The TESSERACT Project for Sub-GeV Dark Matter Detection

Dan McKinsey
LBNL/UC Berkeley
May 12, 2022

Seminar
LPSC, Grenoble

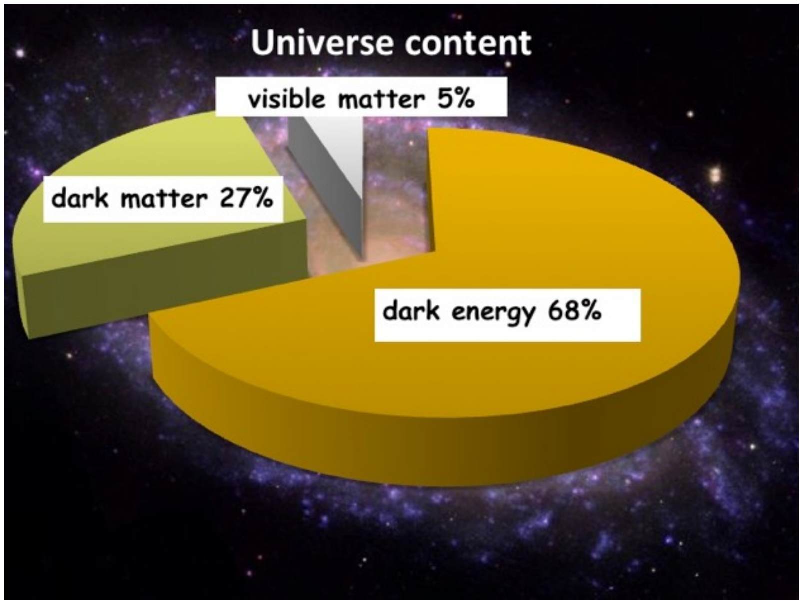
Composition of the Universe

The Higgs particle has been discovered, the last piece of the Standard Model.

But as successful as it has been, the Standard Model describes only 5% of the universe. The remaining 95% is in the form of dark energy and dark matter, whose fundamental nature is almost completely unknown.

Discovery of the fundamental interactions and mass of the dark matter would likely provide important clues about the physics beyond the Standard Model. This may in turn lead us to learn new principles by which the Universe operates.

Image: X-ray: NASA/CXC/CfA/M.Markevitch et al.;
Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.;
Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.



www.quantumdiaries.org

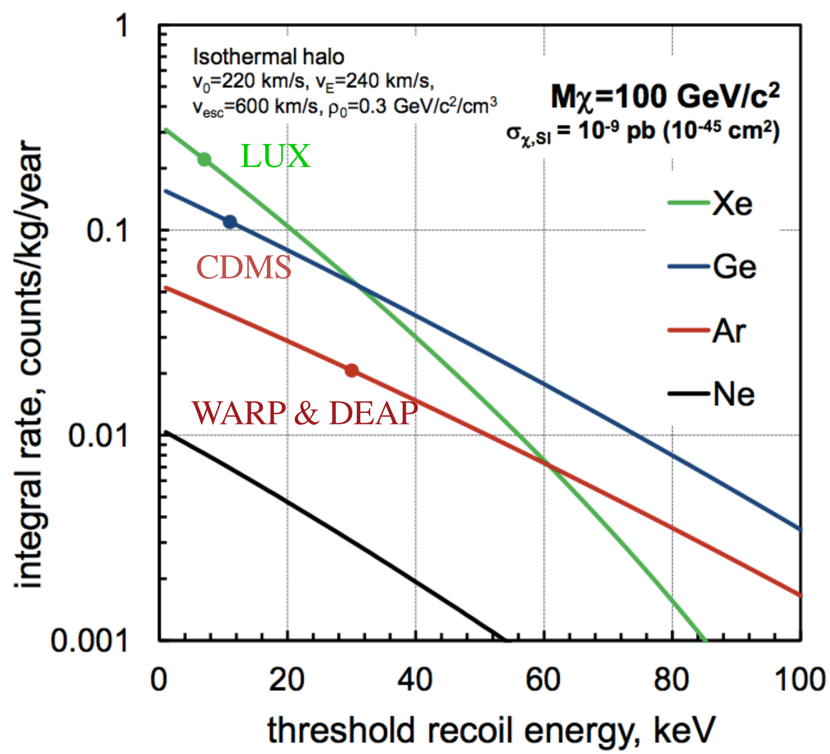
Weakly Interacting Massive Particle (WIMP) Direct Detection

Look for anomalous nuclear recoils in a low-background detector.

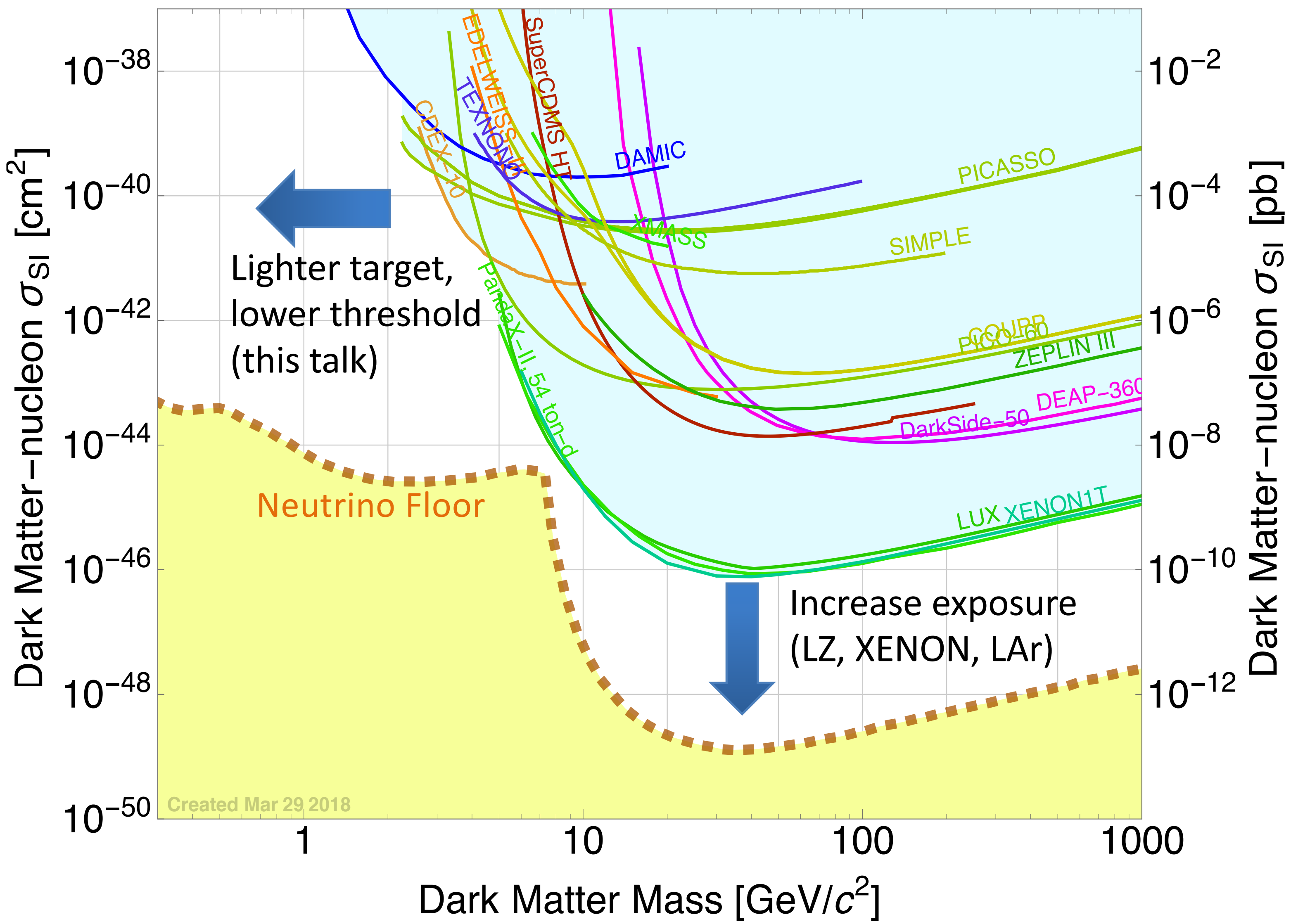
$R = N \rho \langle \sigma v \rangle$. From $\langle v \rangle$ = 220 km/s, get order of 10 keV deposited.

Requirements:

- Low radioactivity
- Deep underground laboratory
- Low energy threshold
- Gamma ray rejection
- Scalability



Dark Matter Nuclear Recoils: Future Directions

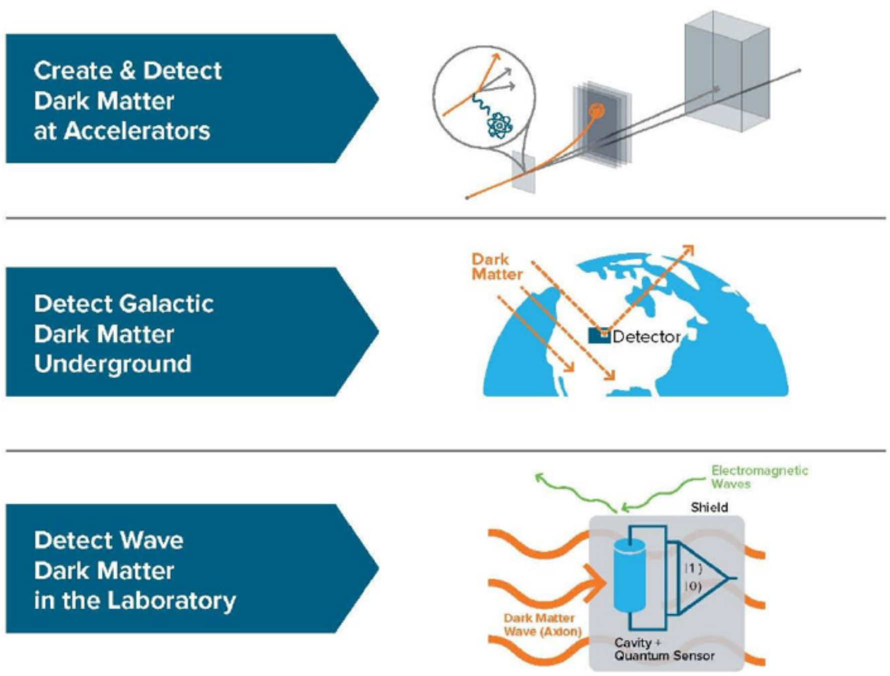


US DOE High Energy Physics Basic Research Needs Study for Dark Matter Small Projects

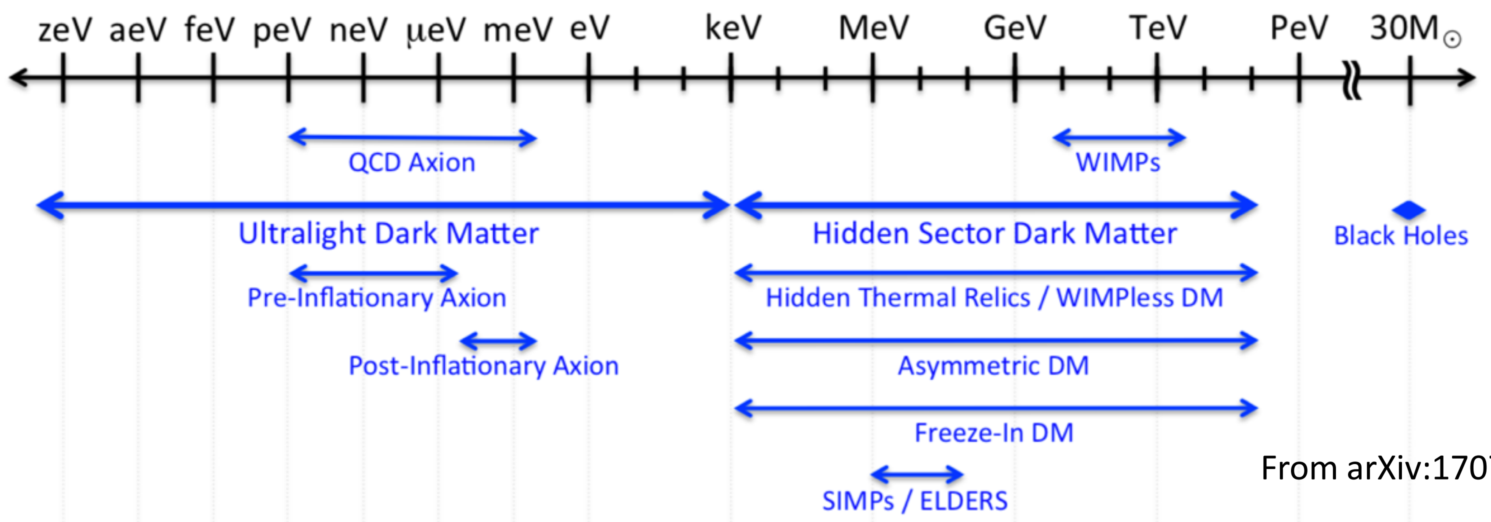
- Workshop held in Washington DC, Oct 15-18, 2018
- Resulted in a report to the Dept of Energy, "Basic Research Needs for Dark Matter Small Projects New Initiatives".

Provenance:

- In 2014 the Particle Physics Project Prioritization Panel(P5) identified the search for dark matter as one of the five priority science drivers for the High-Energy Physics Program: "*There are many well-motivated ideas for what the dark matter should be. These include weakly interacting massive particles (WIMPs), gravitinos, axions, sterile neutrinos, asymmetric dark matter, and hidden sector dark matter. It is therefore imperative to search for dark matter along every feasible avenue*."
- Some of these scenarios –including WIMP searches—are the purview of larger experiments. However, much of the well- motivated parameter space for dark matter can be explored by small experiments in the near future. This corresponds to another recommendation of P5, namely that *"The HEP program should contain a portfolio of small projects to enable an uninterrupted flow of high-priority science results."*

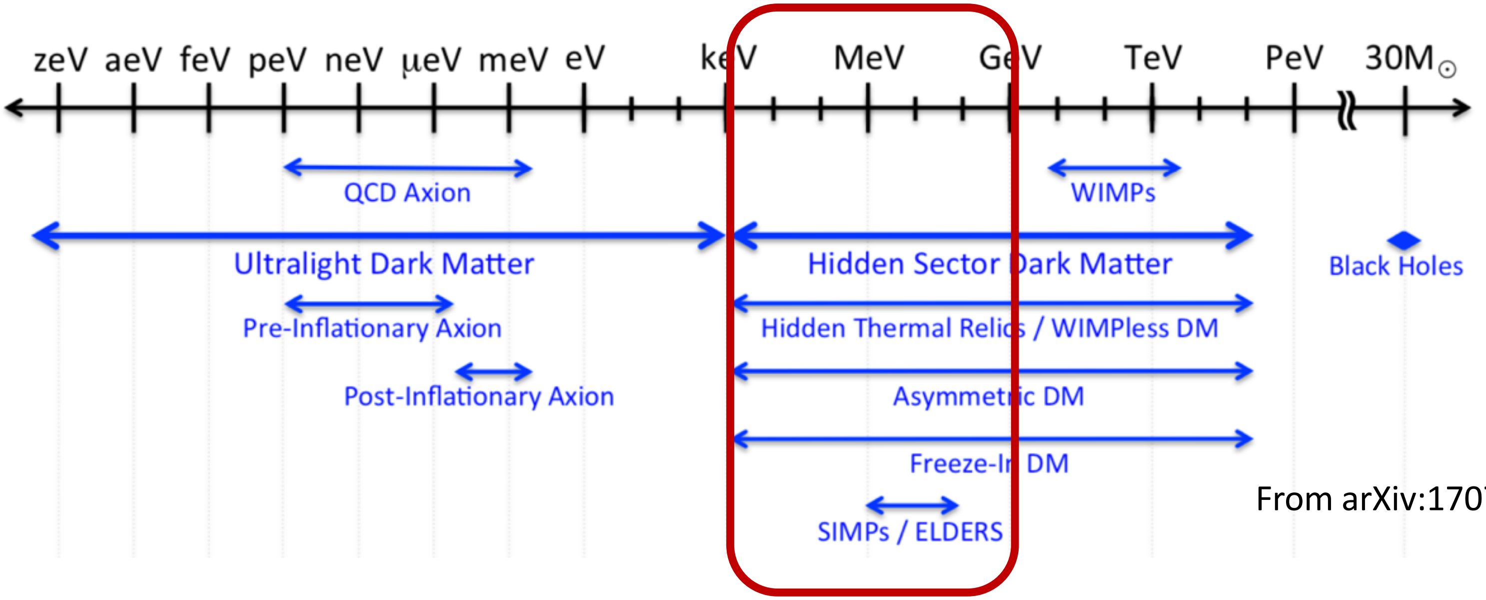


Dark Matter allowable mass range



From arXiv:1707.04591

Dark Matter allowable mass range

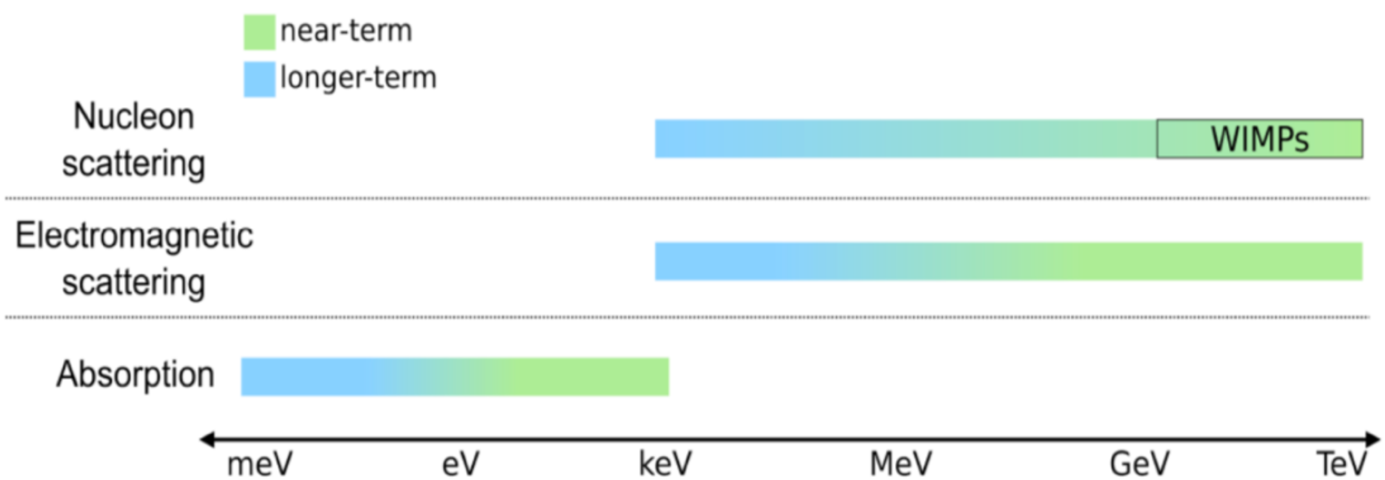


From arXiv:1707.04591

- Unlike WIMPs, composed of particles that interact through the SM weak interactions, the dark matter sector may be instead disconnected from the visible one.
- See summary and references in M. Battaglierei et al., arXiv:1707.04591 .
- General symmetry arguments allow several types of "portal" interaction between generic hidden sectors and the Standard Model, which can be generated by radiative corrections.
- These modest couplings can play a key role in realizing the dark matter abundance, through several possible mechanisms. These include:
  - Determining the DM abundance via **thermal freeze-out** (like in the standard WIMP paradigm)
  - Depleting a thermal component in **Asymmetric DM**
  - Mediating the production of DM from a bath of SM particles in **freeze-in** scenarios
  - Maintaining kinetic equilibrium while hidden-sector dynamics depletes the DM number density **(SIMP/ELDER**)

Dark Matter interaction types

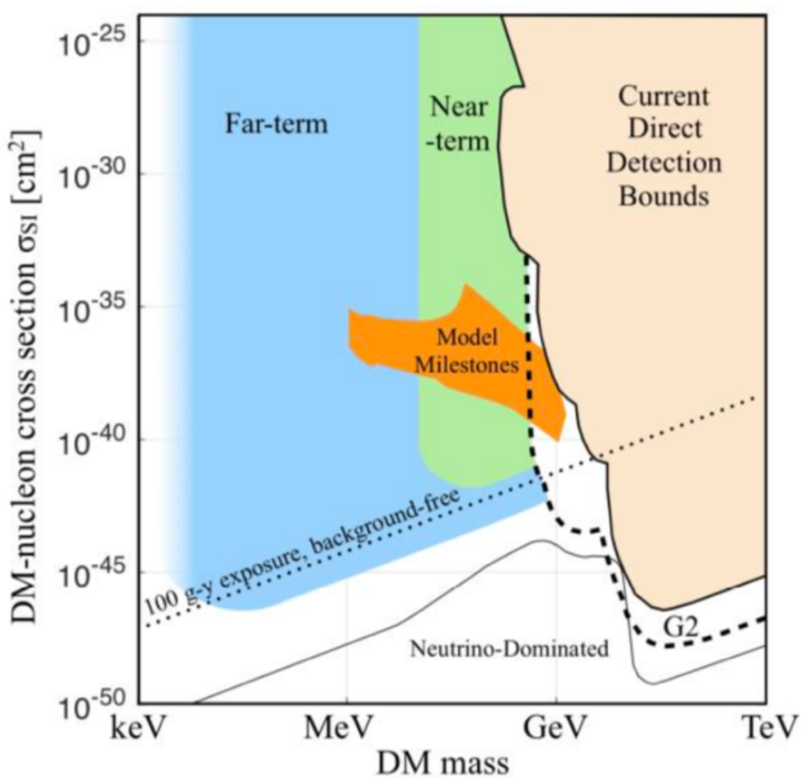
- The dark matter theory landscape has evolved in new directions in the last decade, emphasizing the need to probe non-WIMP dark matter candidates with a mass below about 1 GeV.
- Sharp theory targets exist in which dark matter interacts only with baryons or only with leptons, emphasizing the need for experiments that probe dark matter couplings to electrons *and* experiments that probe dark matter couplings to nuclei.
- ER: dark photon mediator or vector coupling predominantly to leptons
- NR: dark photon mediator, vector coupling predominantly to quarks, or scalar coupling



