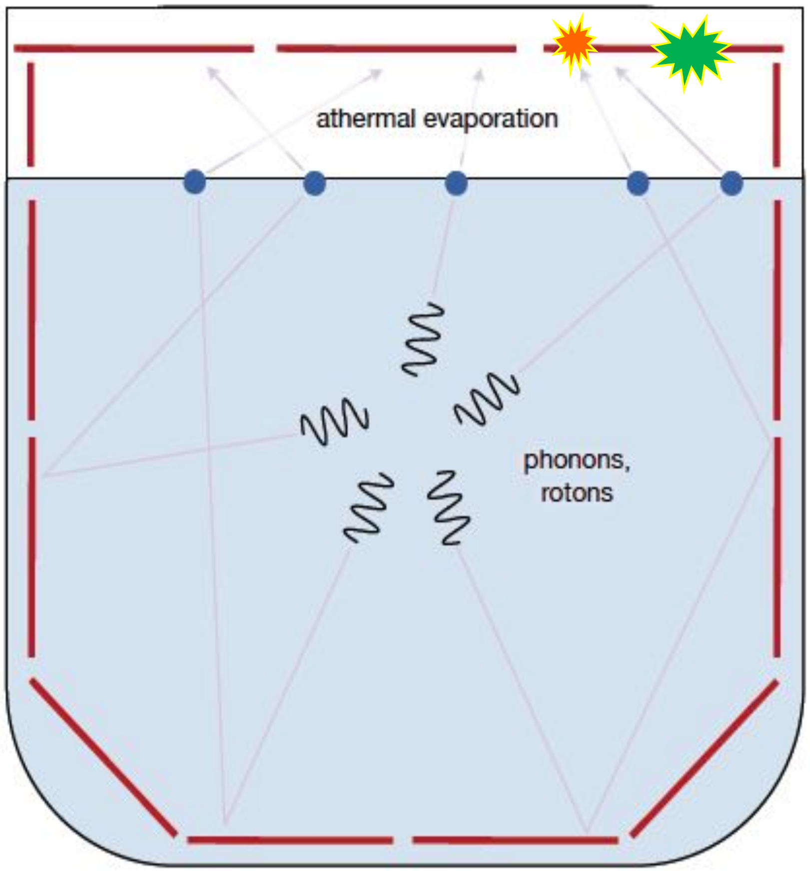
# Backup

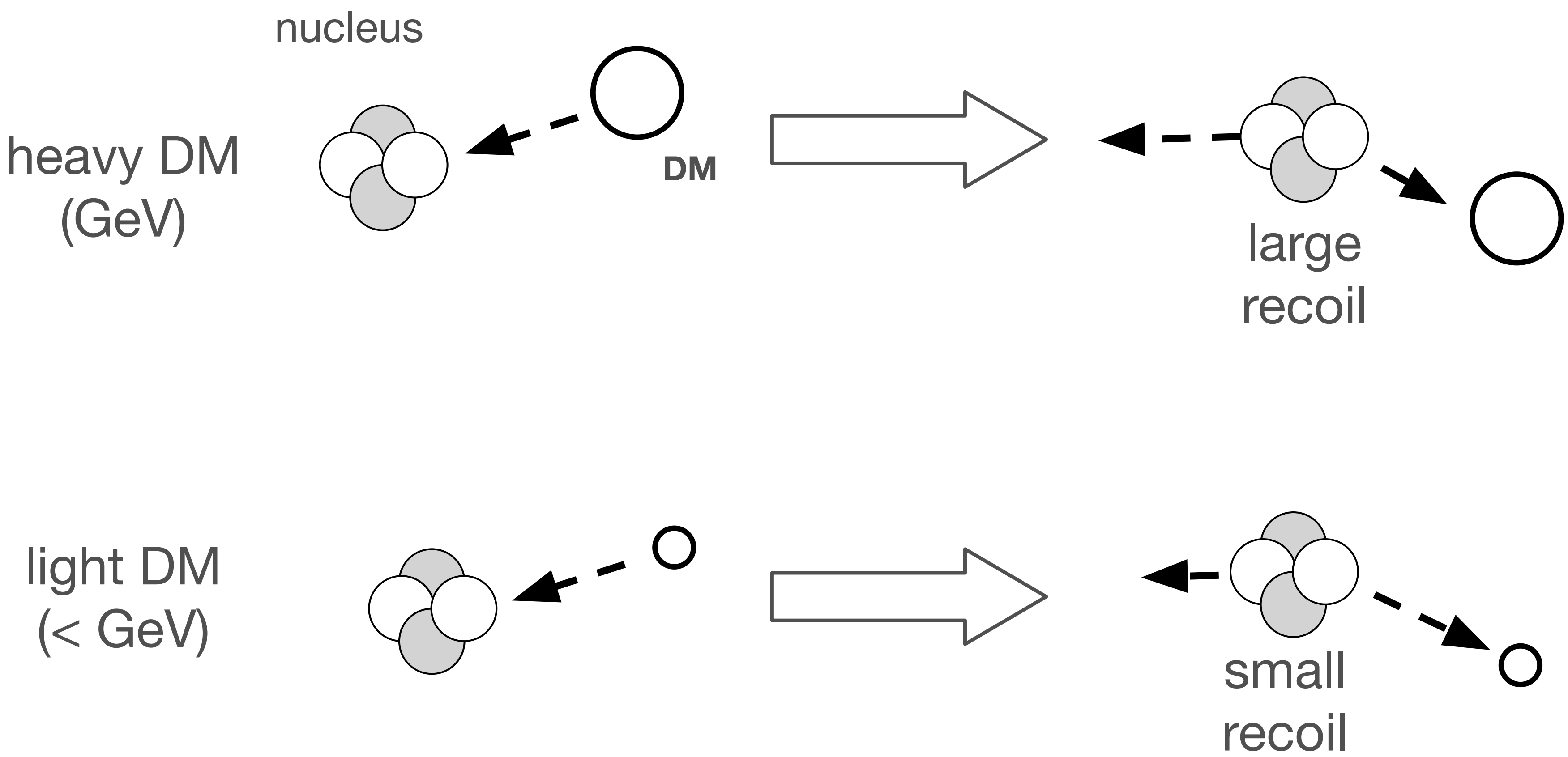



Possible Layout in Majorana Hall at SURF

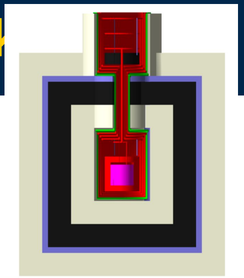


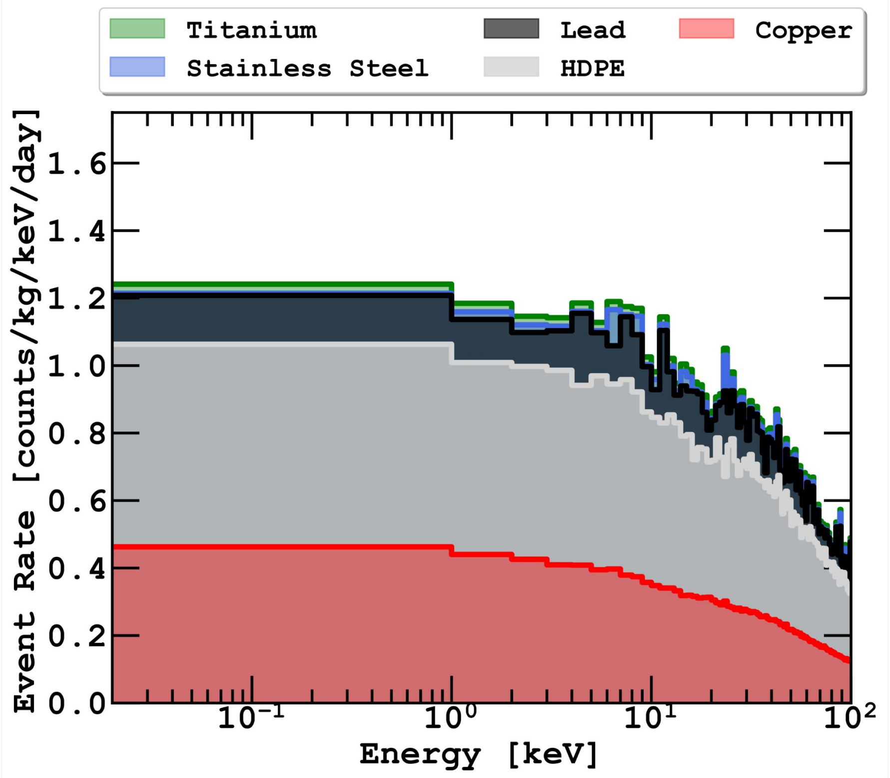

See Scott Hertel's talk (next up)