From BRN report

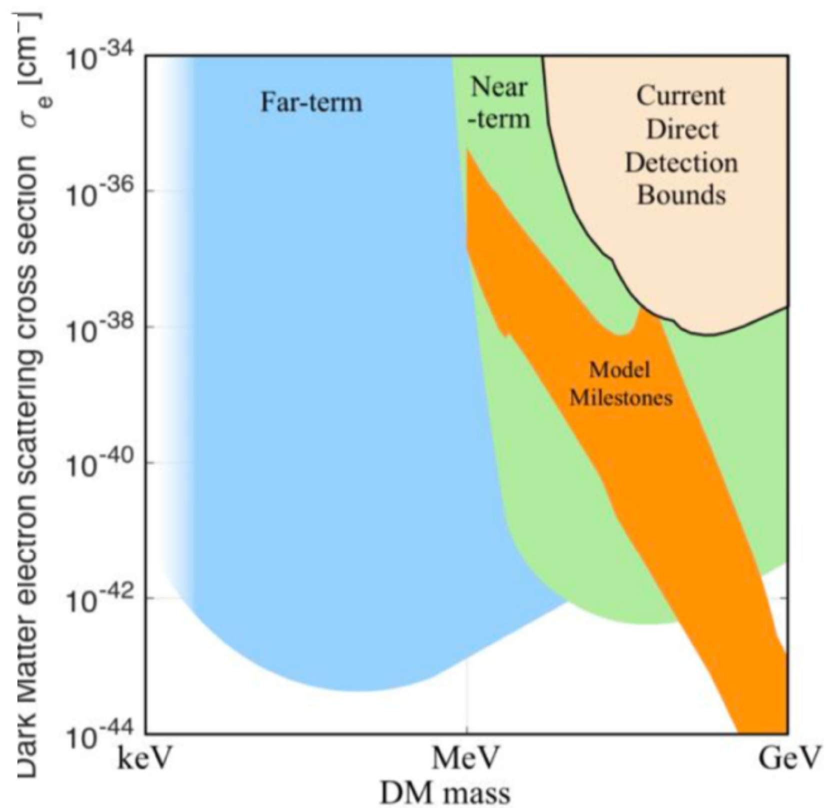
Dark Matter interaction types

DM - nuclear recoil (NR) interactions



DM - electron recoil (ER) interactions

HEAVY MEDIATOR



From BRN report

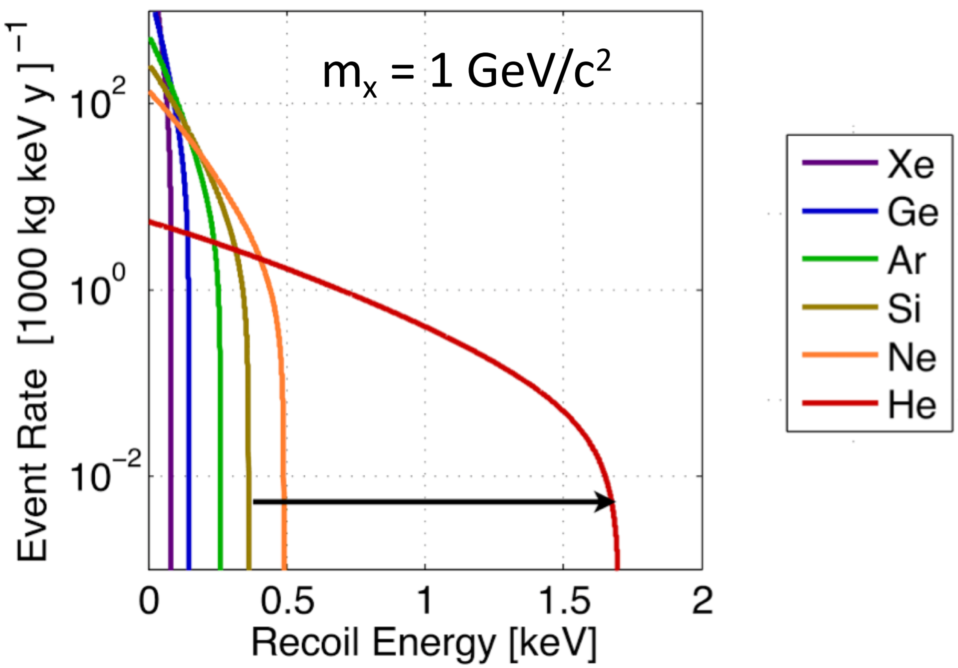
Light target nuclei and low energy thresholds for NRDM

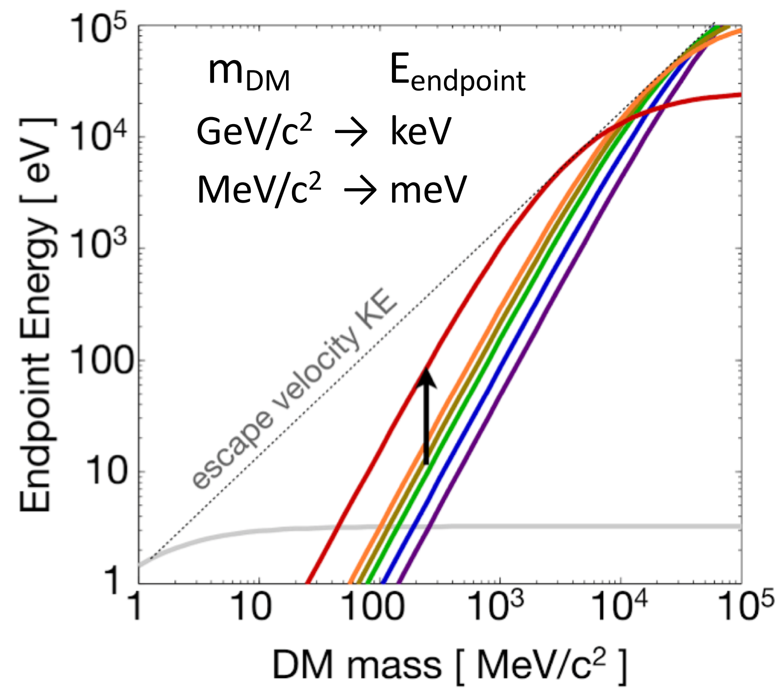
With sufficiently low threshold and/or a light target, lower dark matter masses may be probed.

Current thresholds are on the 10 eV scale**. Not the keV scale of tonne-scale direct detection experiments!**
Heading toward meV energy thresholds -> the topic of ongoing and future R&D.

This low threshold is challenging! But as in WIMP searches, searching for nuclear recoils continues to benefit from significant advantages including

a) Coherent enhancement of dark matter – nucleus scattering cross-sections
b) Gamma-ray and beta-decay background rejection through signal ratios
c) Relatively low nuclear recoil background (neutrons)

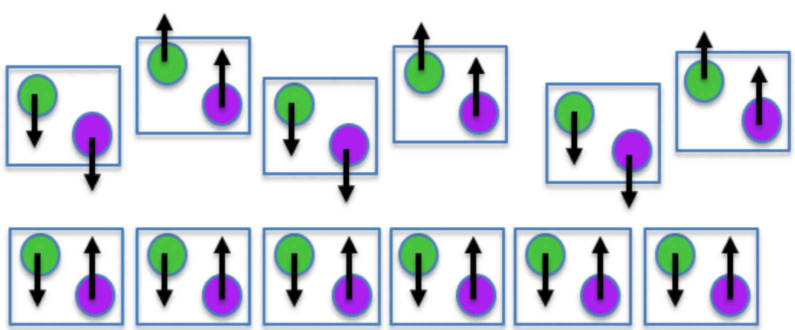


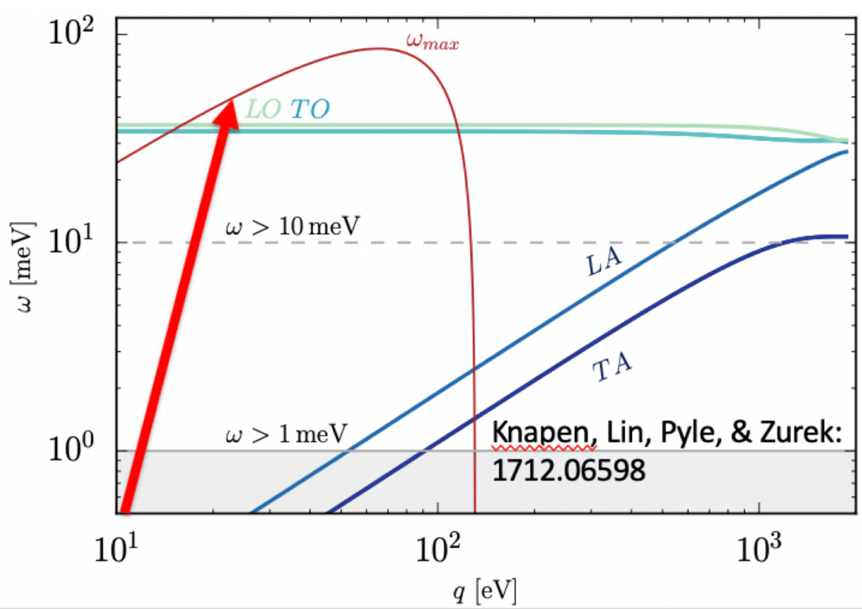


Coherent Excitations for ERDM

Coherent excitations:

- Vibrational energy scale in crystals is O(100 meV)
- For dark matter masses < 100 MeV, we can't use the simplifying approximation that the nucleus is free.
- DM scatters coherently with the entire crystal, producing a single phonon.
- The kinematics of optical phonon production are favorable; due to their gapped nature, all of the kinetic energy of the DM can potentially be used for phonon creation.
- Optical phonons modulate the electric dipole in polar crystals, so they have strong couplings to IR photons, and thus by extension, all DM models that interact through a kinematically mixed dark photon.





Knapen, Lin, Pyle, & Zurek: 1712.06598

Low Bandgaps for ERDM

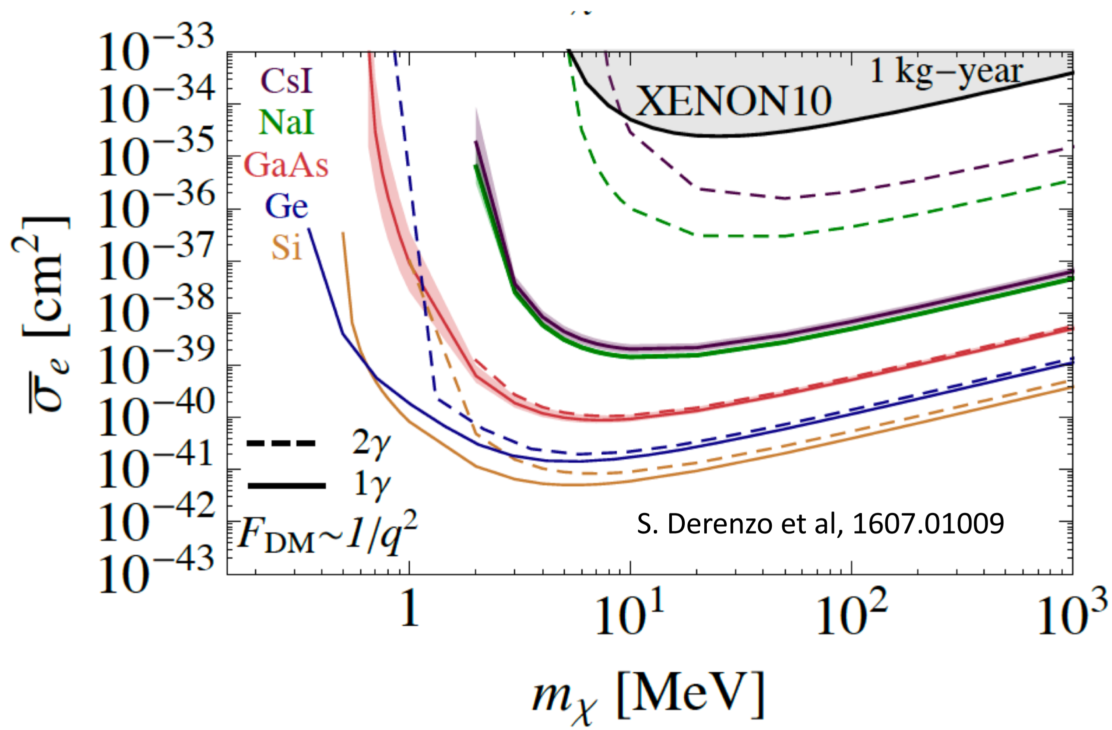
Low bandgaps:

- 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 one can collect both photons and phonons!

Can allow background rejection through phonon/photon ratio

Also, photon-photon and phonon-phonon coincidence should reduce instrumental backgrounds isolated to a single sensor.



Backgrounds

There has been an explosion of theoretical work studying possible materials for detecting sub-GeV dark matter, and quantifying the signals that could be seen for different dark matter models. Very exciting!

But **the world of the experimentalist is largely a world of reducing backgrounds**, and these backgrounds are varied and multifaceted. And because we cannot turn the dark matter off, we can't get a beam-off background measurement. Understanding and reducing backgrounds is a huge challenge, and **conceiving and implementing an experiment approach that mitigates these backgrounds is crucial.**

Traditional backgrounds (keV-MeV scale, nuclear physics) include:

- Gamma-rays
- Beta decay
- Alpha particles
- Neutrons

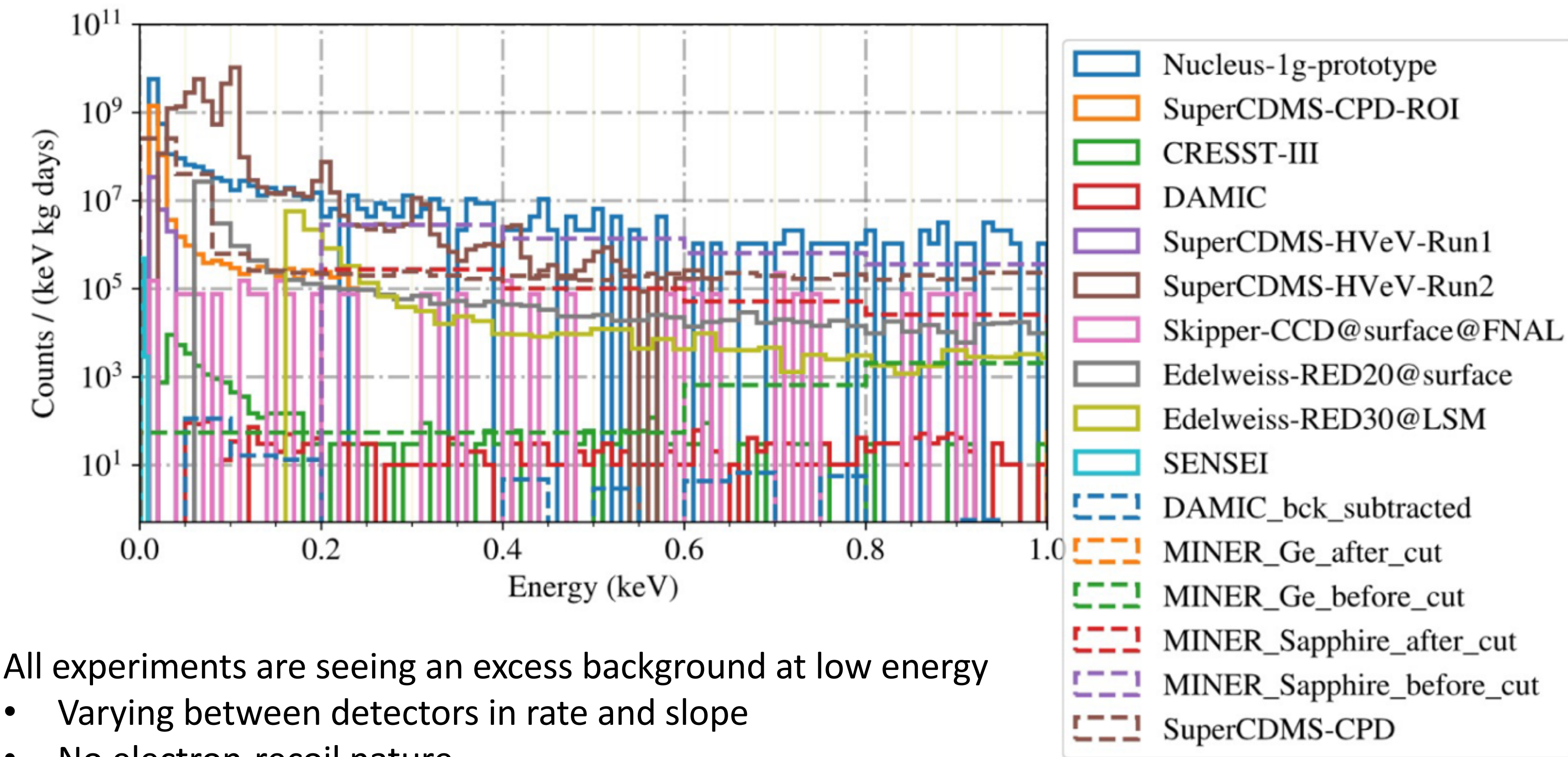
New backgrounds (eV scale) include:

- Cerenkov radiation
- "Little earthquake" stress relaxation
- More generally – chemistry, solid state physics

Substantial backgrounds seen at low energies, across sub-GeV direct detection experiments

EXCESS workshop, see: https://indico.cern.ch/event/1013203/

See summary by J. Billard and R. Strauss



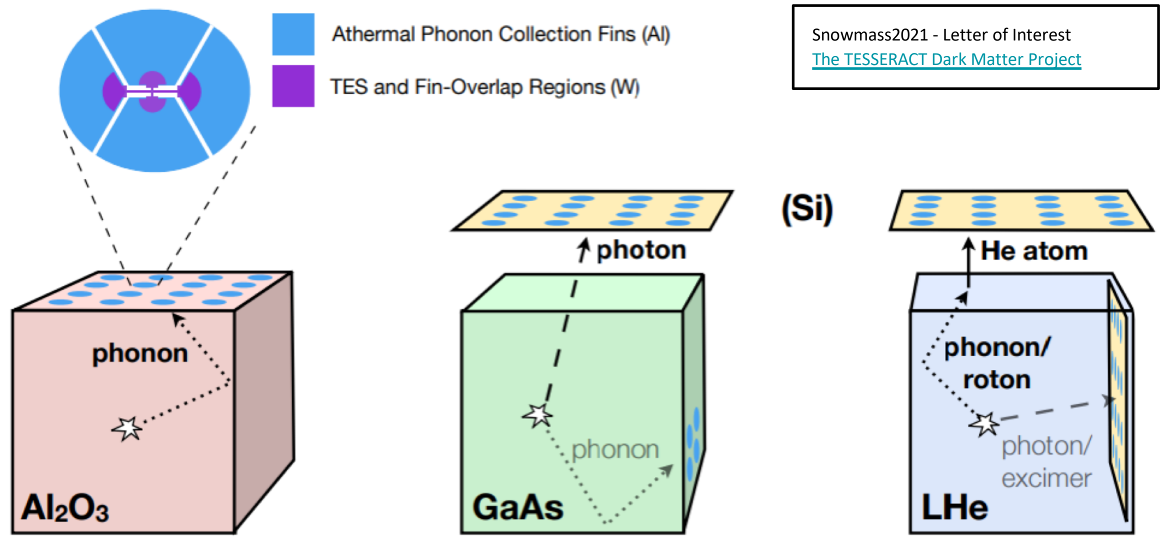
All experiments are seeing an excess background at low energy

- Varying between detectors in rate and slope
- No electron-recoil nature
- Multicomponent
- Some components get reduced with time

TESSERACT project (part of the DMNI suite of DOE-supported efforts)

- Managed by LBNL
- Funding for R&D and project development began in June 2020.
- One experimental design, and different target materials with complementary DM sensitivity. Zero E-field.
- All using TES readout
- ~40 people from 8 institutes
- Includes SPICE (polar crystals) and HeRALD (superfluid helium). These are historical names, now shorthand for the targets.

Snowmass2021 - Letter of Interest
The TESSERACT Dark Matter Project



The Importance of Nuclear Recoil / Electron Recoil Discrimination

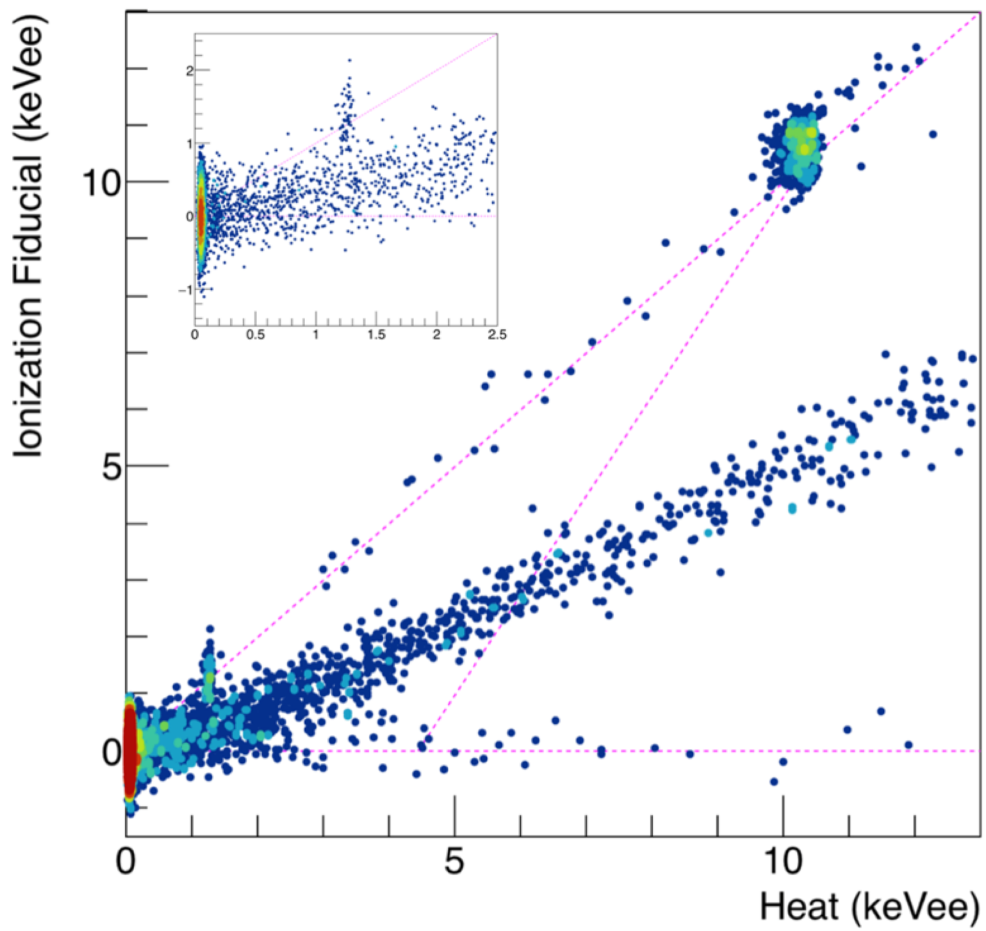
When searching for events of one type (ER or NR), it is very useful to be able to distinguish these from each other and from instrumental backgrounds, **on an event-by-event basis.**

TESSERACT has technologies with multiple signal channels:

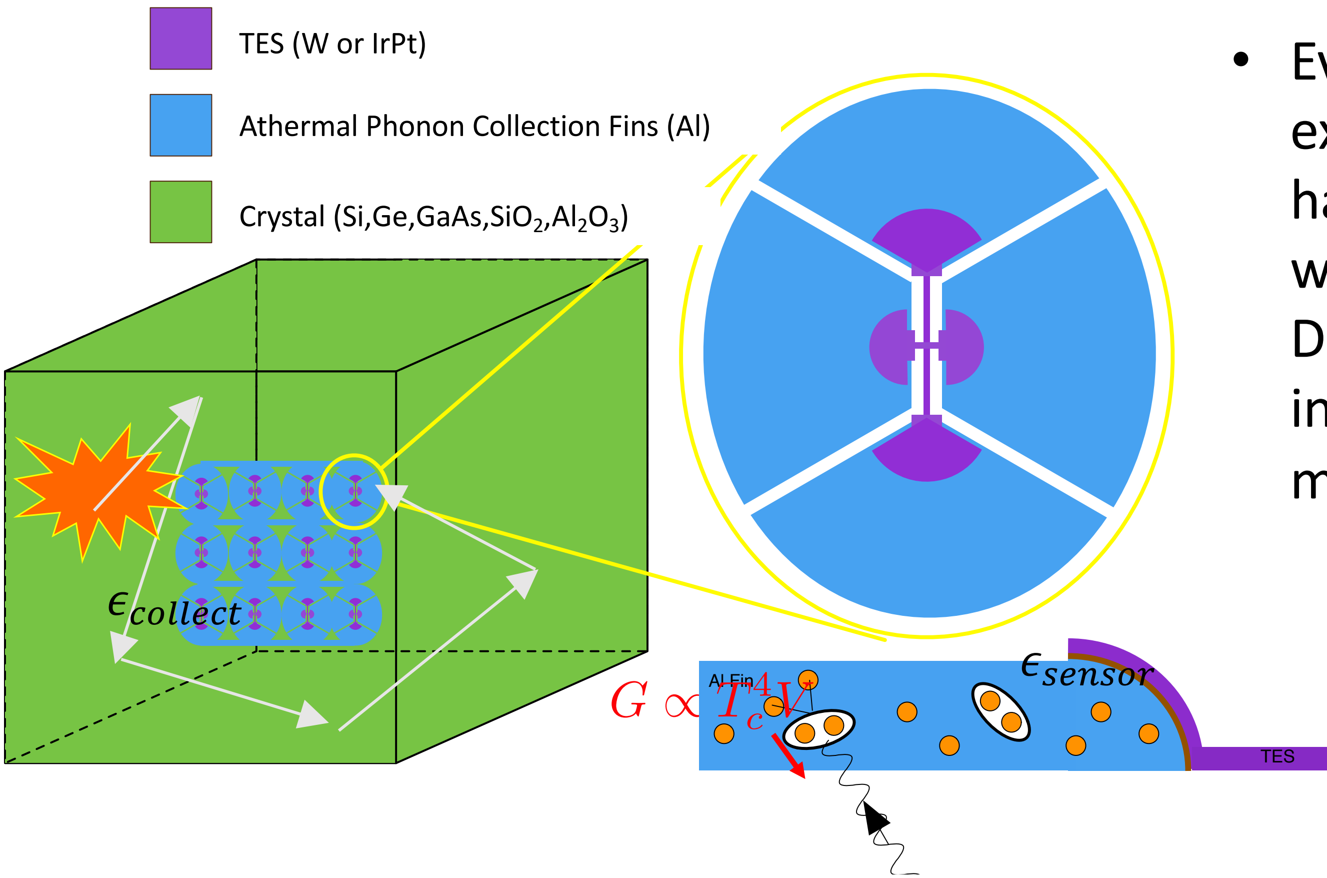
Superfluid helium: scintillation photons, triplet excimers, rotons, and phonons

GaAs: phonons and photons

Example from RICOCHET R&D (courtesy J. Billard)
Neutron calibration, Ge detector, JFET electronics



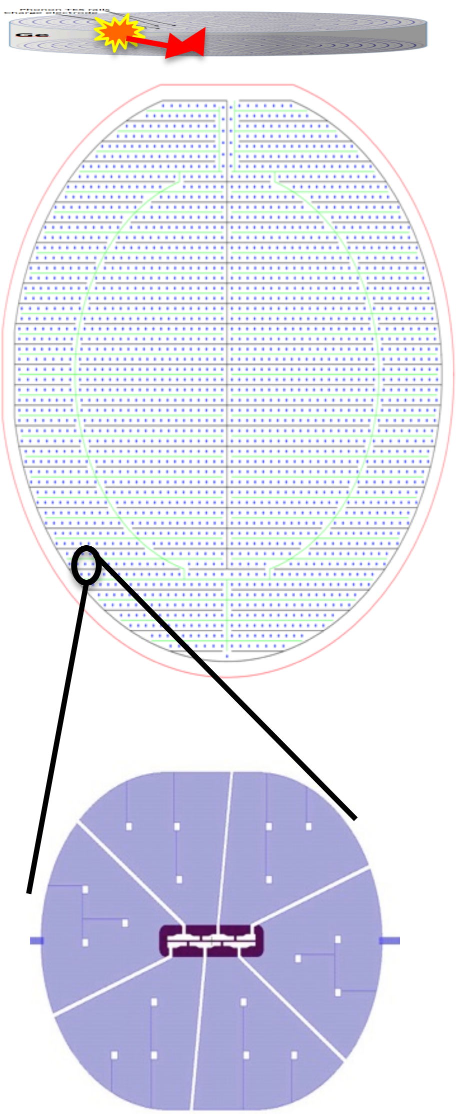
Athermal Phonon Detectors



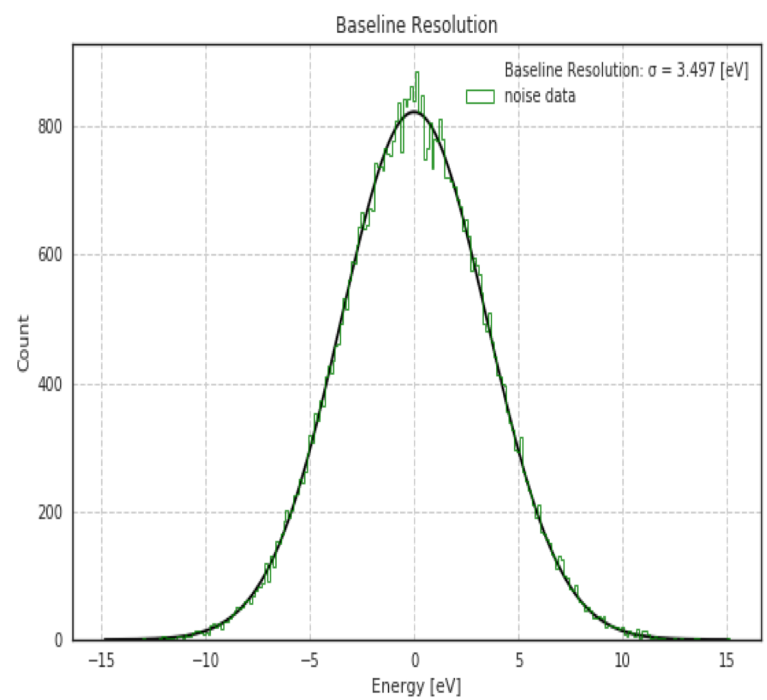
- Everything identical except the substrate … having multiple targets with complementary DM science doesn't increase cost (time & money) significantly!

$$\sigma_E \sim \frac{\sqrt{4k_b T_c^2 G(\tau_{collect} + \tau_{sensor})}}{\epsilon_{collect}\epsilon_{sensor}}$$

Recent Progress: Large Area Photon Calorimeters



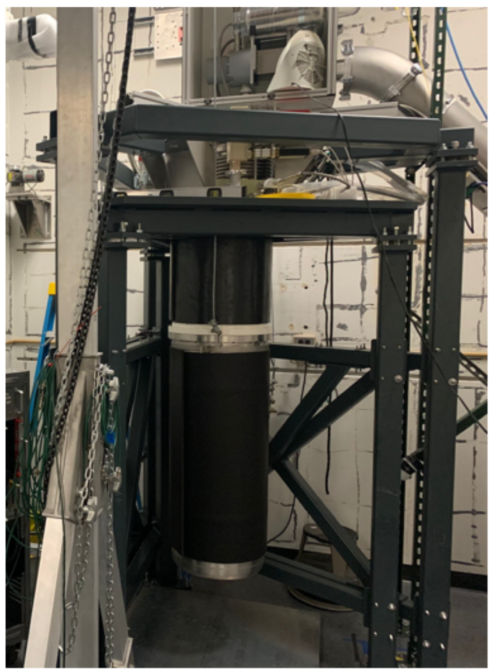
- 3” diameter 1mm thick Si wafer (45.6 cm^2)
- Distributed athermal phonon sensors
  - Athermal Phonon collection time estimated to be ~20us
  - 2.5% sensor coverage
- Tc= 41.5mK
- **17% Athermal Phonon Collection Efficiency**
- **Measured Baseline σ_E =3.5 ± 0.25 eV**



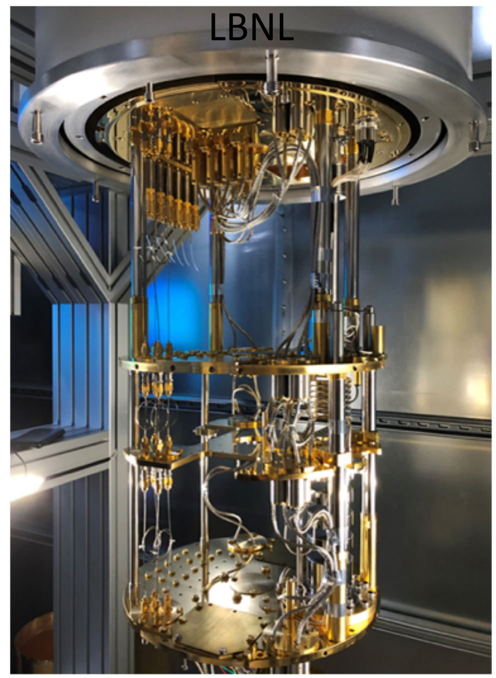
SPICE/HeRALD testbeds

Leiden MNK126-500
McKinsey Group @ UCB

CryoConcept UQT-B 200
Pyle Group @ UCB



BlueFors LD-400
Detector Group @
LBNL



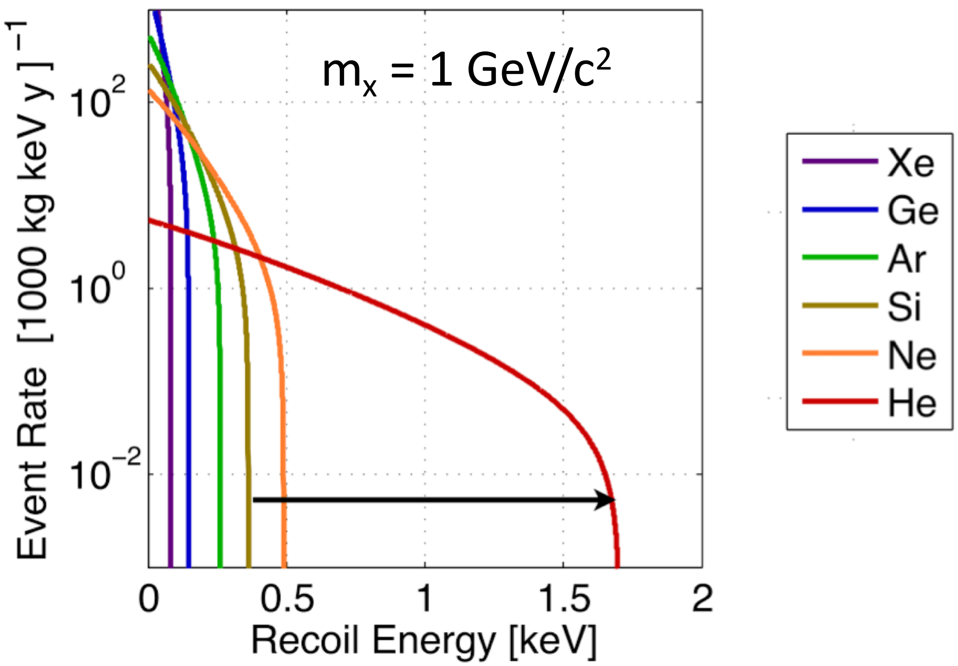
CryoConcept HEXADRY
UQT-B 400

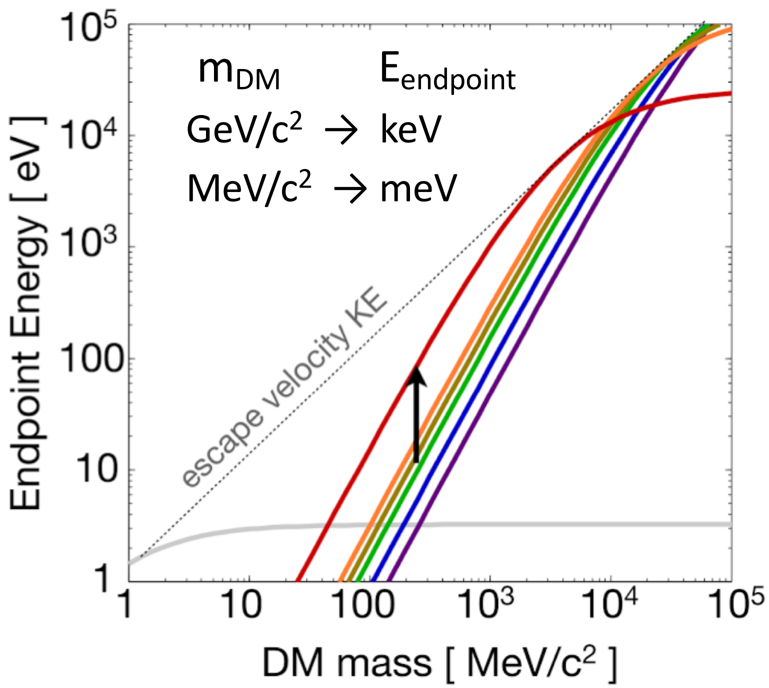
H

Light baryonic target nuclei for NRDM

With sufficiently low threshold and/or a light target, lower dark matter masses may be probed.

In TESSERACT, low thresholds will be achieved using TES readout, enabling reach to DM masses that cannot be reached by detectors that have only ionization or scintillation signals





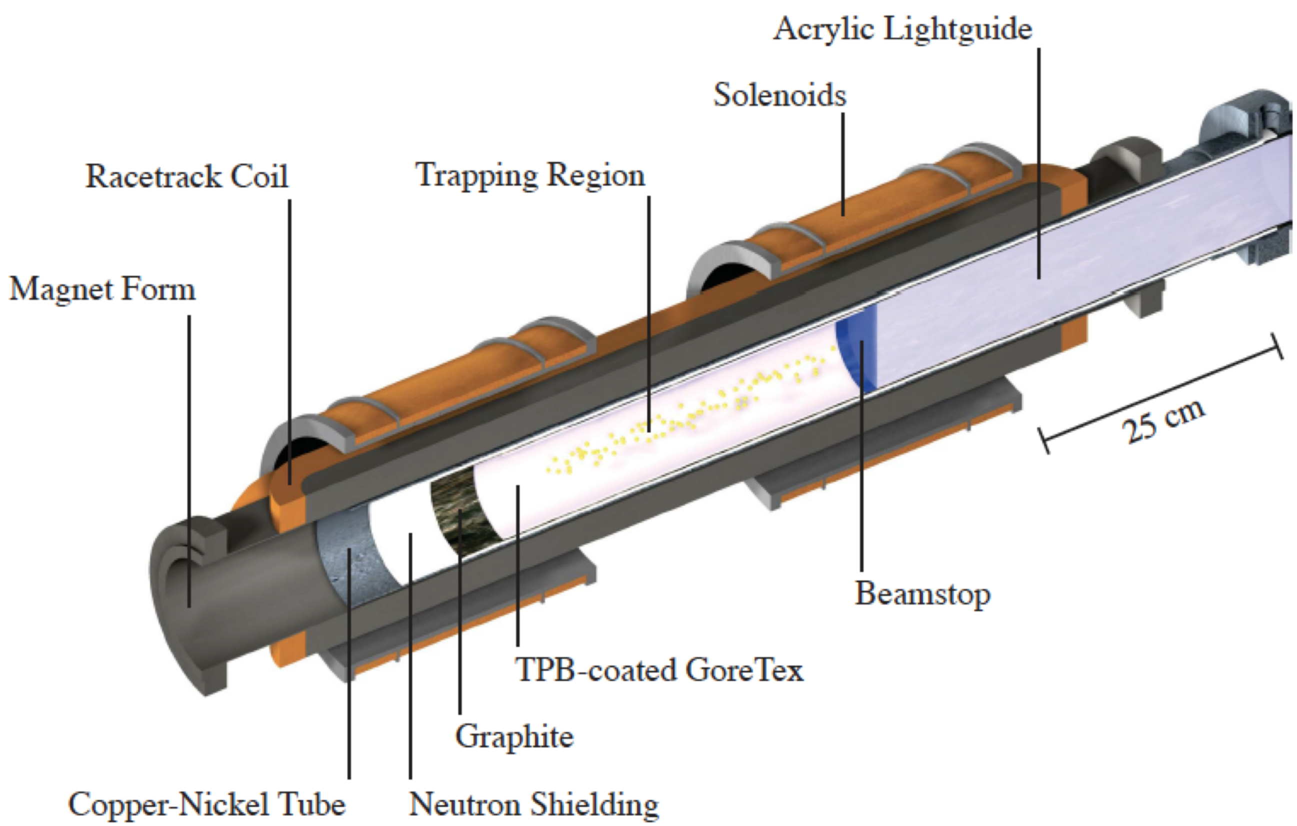
Superfluid helium has significant additional advantages

- Quantum evaporation signal gain
- Multipixel background rejection through requiring coincidence
- Multiple signal channels (rotons, phonons, scintillation, triplet excimers)

Superfluid helium-4 as a detector material

- Search for the neutron electric dipole moment: R. Golub and S.K. Lamoreaux, Phys. Rep. **237**, 1-62 (1994).

Measurement of neutron lifetime: P.R. Huffman et al, Nature **403**, 62-64 (2000).

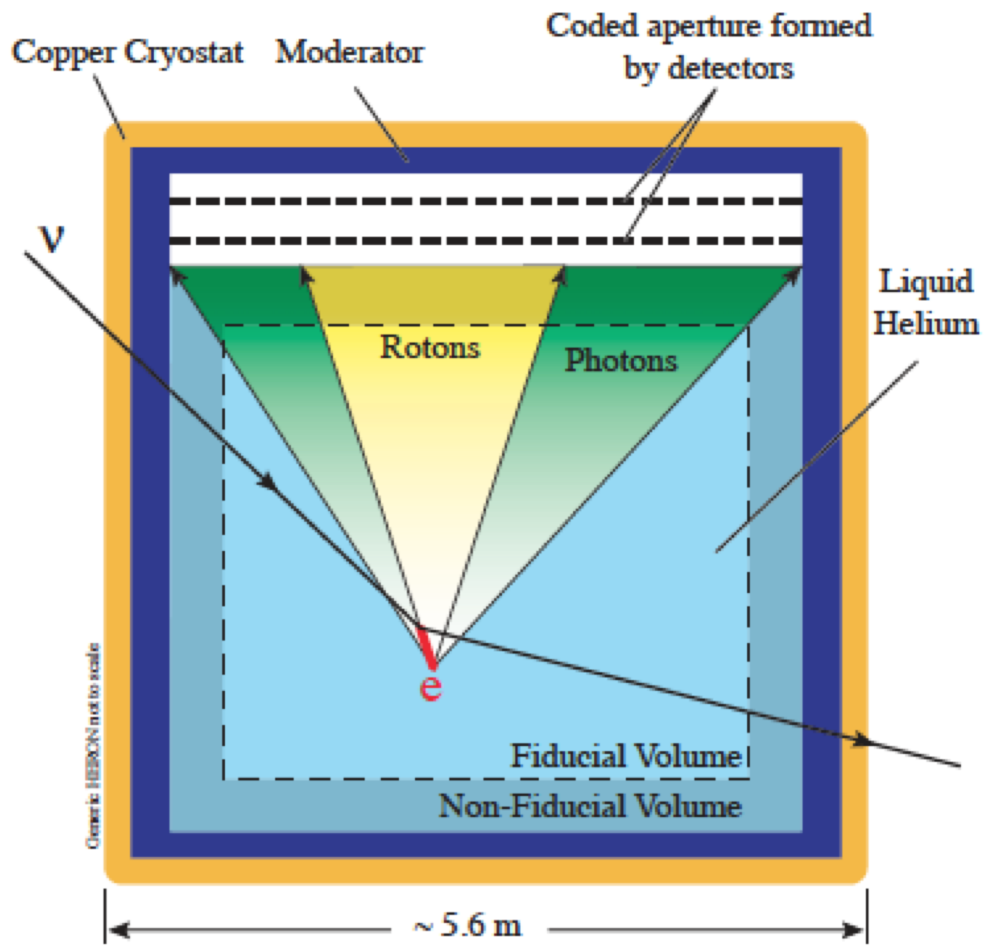


Superfluid helium-4 as a detector material

Proposed for measurement of pp solar neutrino flux using roton detection (HERON): R.E. Lanou, H.J. Maris, and G.M. Seidel, Phys. Rev. Lett. **58**, 2498 (1987).