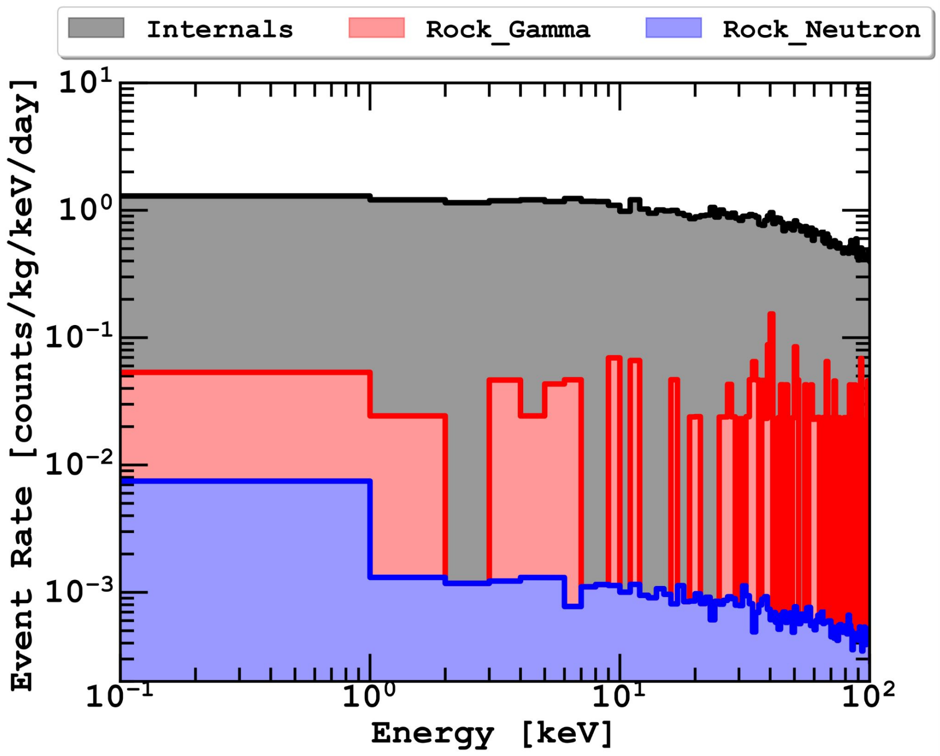
- Superfluid Helium: no stress microfractures due to liquid
- Multiple Pixel Coincidence for He DM events
- DM recoiling off of He: produces signals in multiple roton detectors
  - Require multiple pixel coincidence for He events
  - Pulse Shape discrimination possible!
- HeRALD with multiple background rejection techniques is complementary to crystals




- Momentum transfer crucial
- Low mass difficult
- **LXe dual-phase TPCs** demonstrated best sensitivity for masses at about 1 GeV and more