Two signal channels, heat and light. Both measured with a bolometer array.

Also, “HERON as a dark matter detector?” in “Dark Matter, Quantum Measurement” ed Tran Thanh Van, Editions Frontieres, Gif-sur-Yvette (1996)

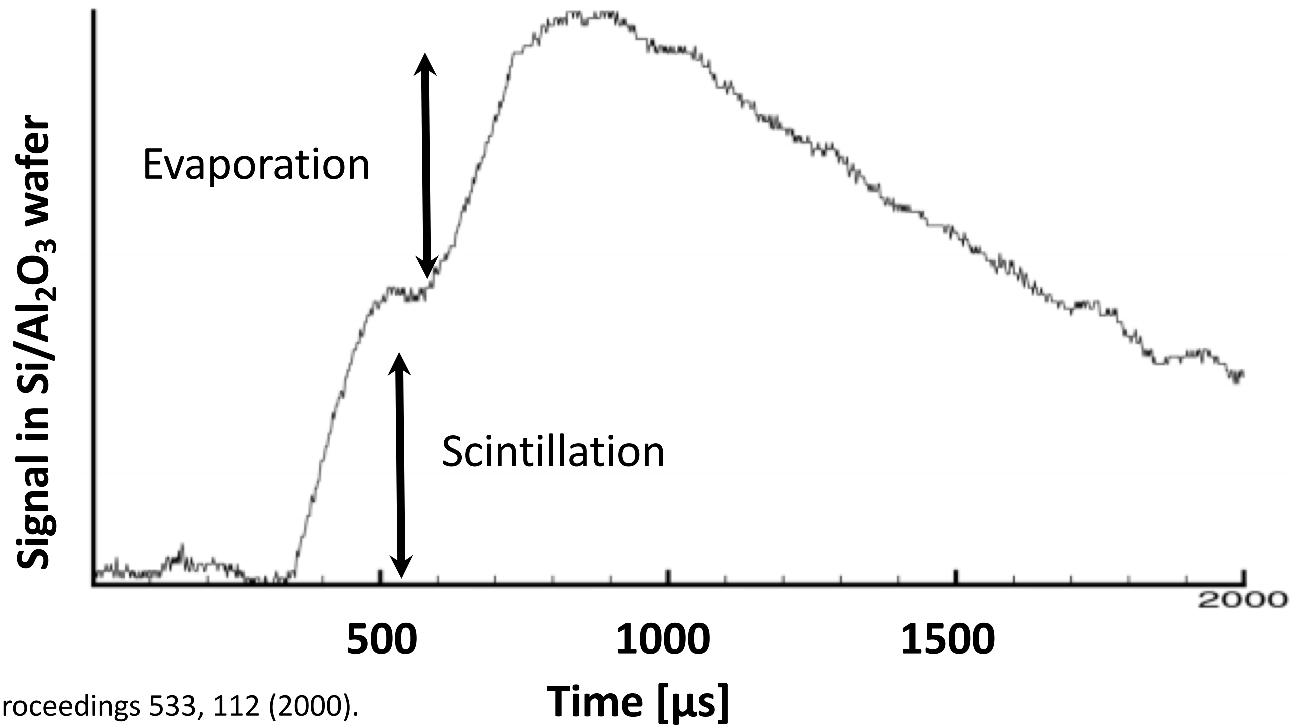


Previous work by HERON

HERON: proposed *pp* neutrino observatory

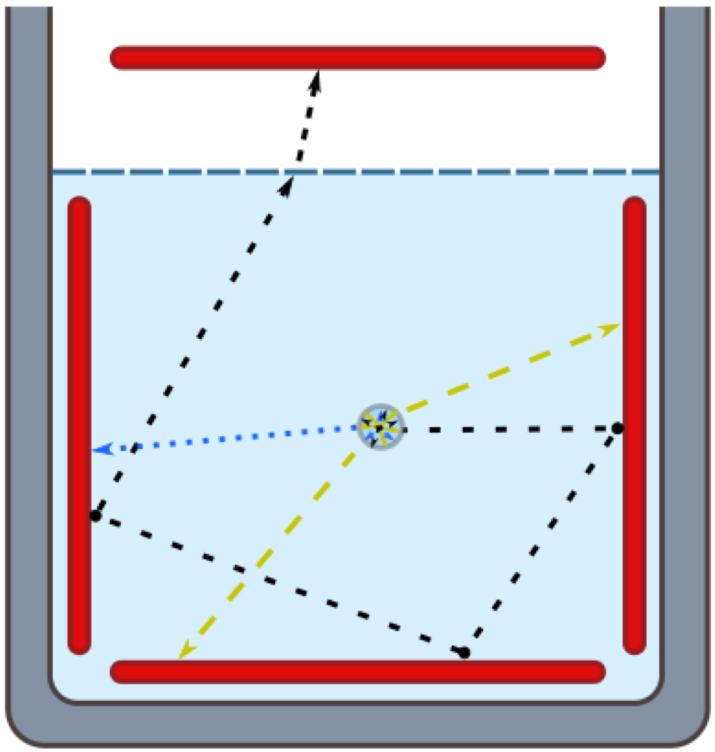
R&D at right shows simultaneous detection of photons and rotons

Achieved 300 eV threshold at 30 mK



Source: J. S. Adams et al. AIP Conference Proceedings 533, 112 (2000).
Also see: J. S. Adams et al. Physics Letters B 341 (1995) 431-434.

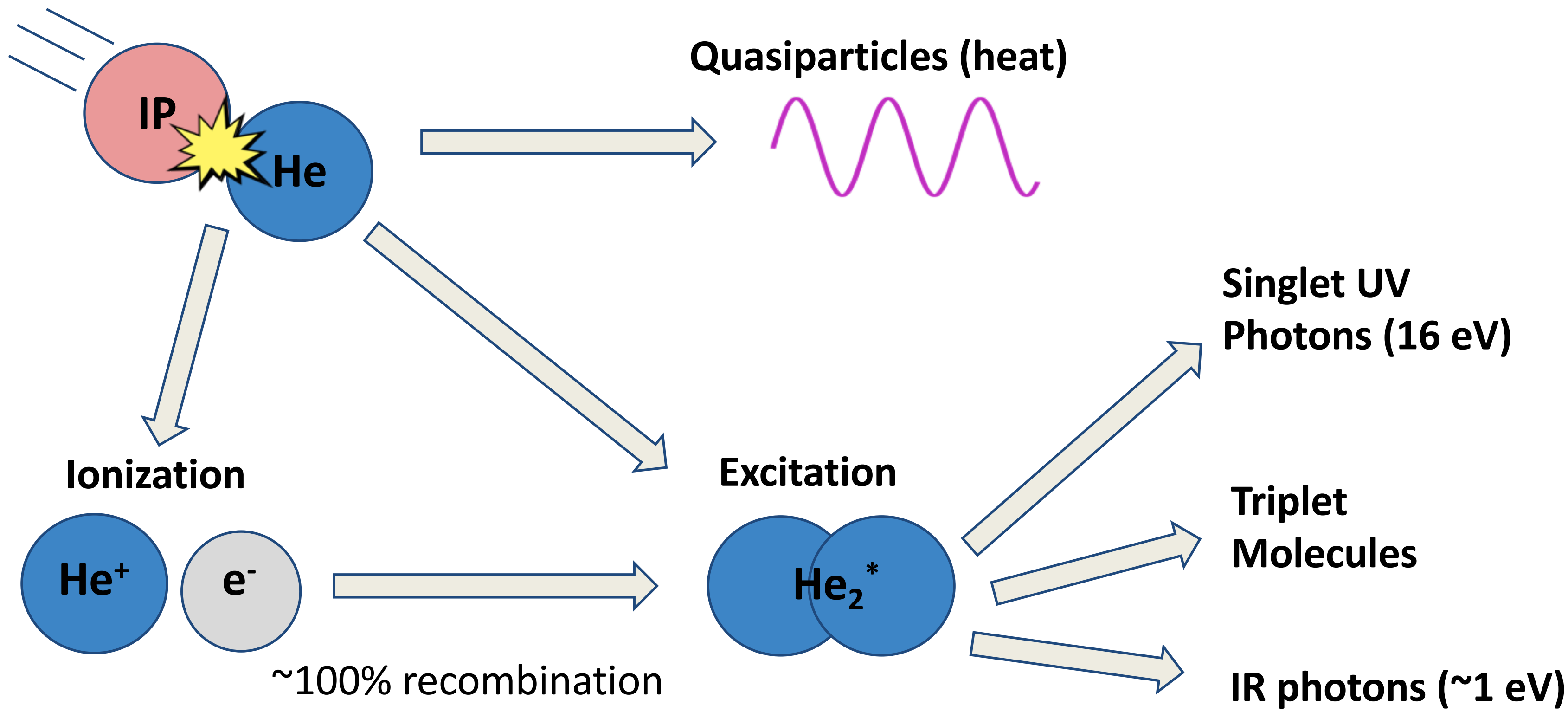
Superfluid Helium as a Dark Matter Target



Advantages of He-4

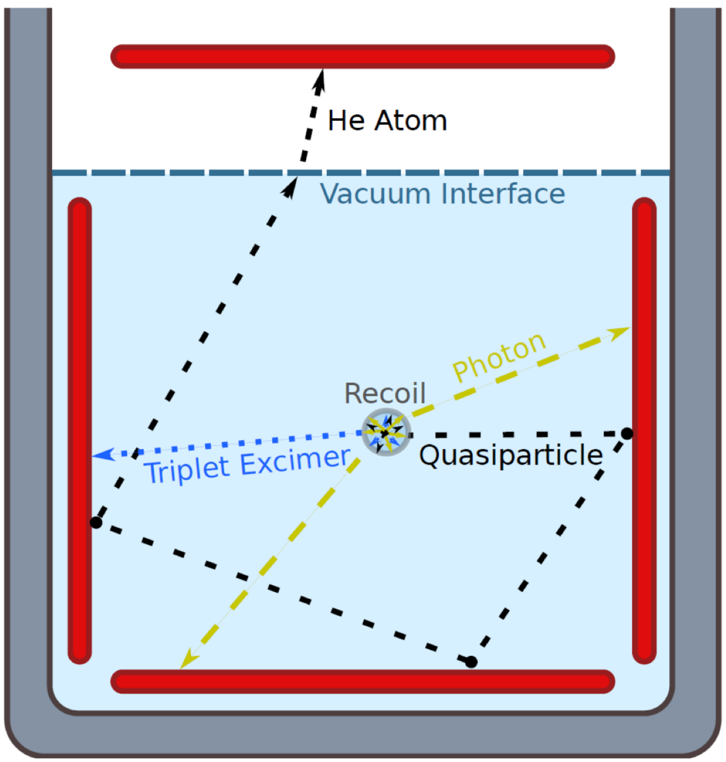
- Kinetic energy transfer from sub-GeV dark matter more efficient than on other nuclei
- Cheap
- Easy to purify; intrinsically radiopure
- Remains liquid/superfluid down to absolute zero
- Monolithic, scalable
- Calorimetry for signal readout

Recoils in Helium (generic incident particle IP)



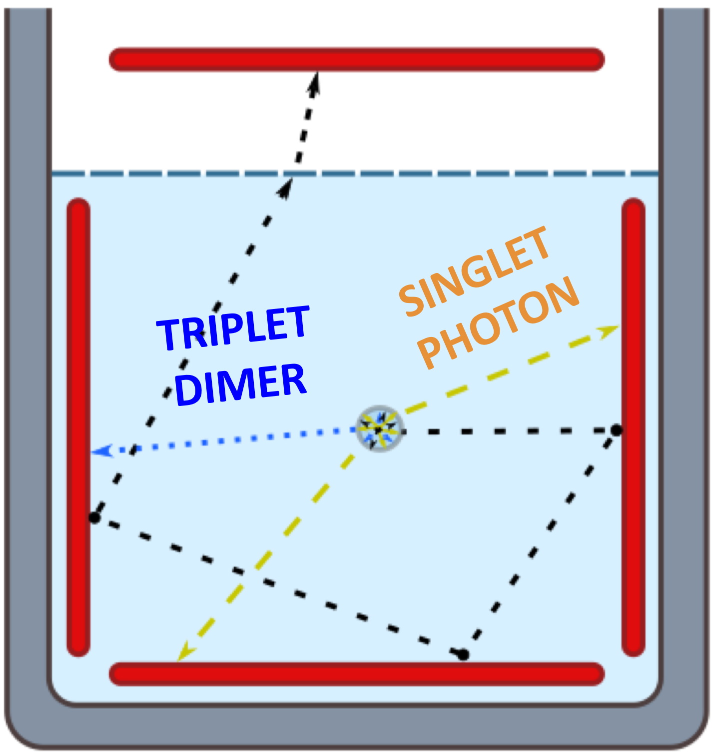
Helium **R**oton **A**pparatus for **L**ight **D**ark matter (HeRALD)

HeRALD concept and sensitivity paper
PhysRevD.100.092007



- Operated at ~30-50 mK
- Calorimeters with TES readout
  - submerged in liquid
    - Detect **UV photons**, **triplet molecules** and **IR photons**
  - suspended in vacuum
    - Detect UV photons, IR photons and **He atoms** (evaporated by quasiparticles)

Detecting Excimer Signal



Singlet decay (16 eV) 

- Lifetime of few ns
- Photons hit detector walls after **~ns**, detected directly by TES
- Weak thermal coupling between helium and calorimeter (*Kapitza resistance)*

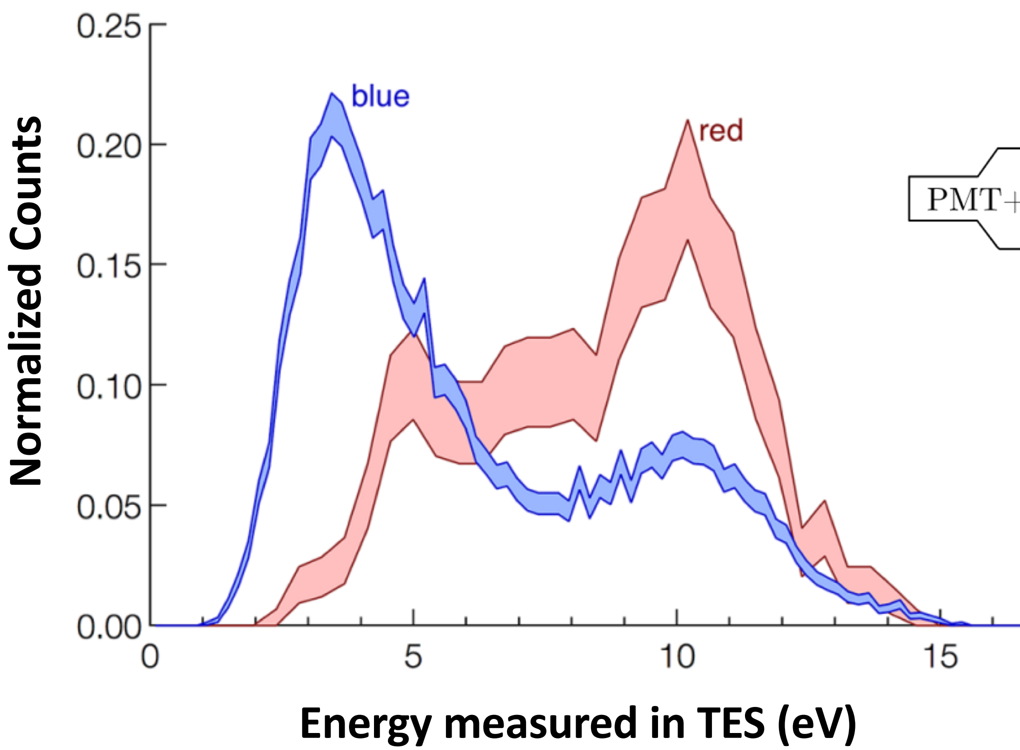
Triplet decay (16 eV)

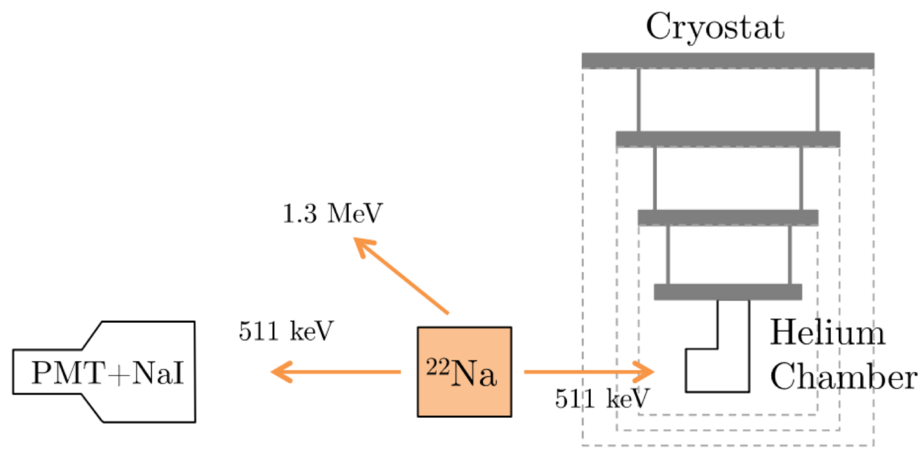
- Lifetime of 13 seconds (McKinsey et al, Phys Rev A **59**, 200 (1999).
- Helium dimer molecule travels ballistically at speed ~1-10 m/s, measured by calorimeter after **few ms**

IR (~1 eV)

Detecting Excimer Signal

Carter et al., J Low Temp Phys 186, 183 (2017)



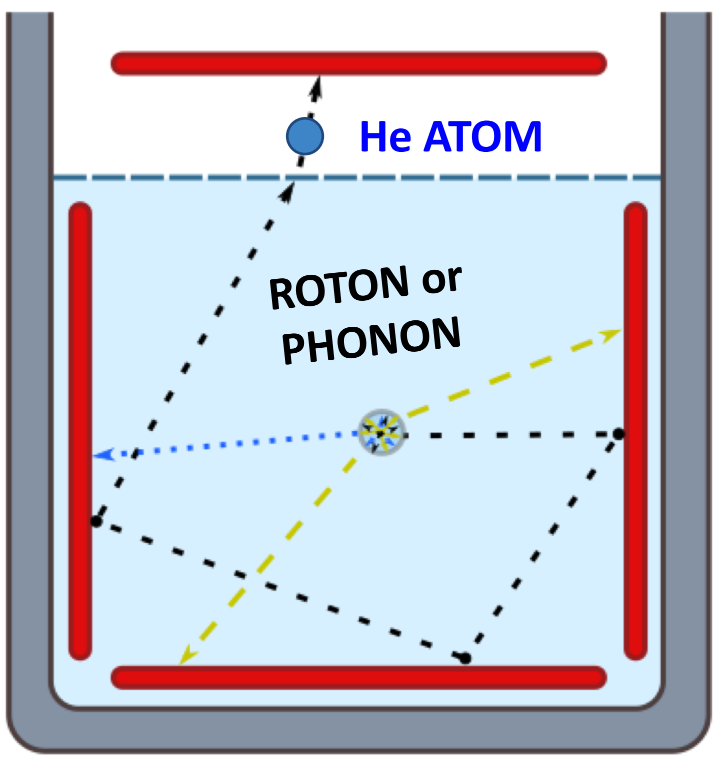


Observation of singlet/triplet excimers by *Carter et al.*

- Titanium TES in 100 mK ^{4}He bath

Singlets from TES coincident with PMT; triplets from only TES

Detecting Quasiparticle Signal



Recoils produce ~0.8 meV phonons and rotons

Propagate ballistically, bounce around the detector **(few ms)**

Transmission of quasiparticles into the wall suppressed by Kapitza resistance

Quantum evaporation of a helium atom into vacuum, followed by energy deposit on top TES

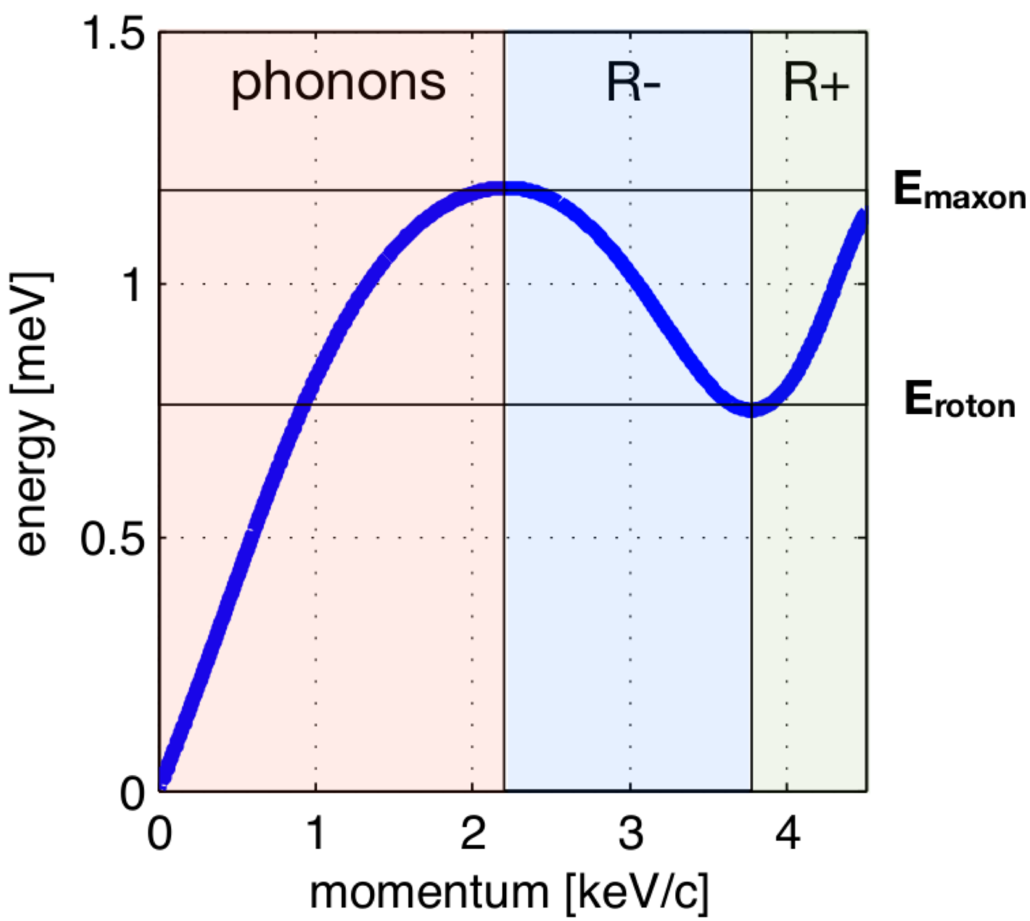
Quasiparticles in ^{4}He

Quasiparticles: collective excitations in superfluid helium

Long-lived, speeds of ~100 m/s

Classified based on momentum:
Phonons, **R-** rotons, **R+** rotons
(roton ≈ high-momentum phonon)

At interface, can transform from one type to another if energy conserved



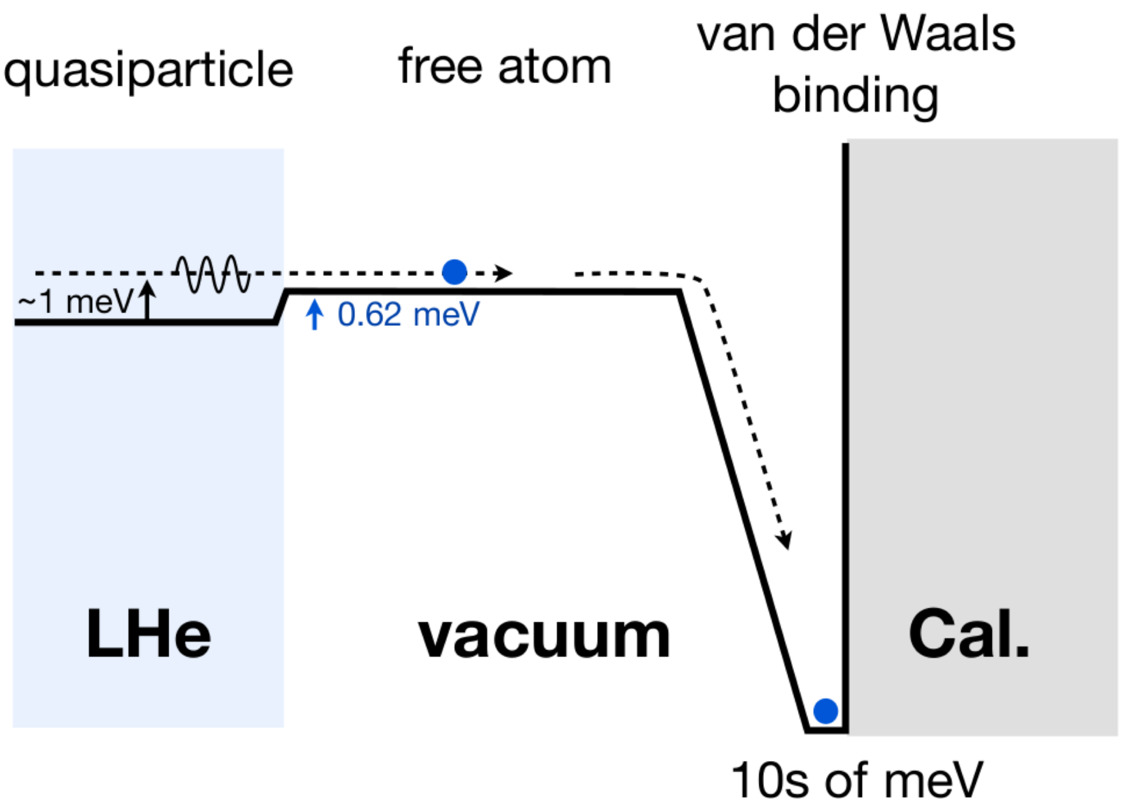
Detecting Quasiparticle Signal

Binding energy between helium and solid amplifies signal

1 meV recoil energy → up to 40 meV detectable energy

Thermal energy negligible (μeV)

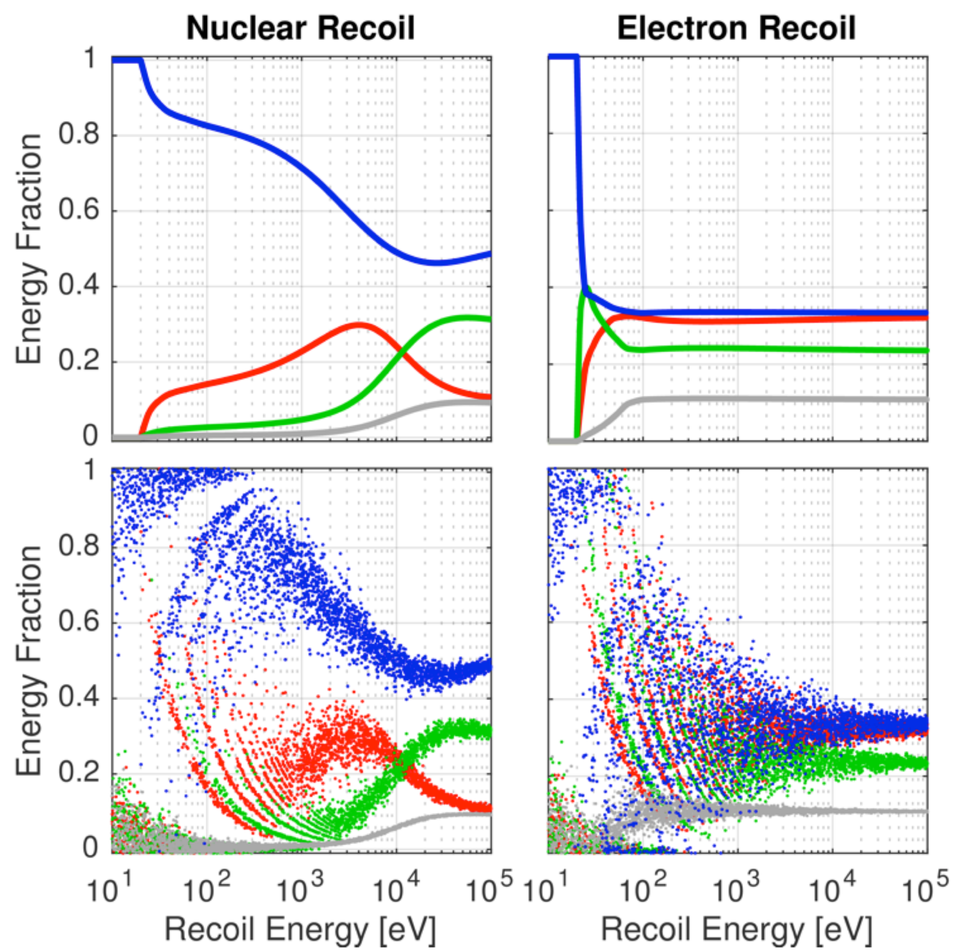
Film burner to remove helium from calorimeter



Energy Partitioning

Means

Simulated Poisson Statistics



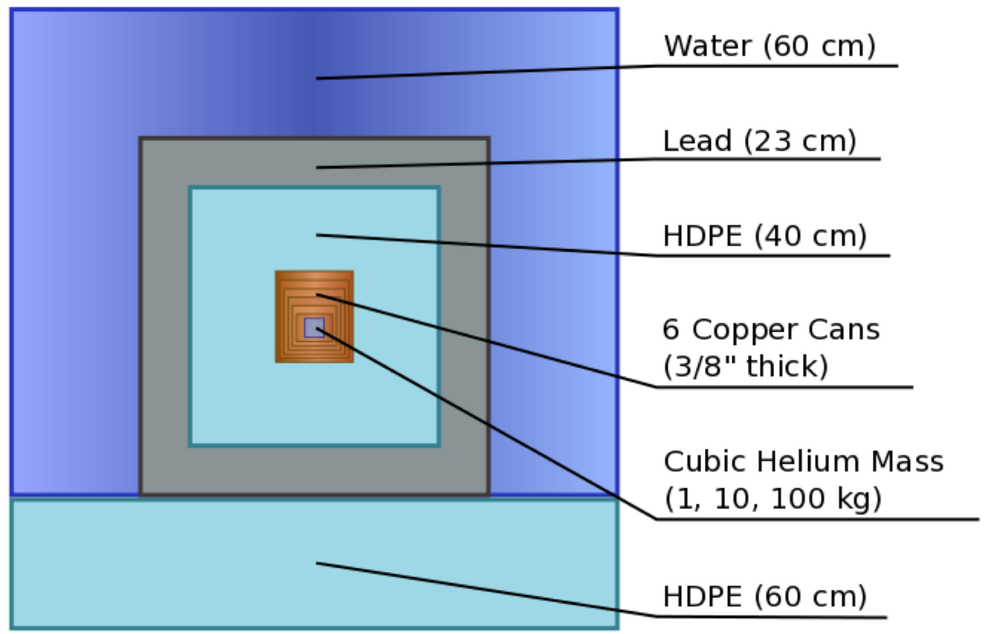
Expected Backgrounds

Backgrounds included:

- Neutrino nuclear coherent scattering
- Gamma-ray electron recoil backgrounds (similar to SuperCDMS)
- Note: Helium itself is naturally radiopure, and easily purified of contaminants
- Gamma-ray nuclear recoil backgrounds (see Robinson, PRD 95, 021301 (2017)

Arguments for low “detector” backgrounds:

- Low-mass calorimeter, easy to hold
- Target mass highly isolated from environment (superfluid: friction-free interfaces)



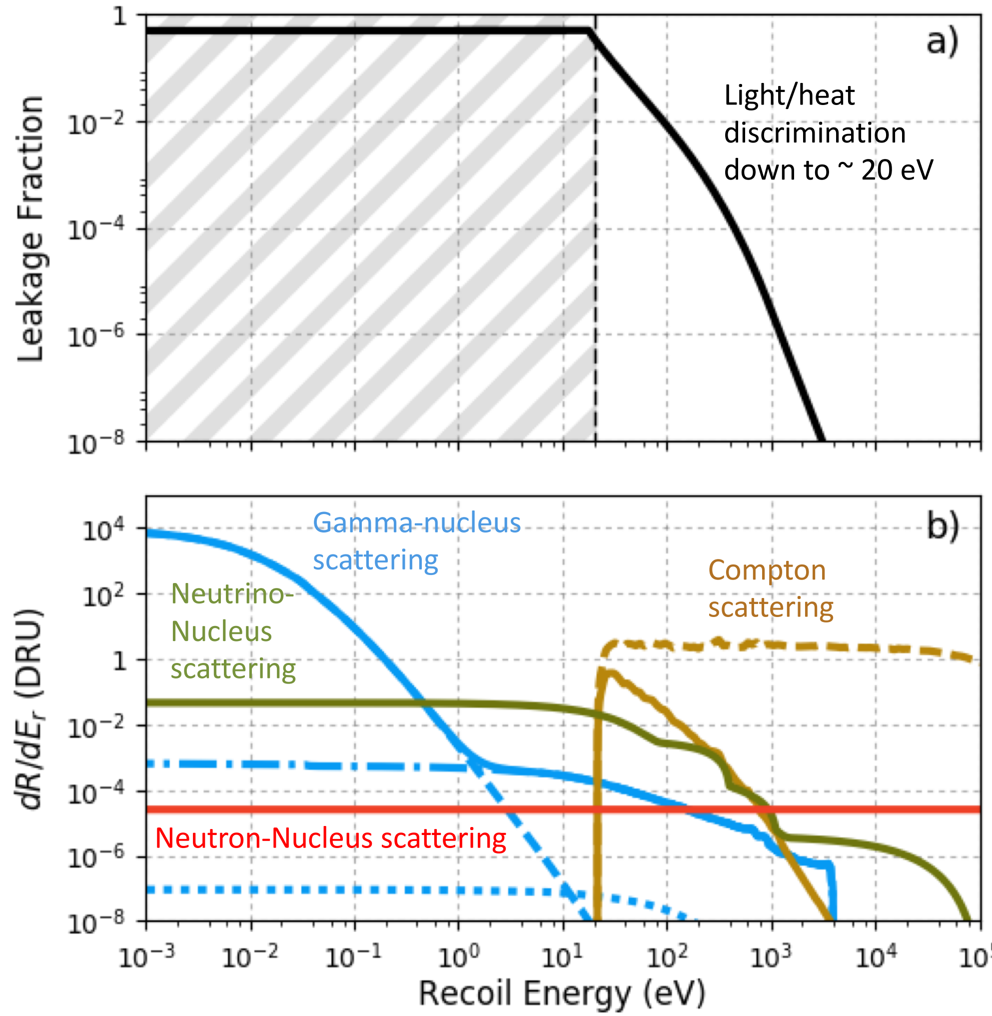
Expected Backgrounds

Backgrounds included:

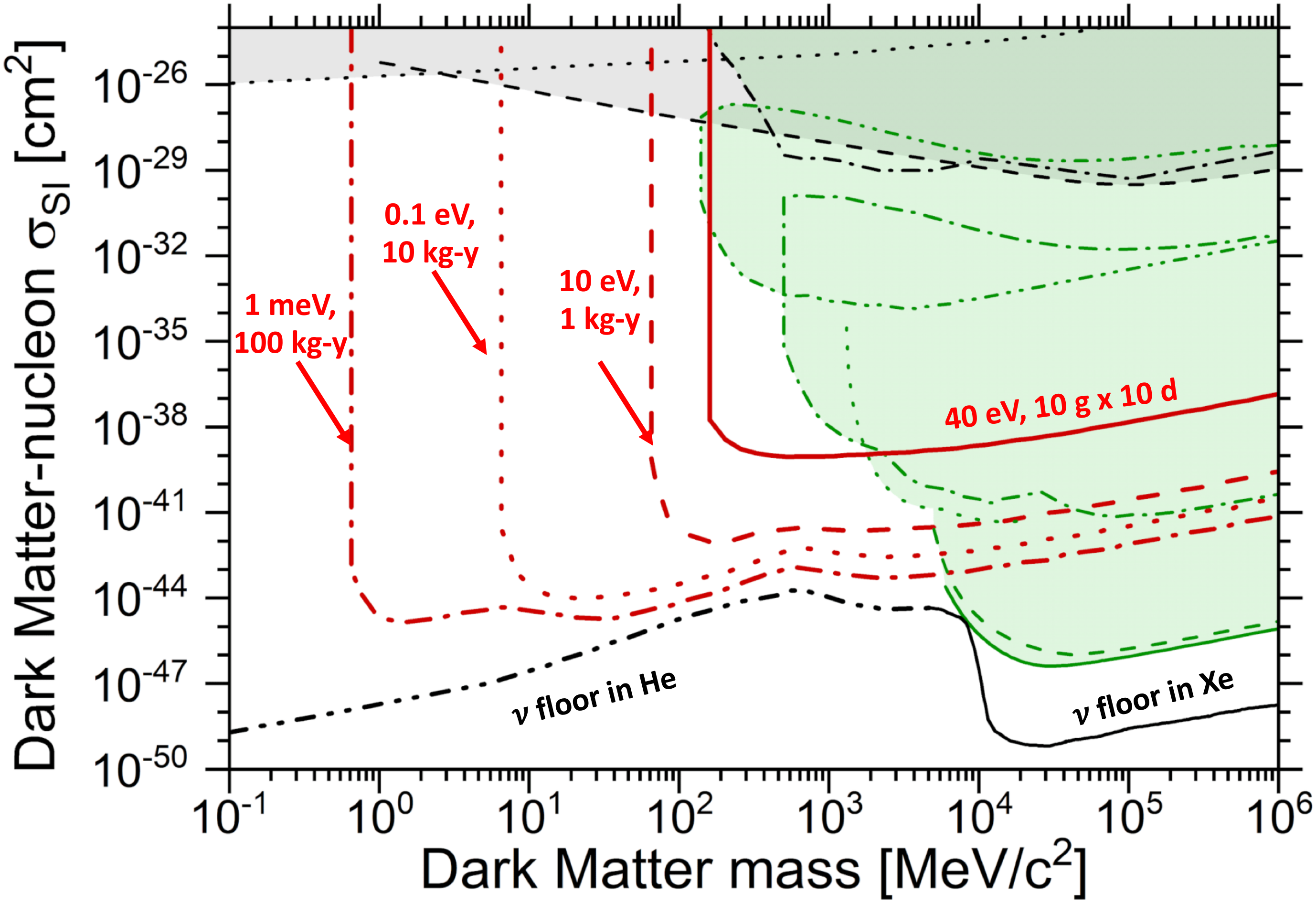
- Neutrino nuclear coherent scattering
- Gamma-ray electron recoil backgrounds (similar to SuperCDMS)
- Note: Helium itself is naturally radiopure, and easily purified of contaminants
- Gamma-ray nuclear recoil backgrounds (see Robinson, PRD 95, 021301 (2017)

Arguments for low "detector" backgrounds:

- Low-mass calorimeter, easy to hold
- Target mass highly isolated from environment (superfluid: friction-free interfaces)
- Can require coincidence between calorimeters



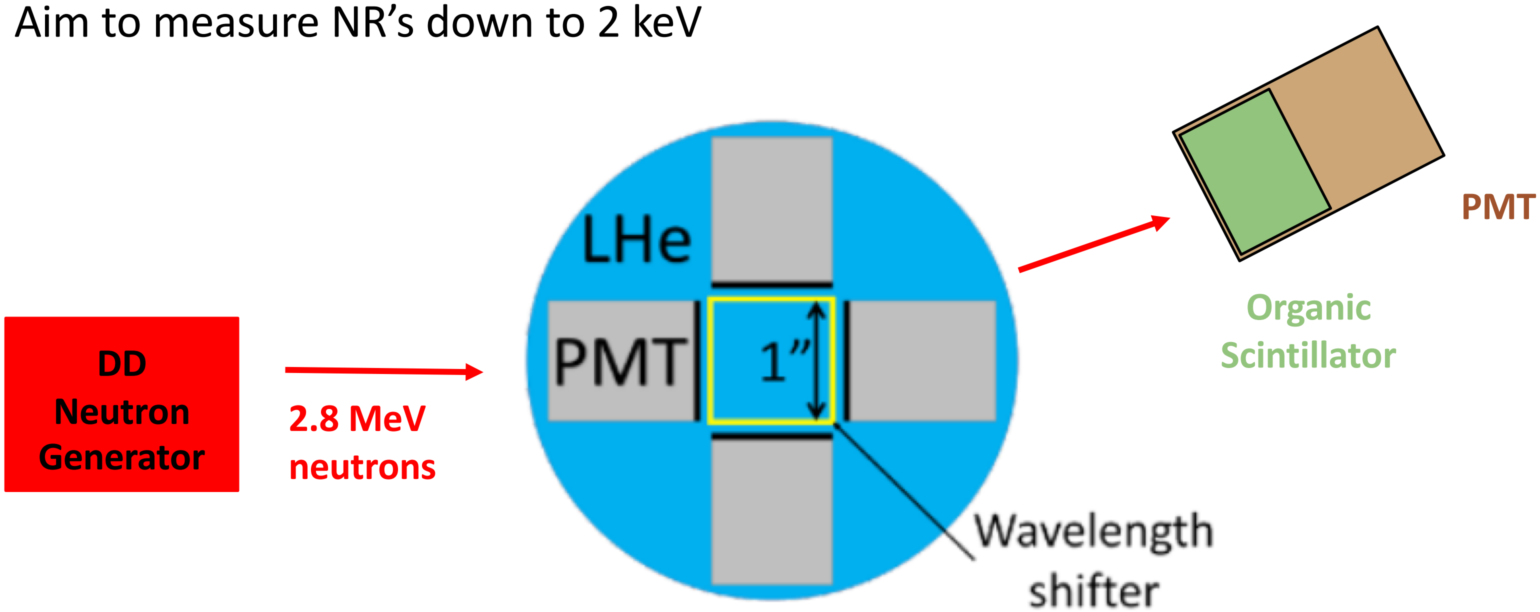
Projected Sensitivity



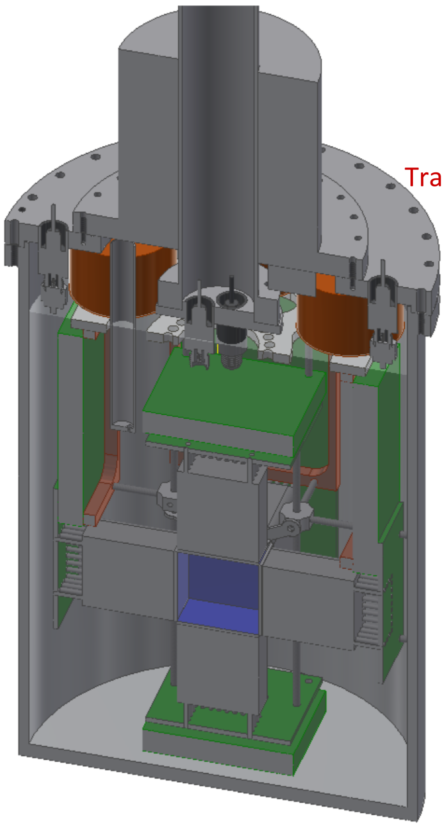
Measurement of Nuclear Recoil Light Yield in Superfluid ^{4}He

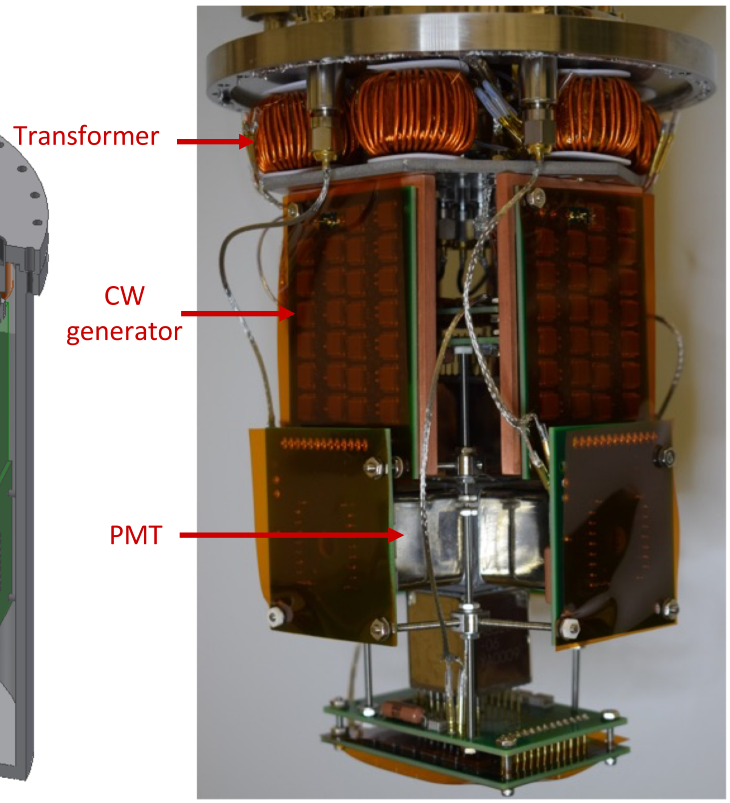
(arXiv:2108.02176, accepted to Phys. Rev. D)