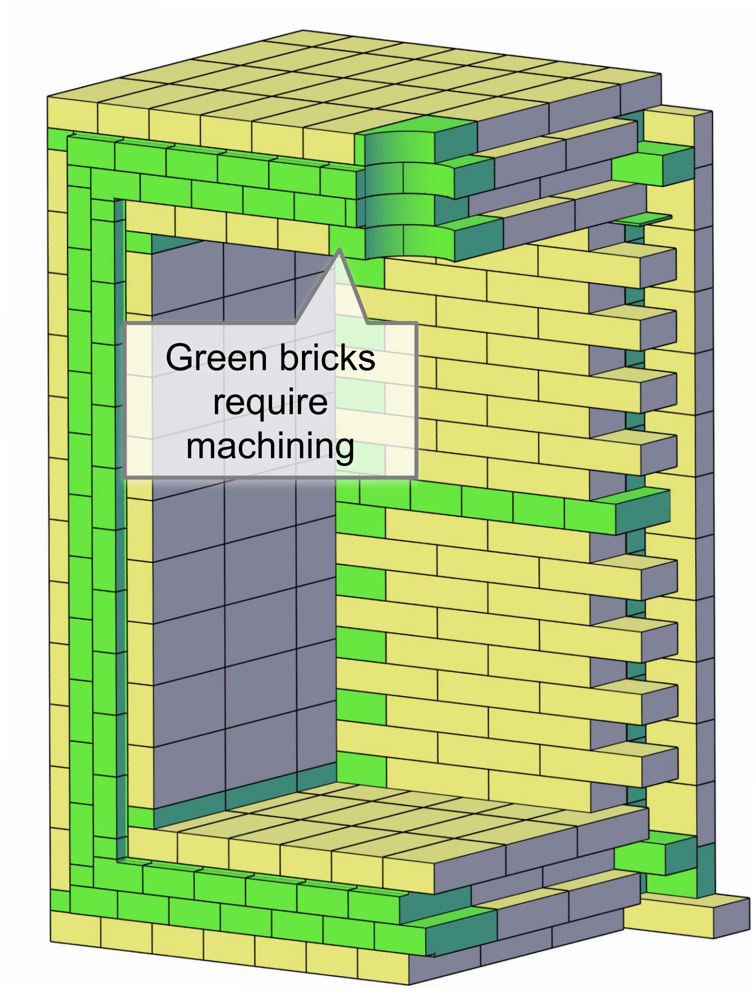


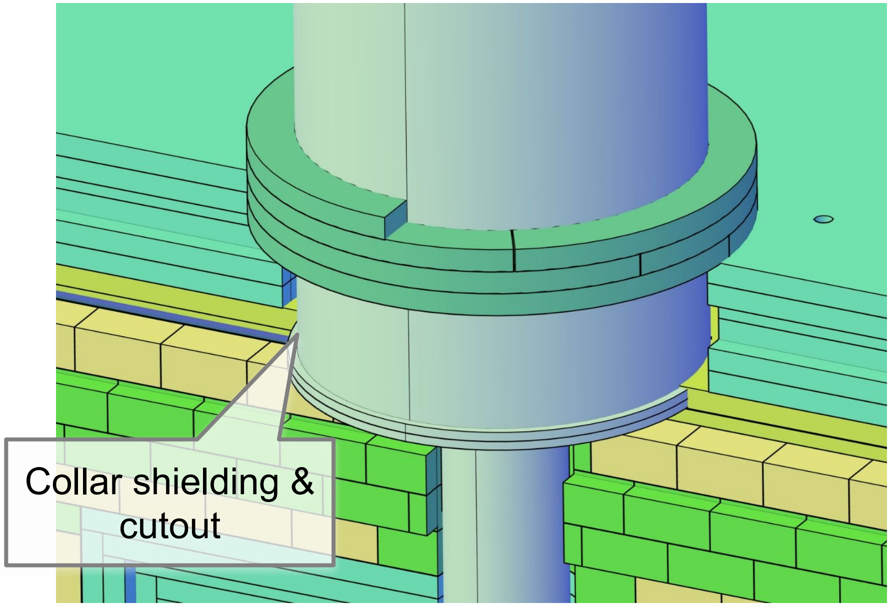


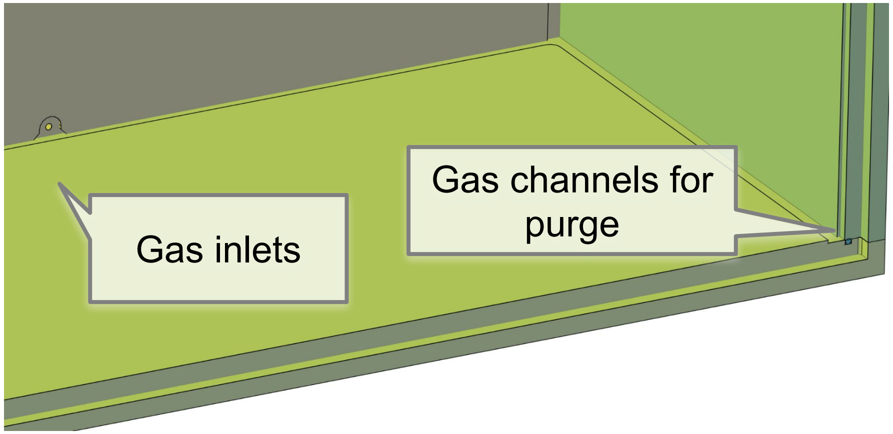




- Total background dominated by internal background
- Total rate for Stem design **1.2 DRU at 1 keV**
- Further background reduction possible via **multi-detector coincidence veto**

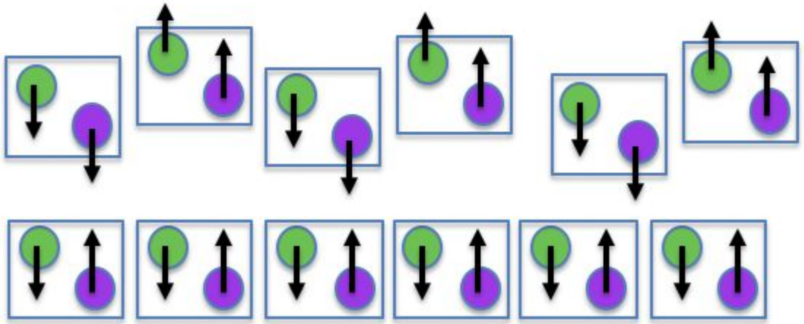
- **Some** more engineering **examples**:

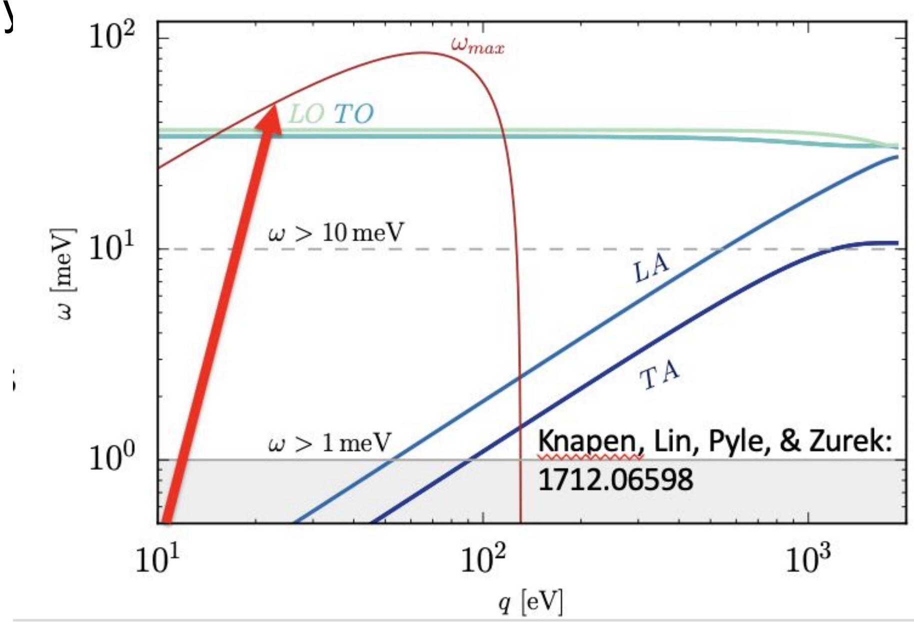


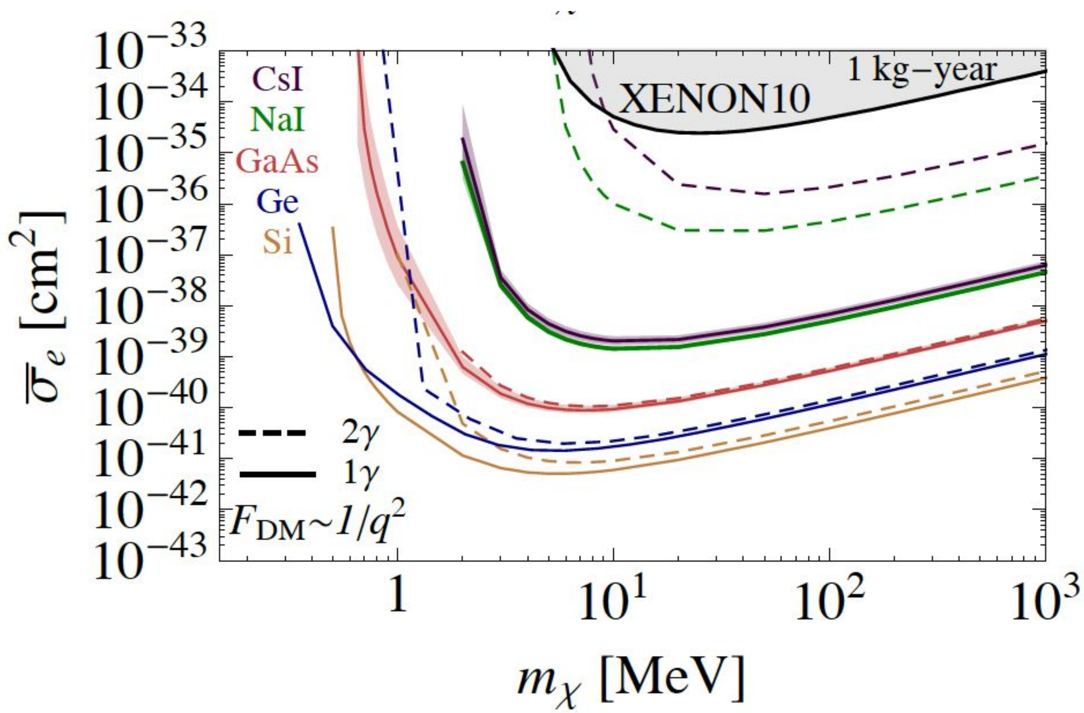
- Coherent excitations:
  - Vibrational energy scale in crystals is O(100 meV)
  - DM scatters coherently with the entire crystal, producing a single phonon
  - Favorable kinematics of optical phonon production: All of the kinetic energy of the DM can potentially be used for phonon creation
  - Optical phonons modulate the electric dipole in polar crystal → couple strongly to IR photons → DM models that interact through a kin. mixed dark photon
  - We chosen Al2O3 and SiO2 as target materials to maximize sensitivity to these electro-magnetically coupled DM models





- Low band gaps:
  - Just as with optical phonons, the gapped nature of an electronic excitations in semiconductors allows them to maximally extract kinetic energy when scattering with or absorbing DM
  - Due to a strong rate dependence upon energy, low bandgap semiconductors like Ge, Si (SENSEI and SuperCDMS HV), and GaAs (SPICE) are the preferred target candidates.