- Will be first measurement of the ^{4}He nuclear recoil light yield!
- Aim to measure NR's down to 2 keV



Light yield measurement of superfluid He-4



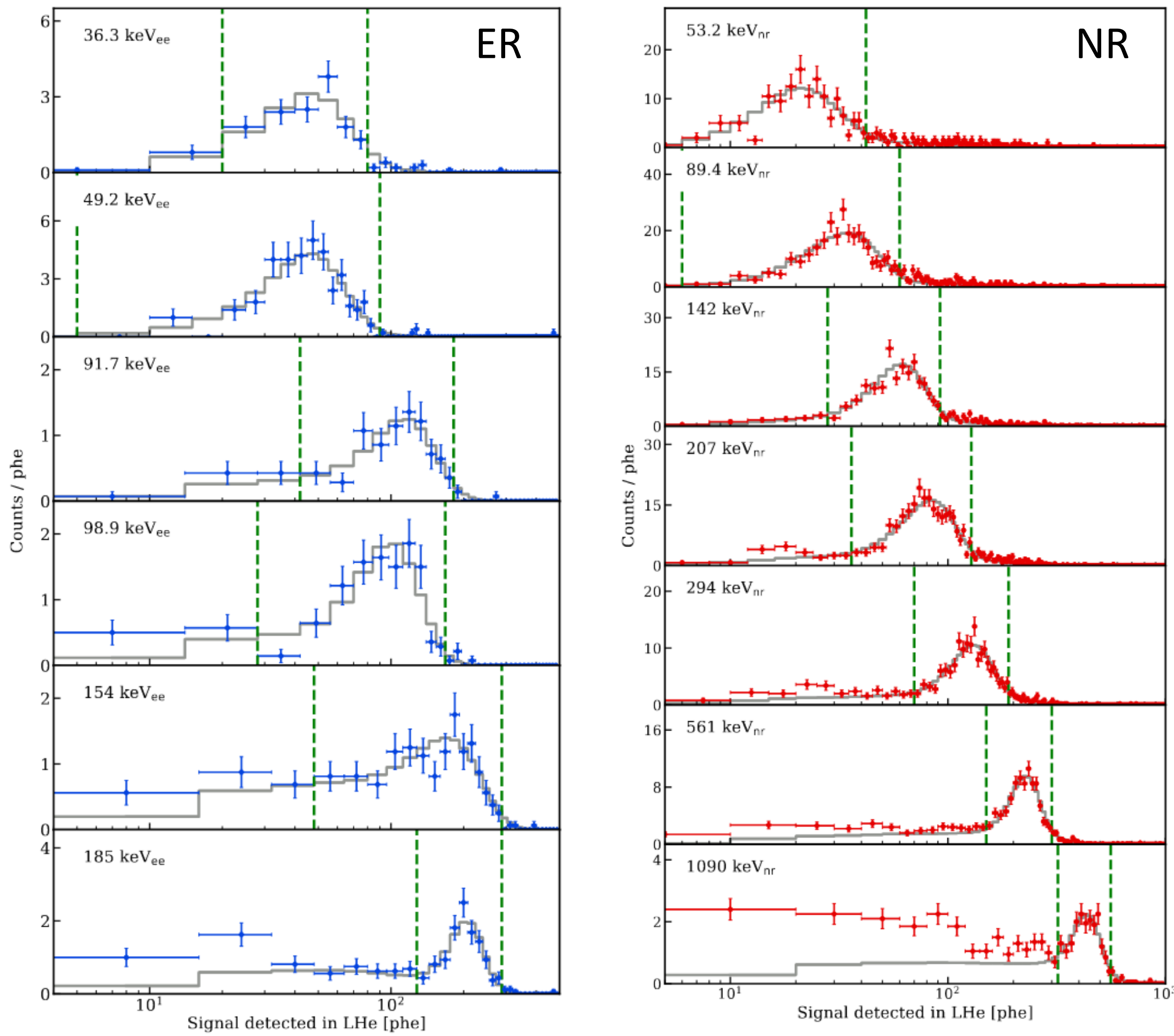


- ➢ Data taken at 1.75K
- ➢ Cockcroft–Walton (CW) generator
  - No voltage divider for PMT
  - No resistive heat
  - Suitable for down to ~mK
- ➢ High light yield
  - ~1.1 PE/keV_{ee}

Light yield measurement of superfluid He-4

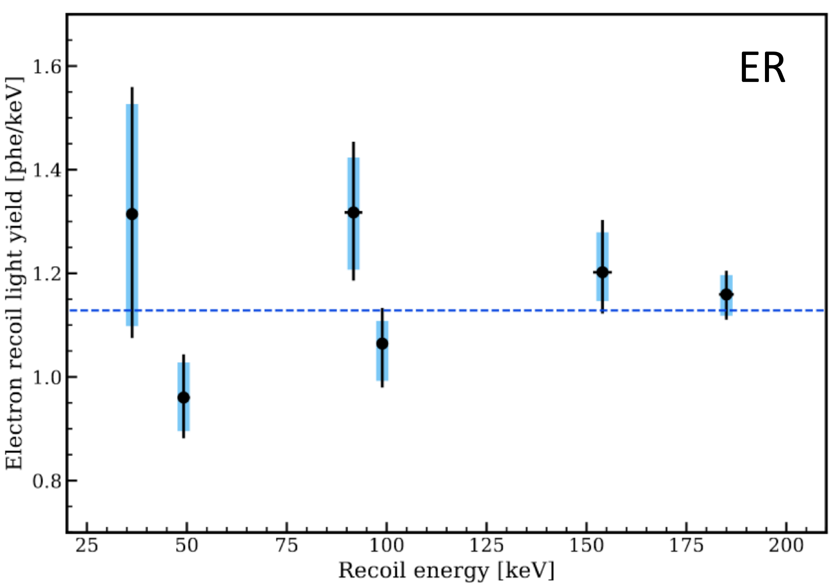
- Data selection cuts
  - Time of flight
  - Pulse shape discrimination (LS detector)
  - Deposited Energy (NaI detector)

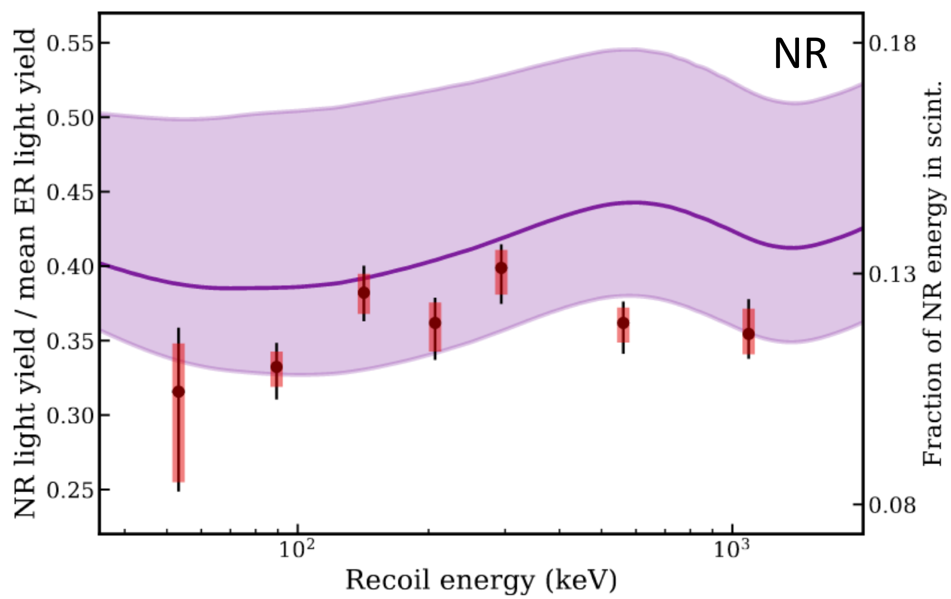
- Fit data with MC sims



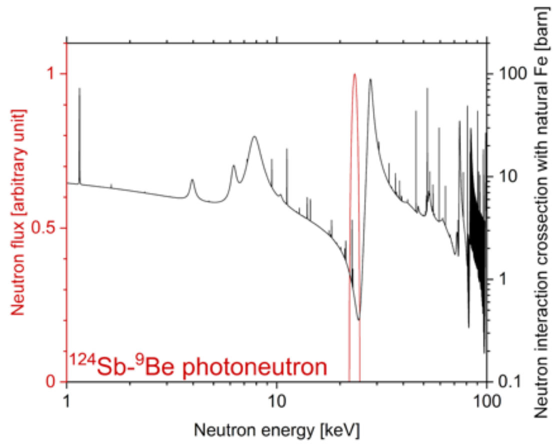
Light yield measurement of superfluid He-4
(arXiv:2108.02176, accepted to Phys. Rev. D

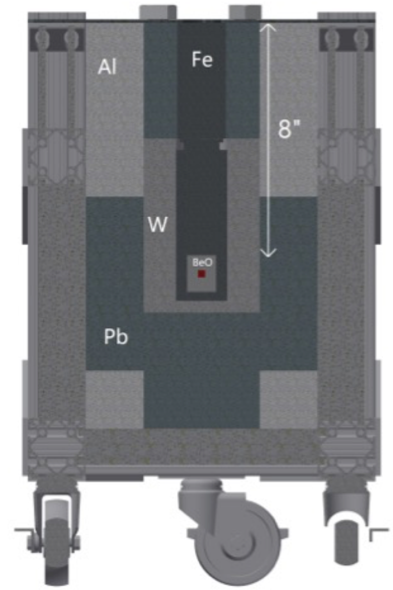
- First measurement of LHe scintillation in tens of keV.
- ER yield relatively flat (as expected)
- NR yield agrees with pre-defined model
- Working on lower energy (keV) measurements
  - ER: Compton scattering from Co-57 source
  - NR: SbBe with iron filter

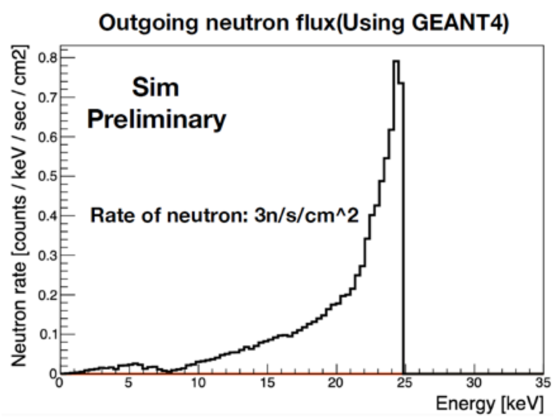




SbBe source with iron filter







- 24 keV photo-neutron from ^{124}Sb-^{9}Be
- Iron cross-section dip at 24 keV neutrons
- 1-GBq Sb produced in nuclear reactor
- Currently being characterized

Readout of Solids Via Helium Evaporation

Generalized evaporation-based detector

Similar philosophy:

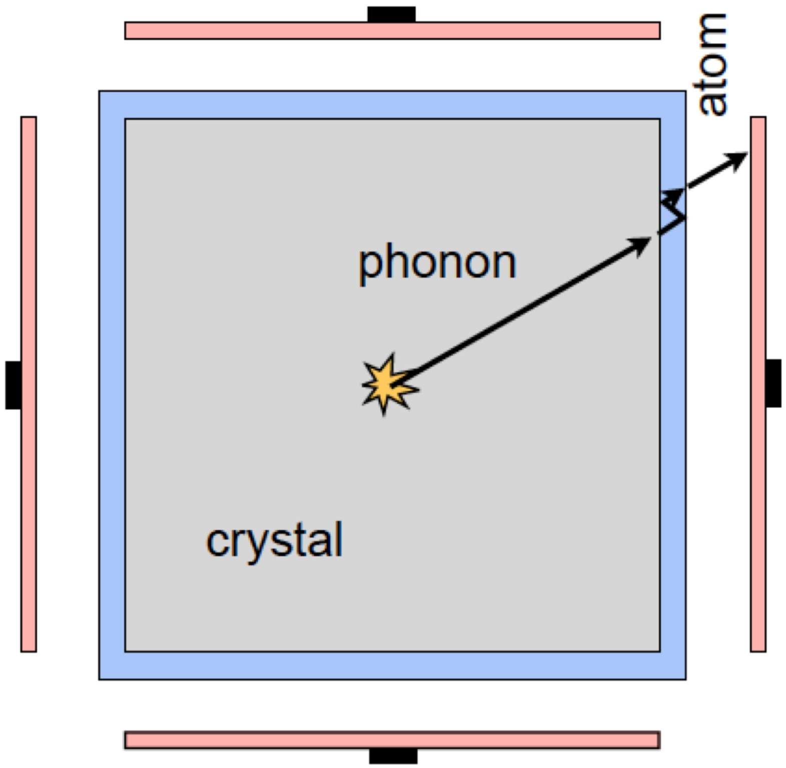
- Separate the target and the calorimetry
- Smaller absorber seen by TES array
- Use helium atoms to jump the gap

Crystals with long phonon mean free path
(pick your favorite crystal, sensitive to your favorite dark matter model)

Swappable targets, natural 4pi coverage.

Coat surface with several layers of helium (unsaturated film) at third layer binding energy is within few percent of bulk value

<u>**Or**</u> material having low binding energy for helium,
helium on cesium: ^{4}He – 3.8 K; ^{3}He – 1.9 K



Detector Performance Specifications

$$\sigma_E \sim \frac{\sqrt{4k_bT_c^2G(\tau_{collect}+\tau_{sensor})}}{\epsilon_{collect}\epsilon_{sensor}}$$

Too close to bath temperature

Sensor Characteristics	Required	Goal	Stretch Goal
TES T_c	40 mK	20 mK	15 mK ~~10 mK~~
Total TES Volume	$[100\times400]\mu m\times40nm$	$[33\times133]\mu m\times40nm$	$[33\times133]\mu m\times40nm$
Bare TES noise σ_{TES}	40 meV	4 meV	2 meV
W/Al interface transmission probability $\epsilon_{W/Al}$	10^{-4}	10^{-4}	10^{-3}

Target Excitation Efficiencies	Required	Goal	Stretch Goal
Phonon collection efficiency $\epsilon_{collect}$	Si/Ge >99% Polar	>99.9%	>99.9%
GaAs scintillation efficiency ϵ_γ	25%	60%	60%
LHe quantum evaporation: efficiency $\epsilon_{collectHe}$	4%	10%	10%
LHe quantum evaporation: adsorption gain g_{He}	8×	16×	16×

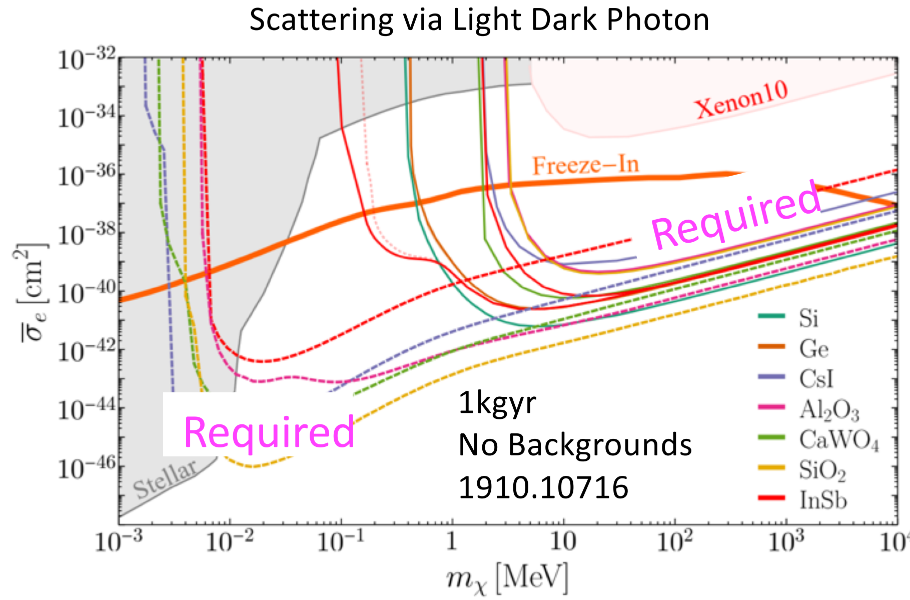
Resulting 5σ Recoil Energy Thresholds

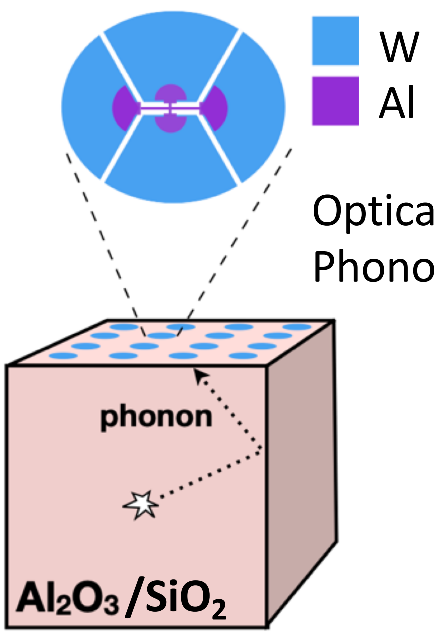
Scaled from Si demonstrator (3.9 eV σ_{phonon}) by phonon velocity, mean free path, and sensor area.

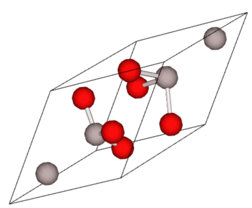
	Required	Goal	Stretch Goal
1 cm^3 Al_2O_3/SiO_2 (phonon only)	**3.5 eV**	**350 meV**	**20 meV**
1 cm^3 GaAs (phonons GaAs + photons on Ge)	**2.8 eV** ($\sim 2-\gamma$)	**900 meV** ($1-\gamma$)	**35 meV** (optical phonon)
$0.1\times1\times1\,cm^2$ Ge-based photon sensor	2.3 eV	300 meV	12 meV
$0.1\times1\times1\,cm^3$ GaAs phonon sensor	4.6 eV	600 meV	24 meV
64 cm^3 LHe (evaporation via Si-based sensor)	**21 eV**	**570 meV**	**24 meV**
includes scaling by $\epsilon_{collectHe}\times g_{He}$			
$0.1\times4\times4$ cm Si-based He evaporation sensor	6.7 eV	900 meV	38 meV

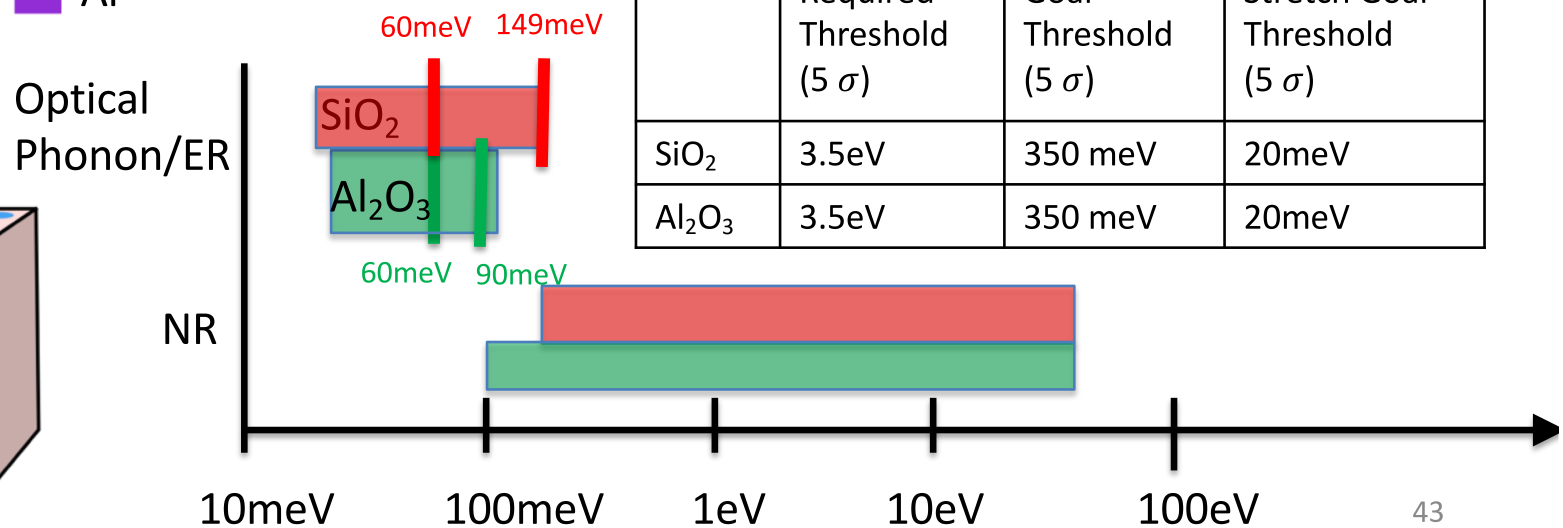
SPICE: **S**ub-ev **P**olar **I**nteractions **C**ryogenic **E**xperiment

- In ionic crystals, optical phonons are oscillating electric dipoles!
- Very large coupling to photons (black in the IR)… Very large coupling to the dark photons
- 1712.06598
- 10-1000gyr exposure