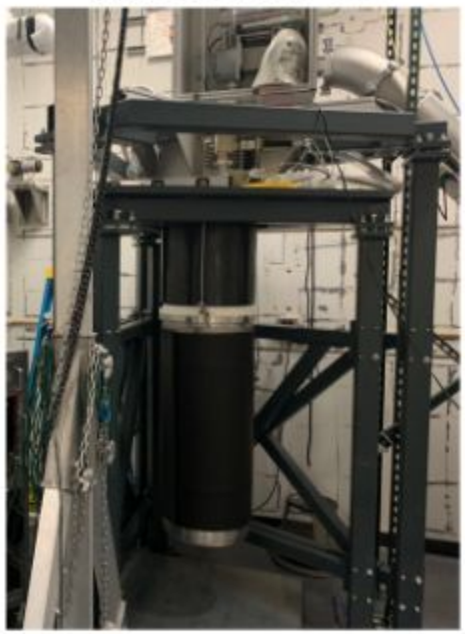
- With GaAs we can collect both photons and phonons!
  - Allows **background rejection** through phonon/photon ratio
  - Photon-photon and phonon-phonon **coincidence should reduce instrumental backgrounds** isolated to a single sensor



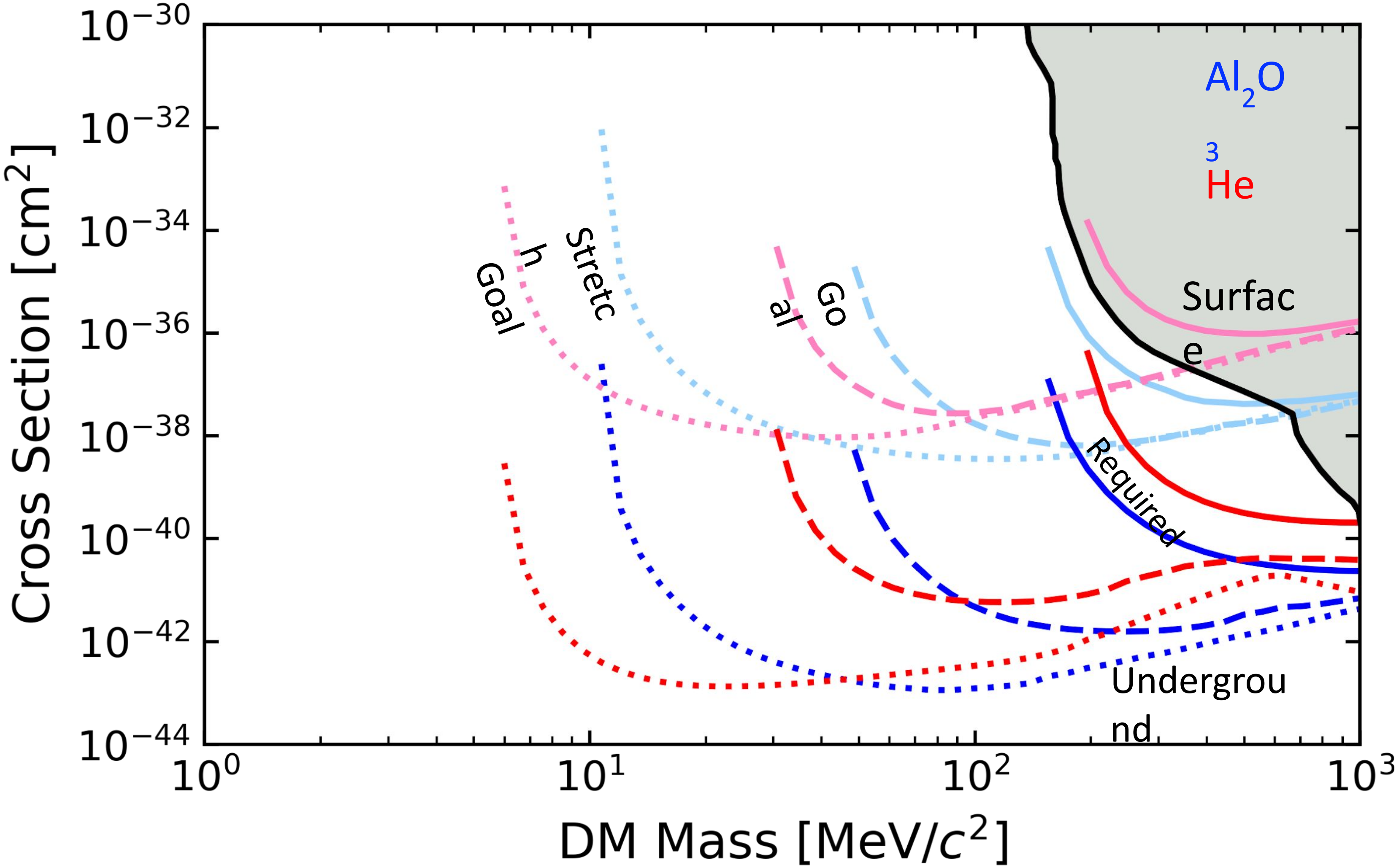
# SPICE/HeRALD testbeds

Leiden MNK126-500
McKinsey Group @ UCB

CryoConcept UQT-B 200
Pyle Group @ UCB

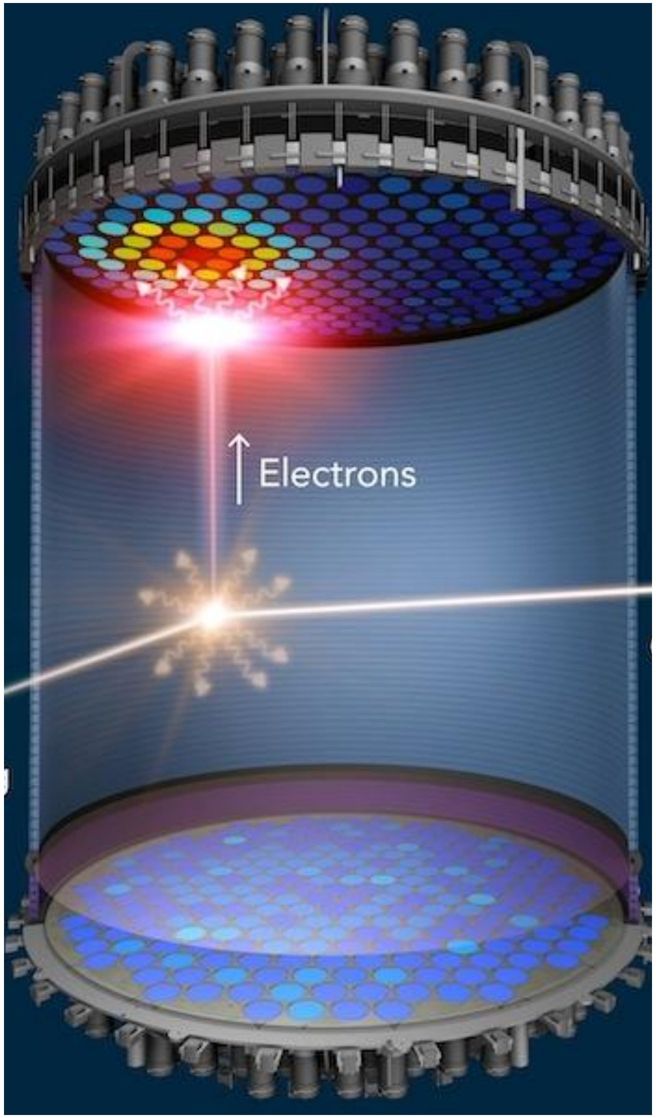


Blue
Dete




- Tesseract will **probe multiple unexplored DM parameter spaces**
  - A discovery could come at any point
  - First physics results with surface runs forthcoming

Snowmass LoI




- E-field leads to dark current: PMT, TPCs, SiPMs, SuperCDMS HV

- Want to get rid of E-field
- Using transition-edge sensor (TES)
  - No E field
  - O(100 meV) thresholds