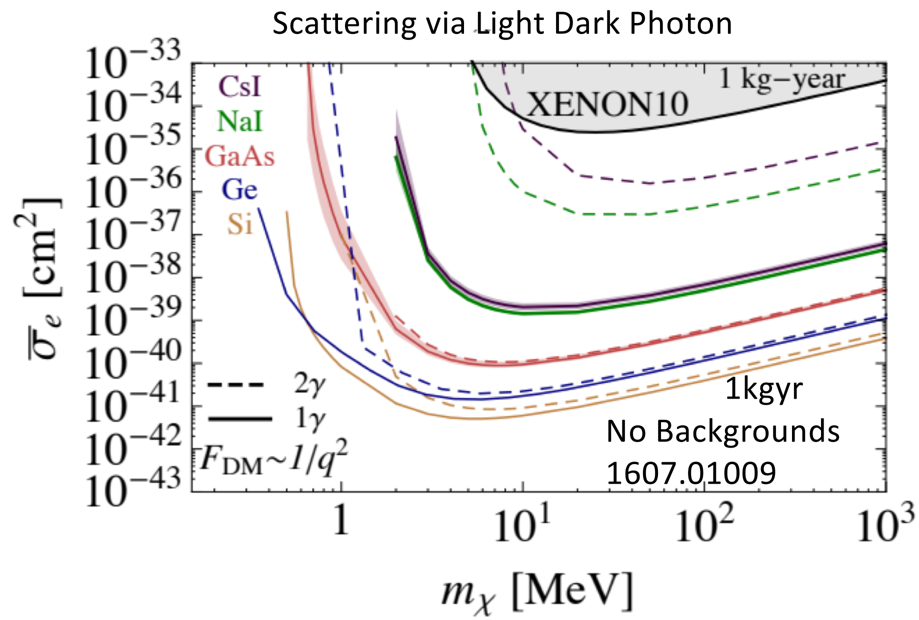




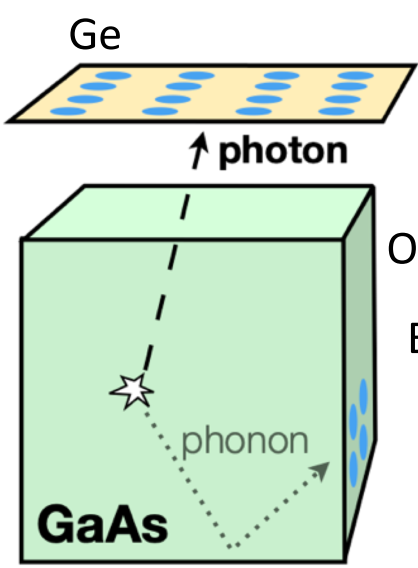
	Required Threshold (5 σ)	Goal Threshold (5 σ)	Stretch Goal Threshold (5 σ)
SiO_2	3.5eV	350 meV	20meV
Al_2O_3	3.5eV	350 meV	20meV

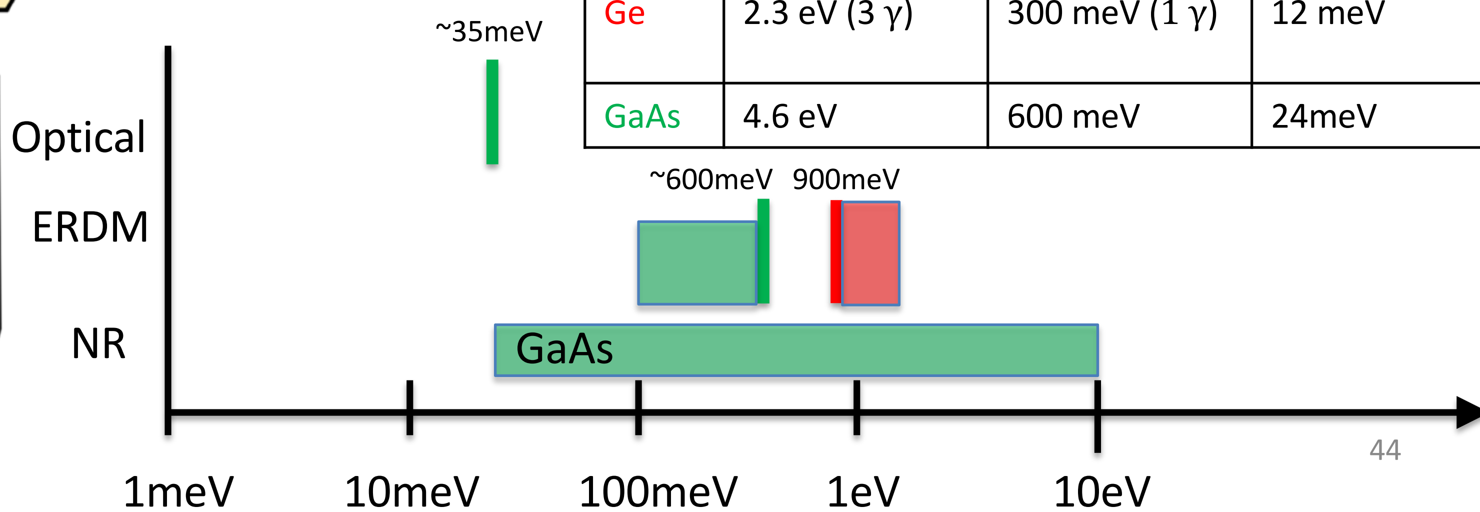
SPICE: GaAs ERDM

- "CRESST for ERDM"
- GaAs has very high scintillation yield (1802.09171)
- 10-1000gyr exposure
- Notice GaAs has worse background free reach than both Si and Ge! It's actually even worse than this because this doesn't include quantum efficiency suppression
- However, GaAs has background control:
  - 2 photon coincidence in 2 separate detectors
  - No charge leakage



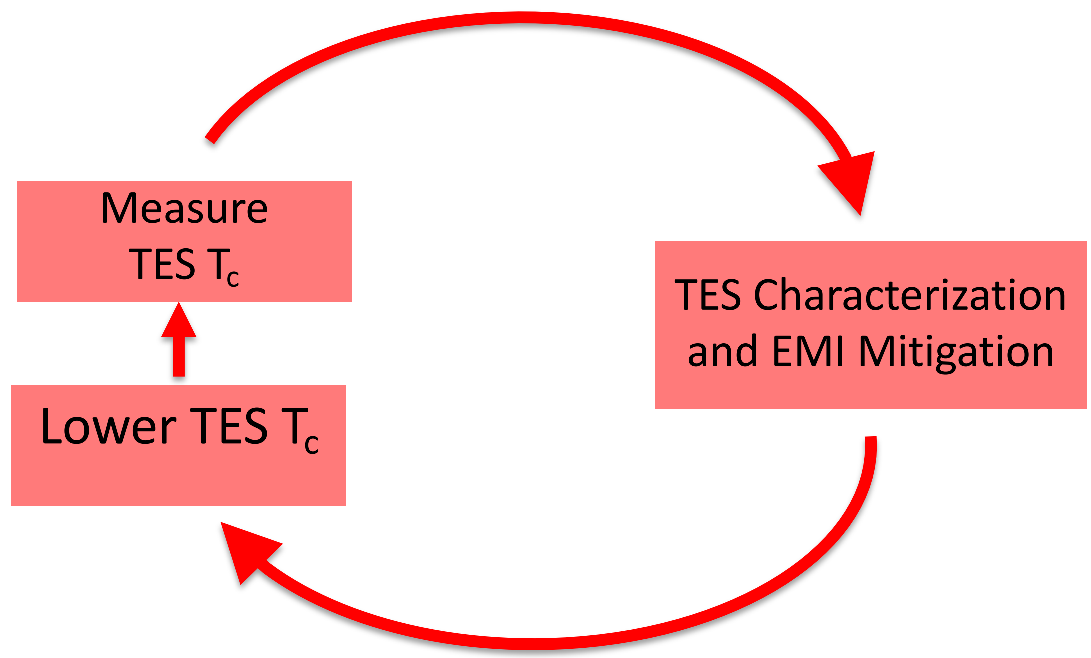
	Required (5 σ)	Goal (5 σ)	Stretch Goal (5 σ)
Ge	2.3 eV (3 γ)	300 meV (1 γ)	12 meV
GaAs	4.6 eV	600 meV	24meV





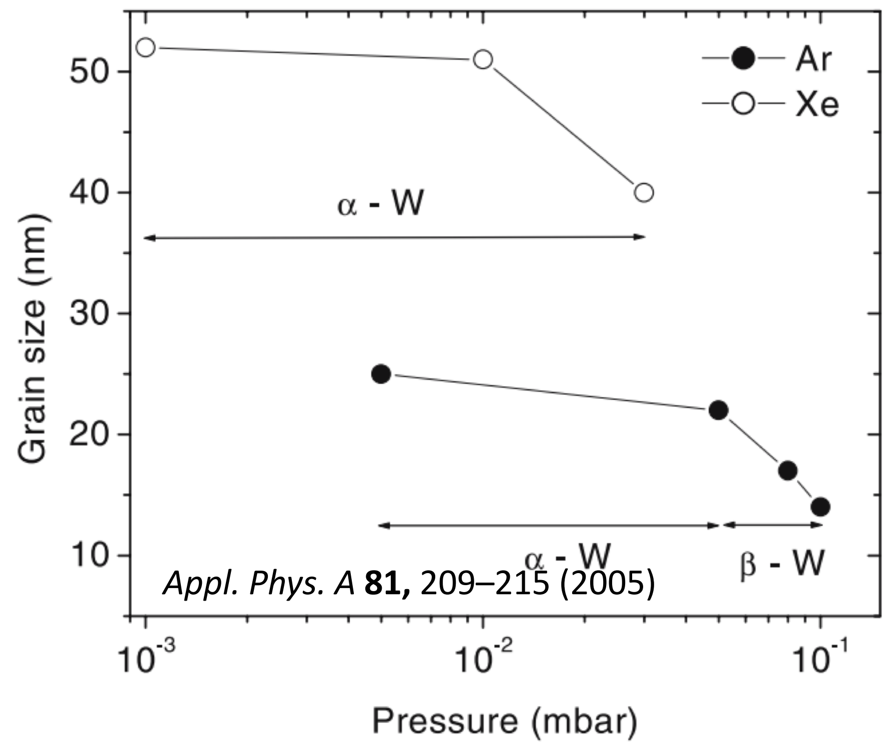
Major R&D goal: Develop ultra sensitive TES

Work ongoing on fabrication (TAMU and ANL) and testing (UC Berkeley, LBNL, UMass)



Low Tc W TES Fabrication (TAMU)

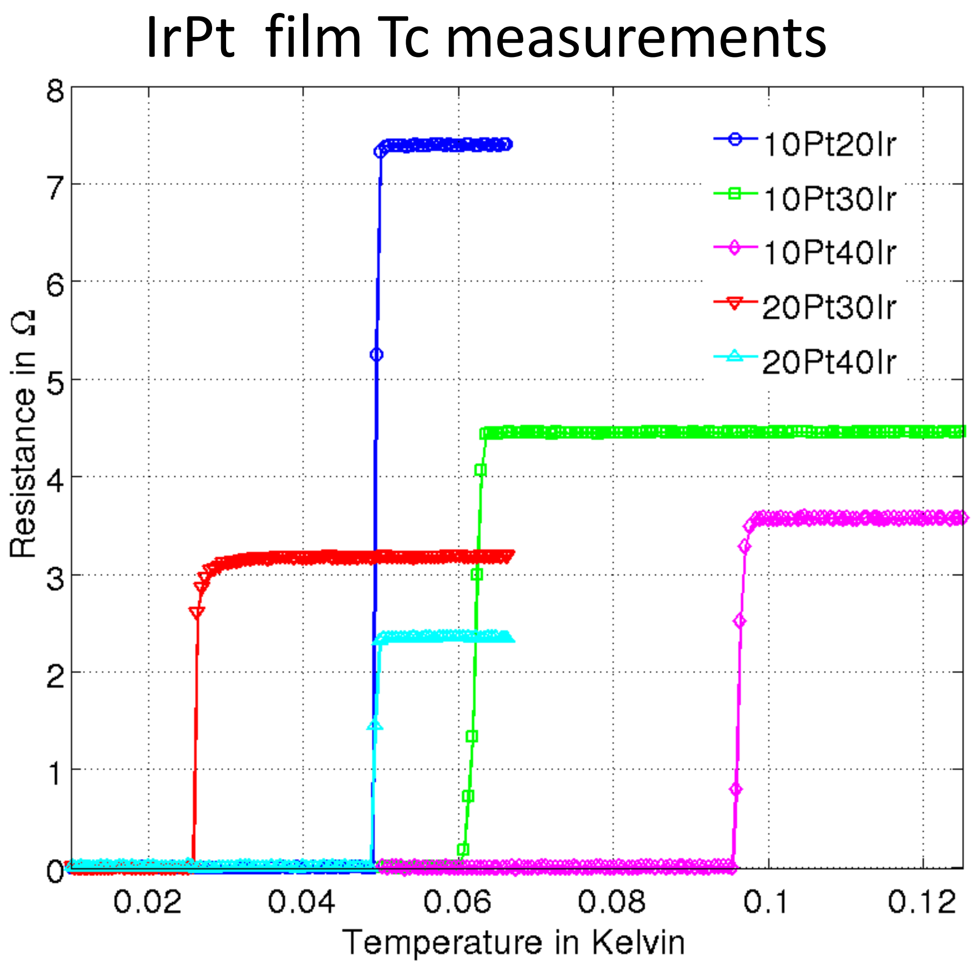
- What sets W T_c? 2 crystal configurations
  - Alpha: T_c=15mK
  - Beta: T_c~ 3K
- Goal: produce a stress free, alpha phase W film
- Bouziane et al: Xe plasma produces better alpha films



Appl. Phys. A **81,** 209–215 (2005)

- Year 1 TESSERACT Progress: Produced W film with T_c= 19 mK
  New, have reached below 20 mK goal Tc

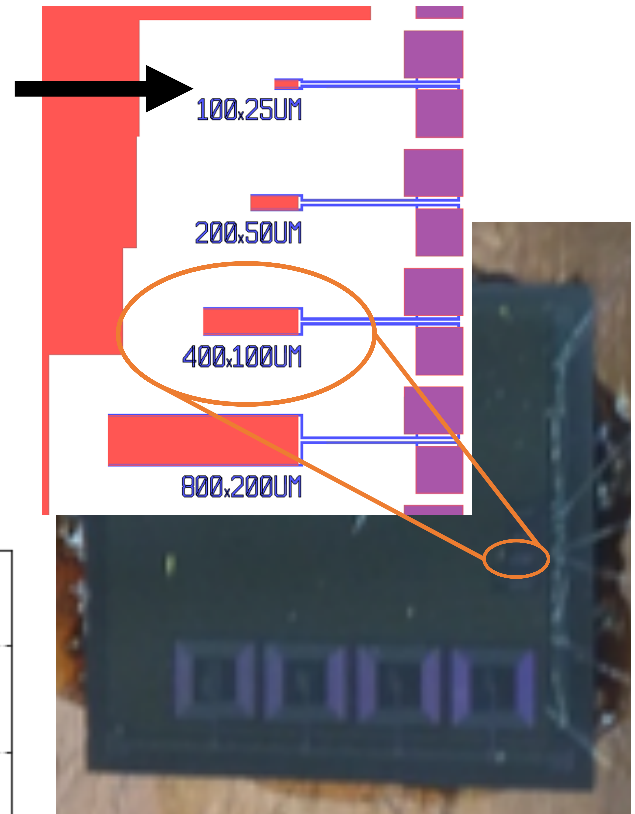
Low Tc IrPt Films (Argonne)

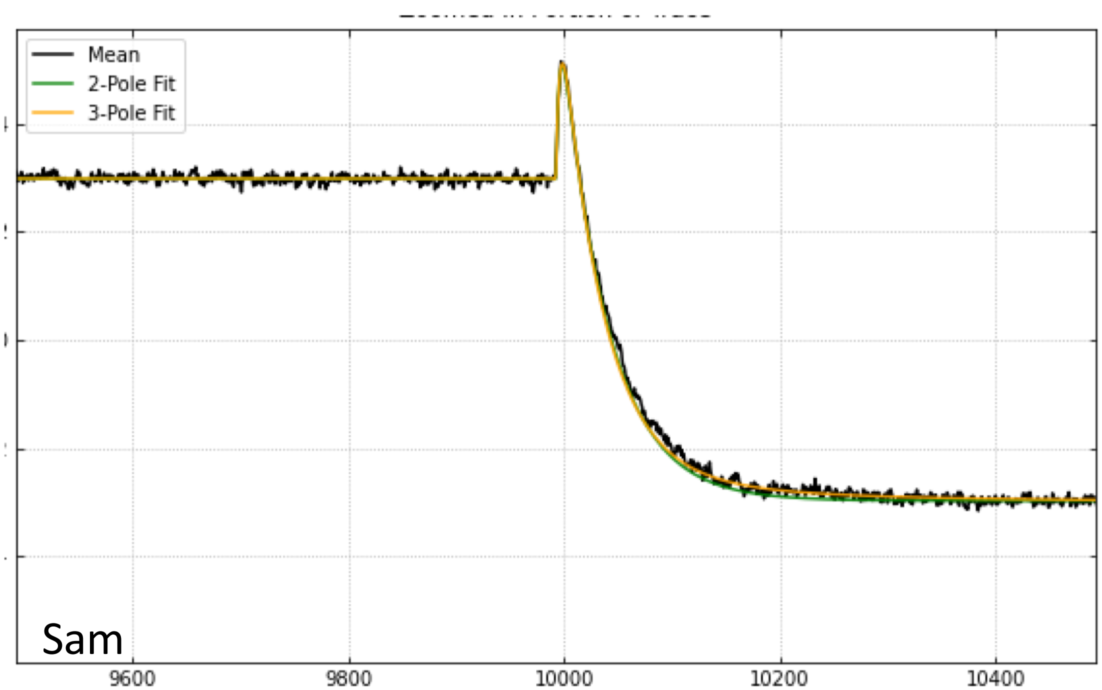


- Argonne has produced 25mK IrPt films **... nearing goal**
- Next steps:
  - map out space between 15-25mK
  - Test reproducibility
  - Measure TES characteristics

TES Characterization

- 25umx100umx40nm W TES at 62mK
- Smallest device on chip … lower Bias Power (P_0) = 22.5fW
- x2 better than required performance (x20 worse than goal)

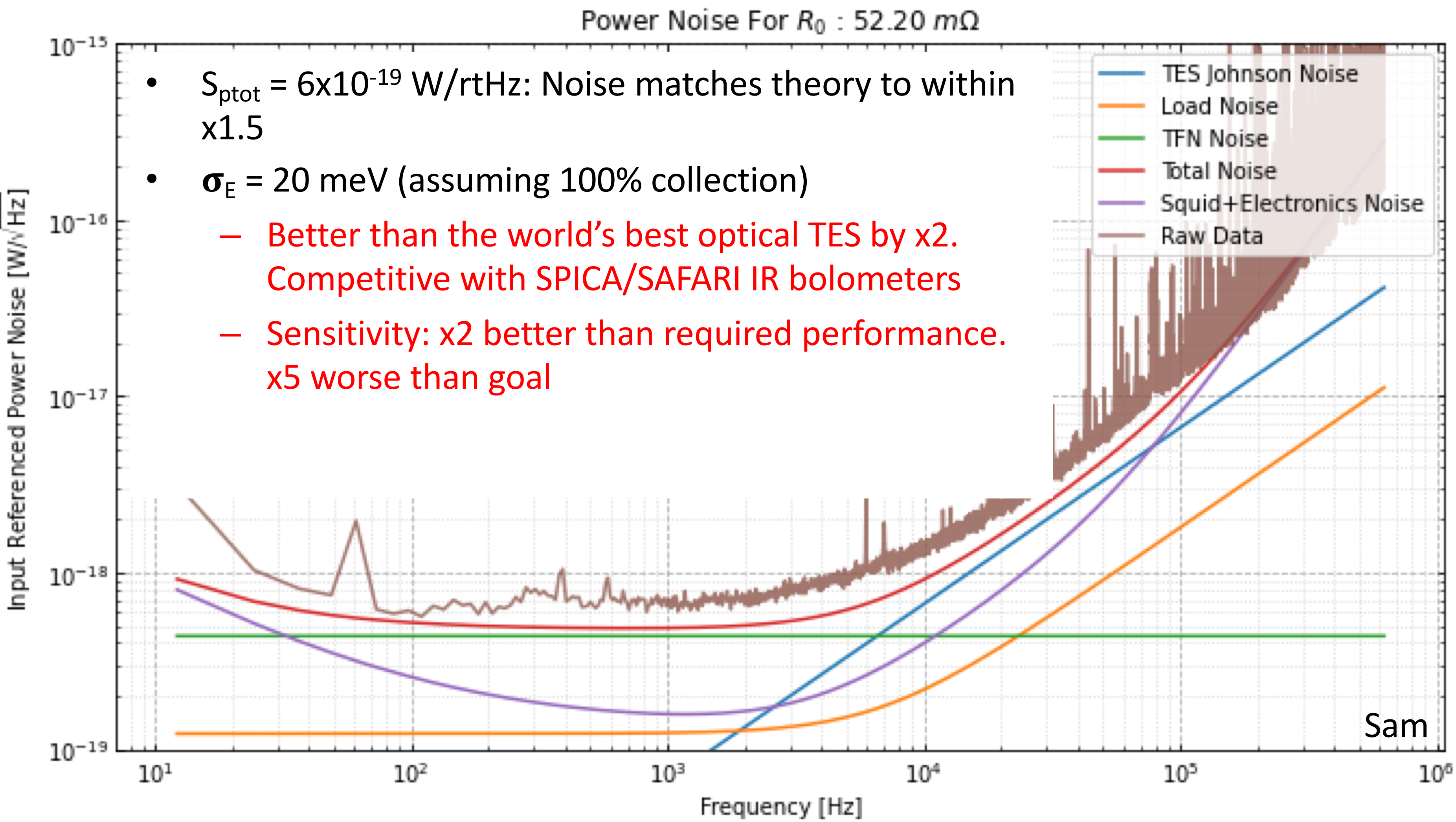




- Falltime: 42us (3.8kHz)

25um x100um TES Noise

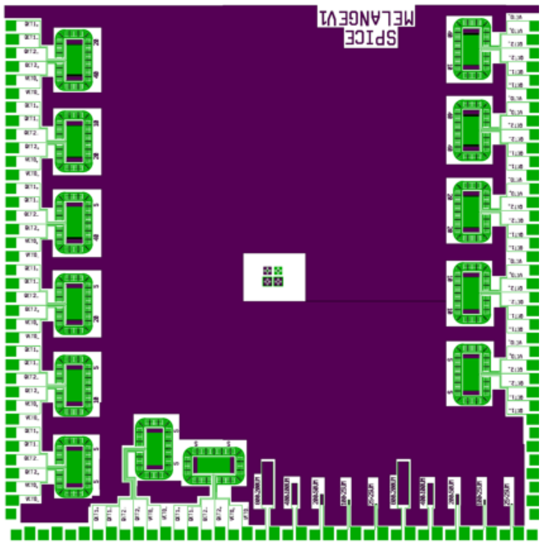
- S_{ptot} = 6x10^{-19} W/rtHz: Noise matches theory to within x1.5
- **σ_E** = 20 meV (assuming 100% collection)
  - Better than the world's best optical TES by x2. Competitive with SPICA/SAFARI IR bolometers
  - Sensitivity: x2 better than required performance. x5 worse than goal



We have this new 19mK W(Xe) TES set from TAMU ….

19mK TES Chip: Stretch Goal Sensitive

$$\sigma_{<E>} \propto \sqrt{VT^3}$$

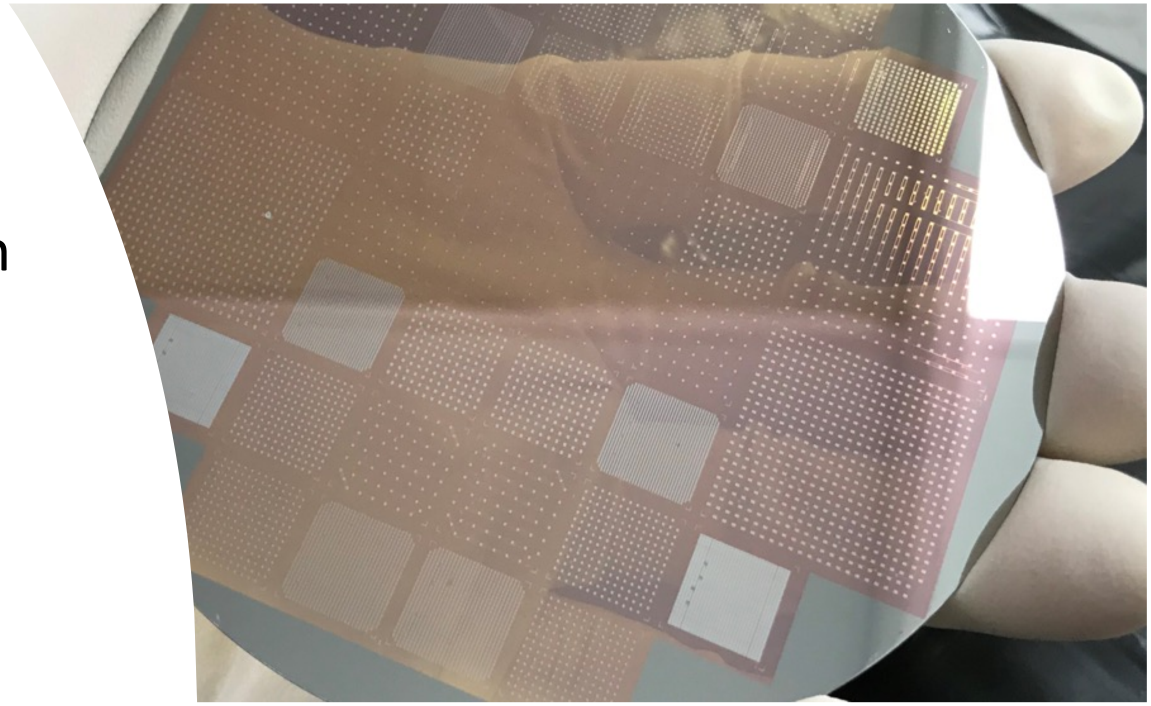


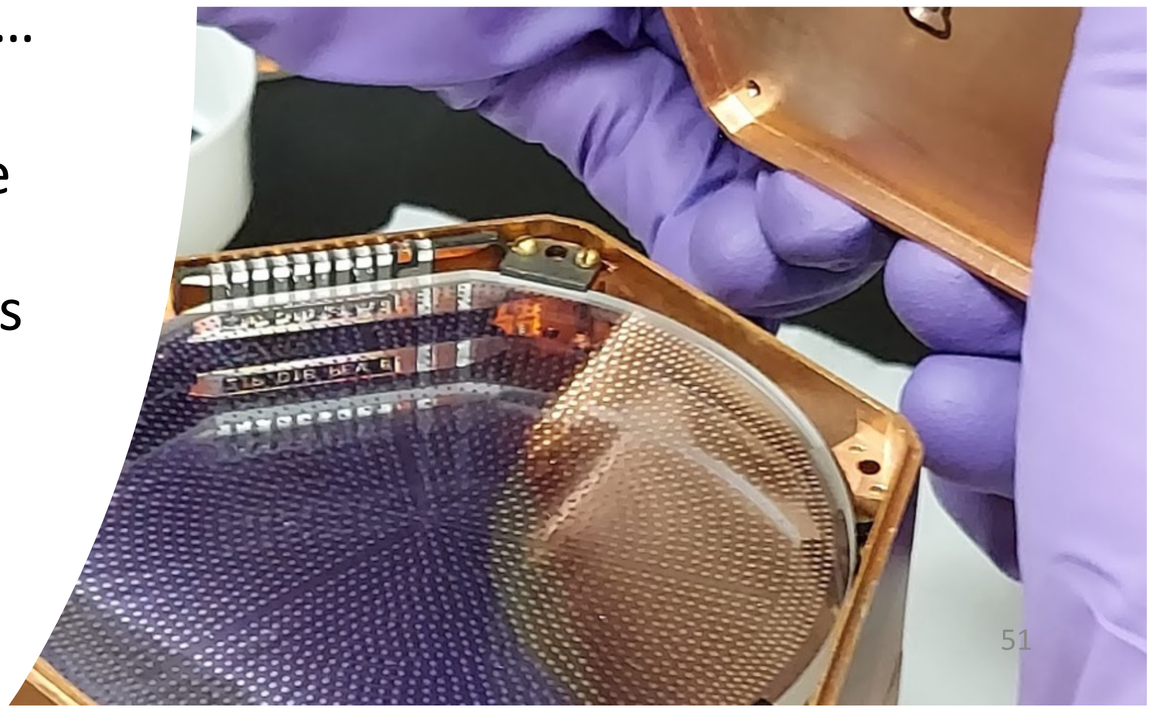
Volume (40nm thick)	Tc (mK)	Bias Power	Sensitivity
25x100um	62mK	22.5fW	20meV
200x800um	19mK	3.6 fW	-
100x400	19mK	Normal	-
25x25um	19mK	Future	Est: ~2meV

If we can make the 25umx25um device operate without excess noise on the already produced TAMU19mK TES chip … we can meet stretch goal EMI mitigation requirements.

Alternate Crystal Fabrication

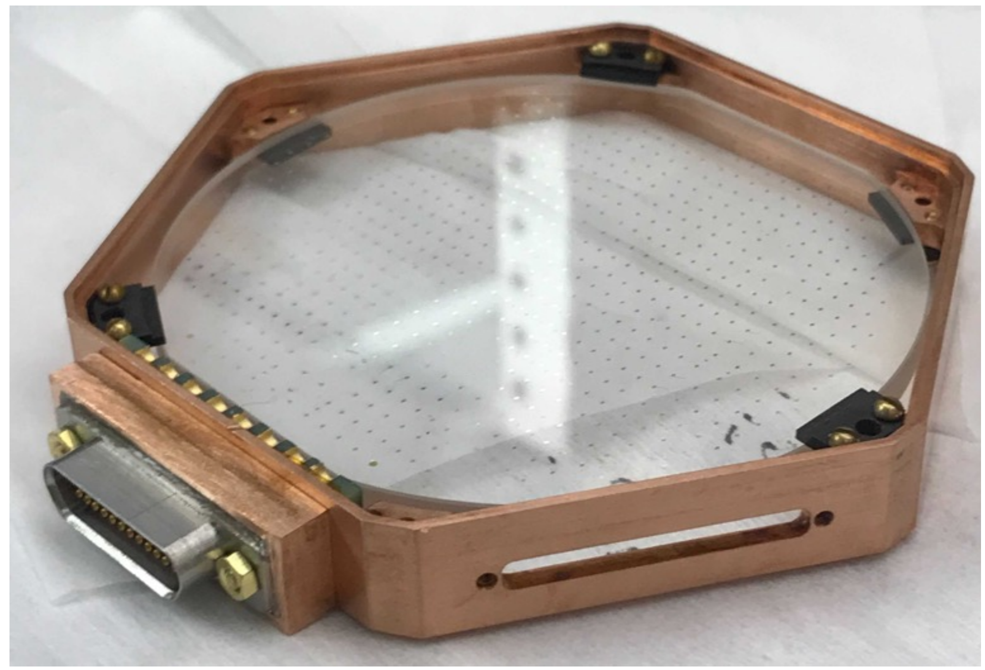
- SPICE requires fabrication of athermal phonon sensors on Al_2O_3,SiO_2,and GaAs. SuperCDMS has never fabricated on anything but Ge/Si.
- CRESST has fabricated W TES on $CaWO_4$ and Al_2O_3 … giving us optimism
- SuperCDMS has had some issues getting good Tc when using blocking layers other than aSi … perhaps foreshadowing problems





Progress: Alternate Crystal Fabrication

- Fabricated 45-50mK W Films on Al_2O_3, SiO_2, GaAs, both with and without aSi blocking layers. W T_c films seem surprisingly invariant to substrate type.
- Fabrication fully tested on Al_2O_3. TAMU has already successfully fabricated on sapphire for a scintillation detector concept.



TESSERACT Detector R&D Highlight

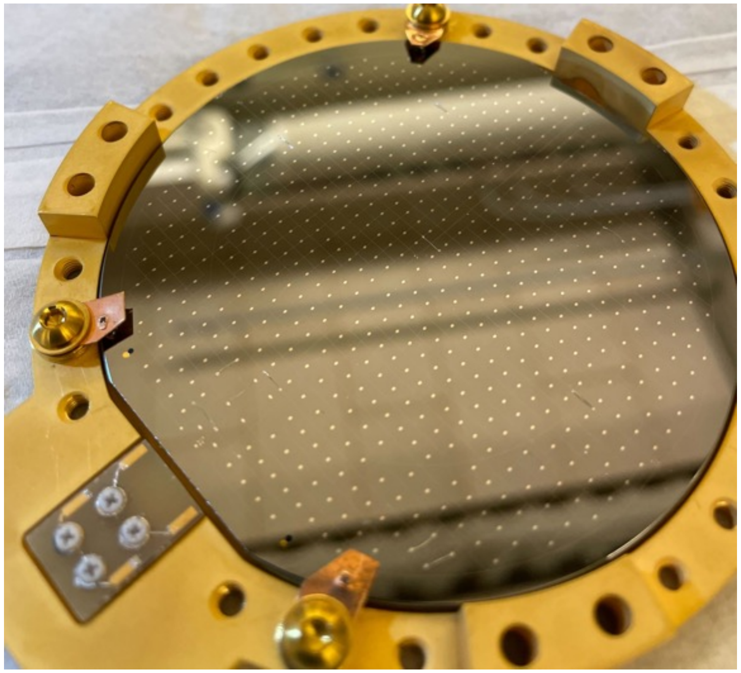
With sufficiently low threshold and/or a light target, lower dark matter masses may be probed.

Unlike large WIMP detectors with keV-scale energy thresholds, expect eV-scale thresholds in first-generation TESSERACT detectors, and meV-scale thresholds in the longer term.

Some technical news this January: TESSERACT has demonstrated the lowest phonon detector event-by-event energy thresholds in the field to date.

These will soon be used to detect evaporated helium atoms from liquid helium (HeRALD) and photons from GaAs (SPICE).

Thresholds will also drop significantly as we move to our new 19 mK Tc devices.



TESSERACT detector running at UMass (group of S. Hertel), with 55 mK critical temperature and 3 eV resolution.

Progress on Superfluid Helium

First TESSERACT measurements of quantum evaporation signals in liquid helium, done at U Massachusetts (group of S Hertel).

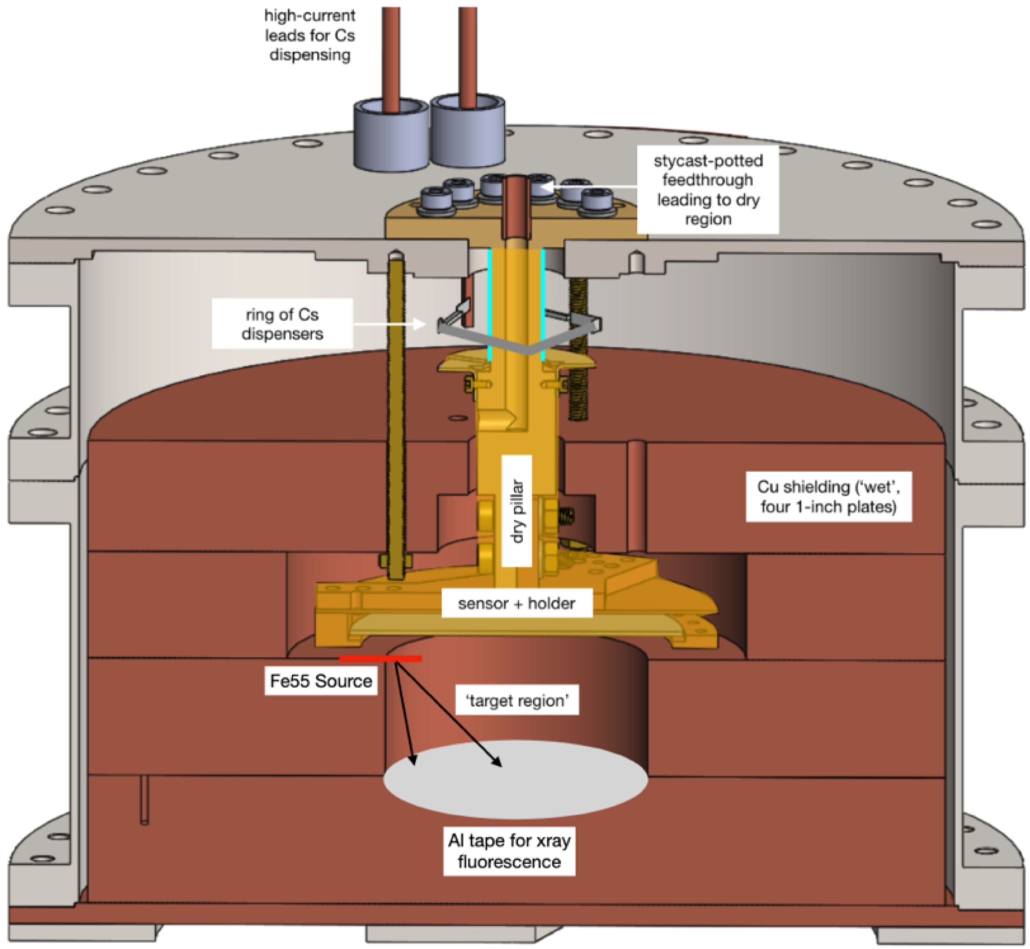
Superfluid 4He covers all surfaces of a closed container. Do not want this on calorimeter!

• Preserve adsorption gain

• Empirically: superfluid on calorimeter degrades performance

• Superfluid 4He does not wet Cs, deposit a ring of Cs between helium target and calorimeter

Ketola, Wang, Hallock PRL 68, 201 (1992)



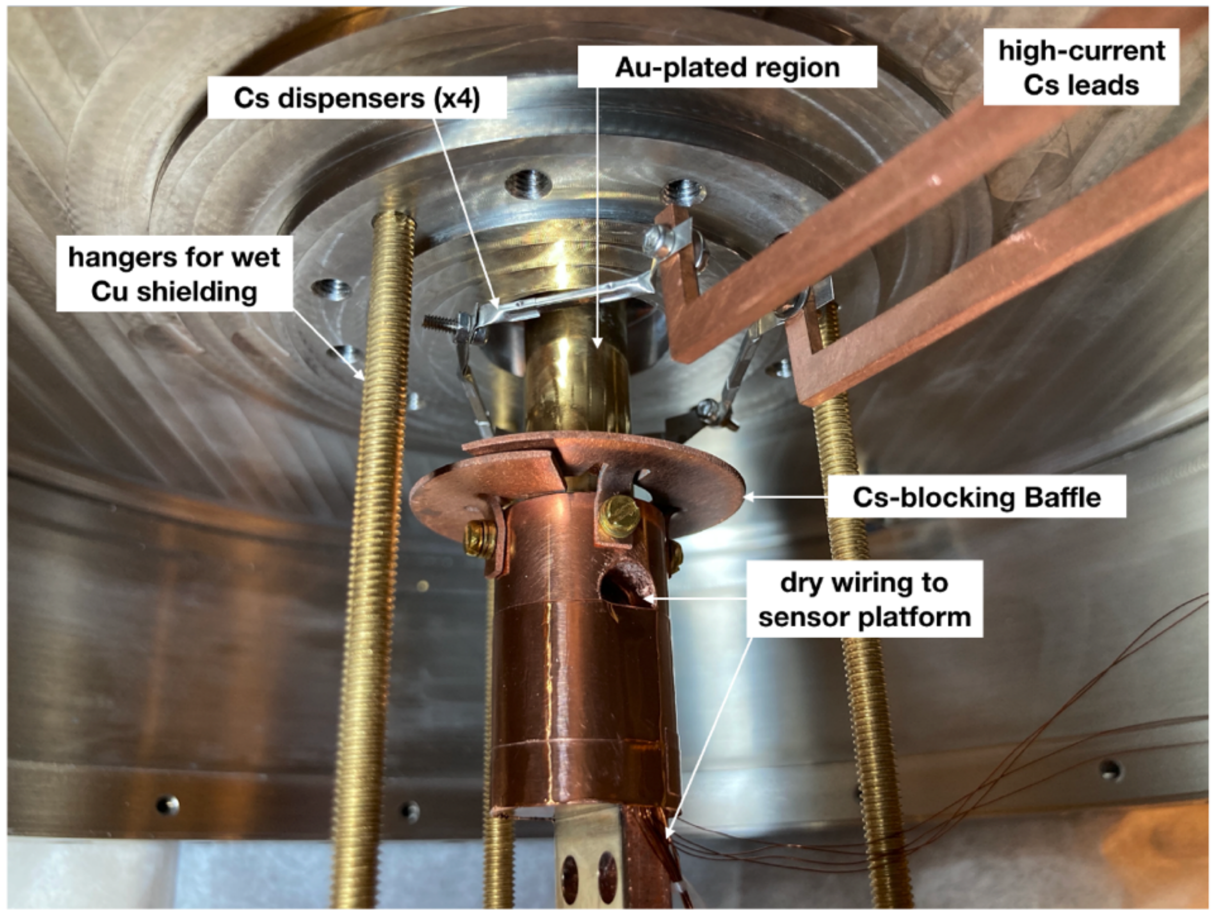
Progress on Superfluid Helium

First measurements of quantum evaporation signals in liquid helium, done at U Massachusetts (group of S Hertel).

The Cs film stopper: success!

Deposit Cs in situ below 100 K

Au-plated Cu substrate



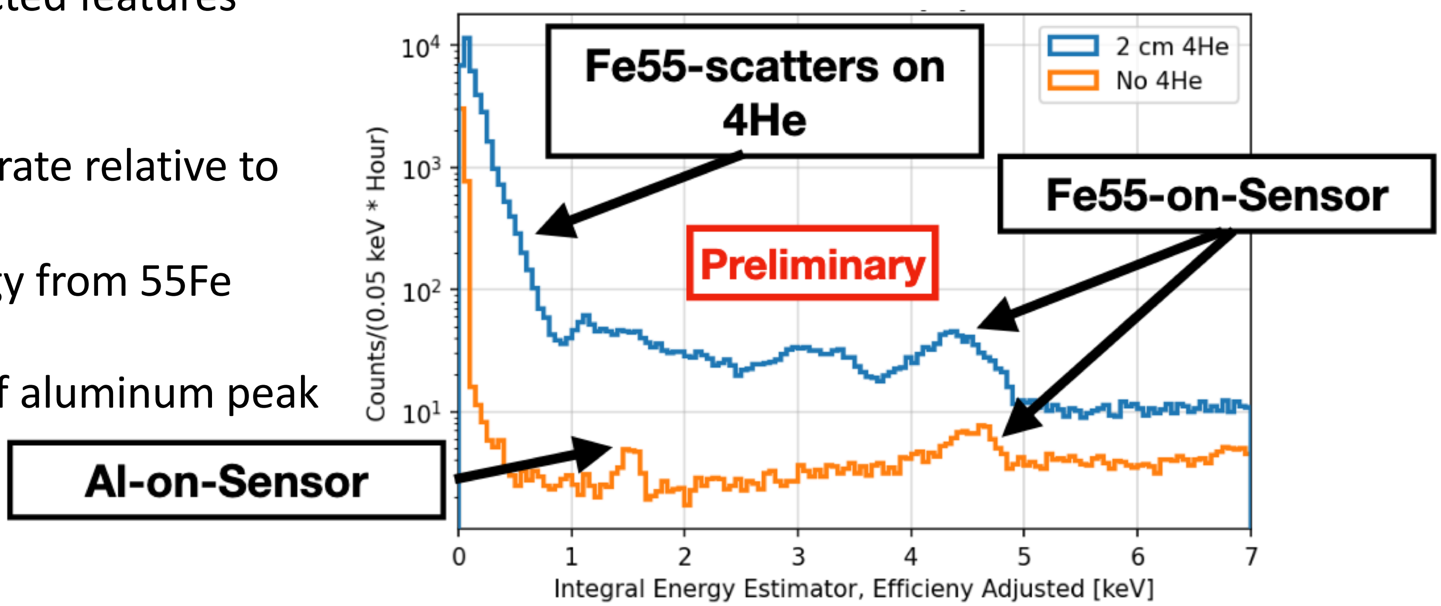
Progress on Superfluid Helium

First TESSERACT measurements of quantum evaporation signals in liquid helium, done at U Massachusetts (group of S Hertel).

Detector platform reached 9 mK

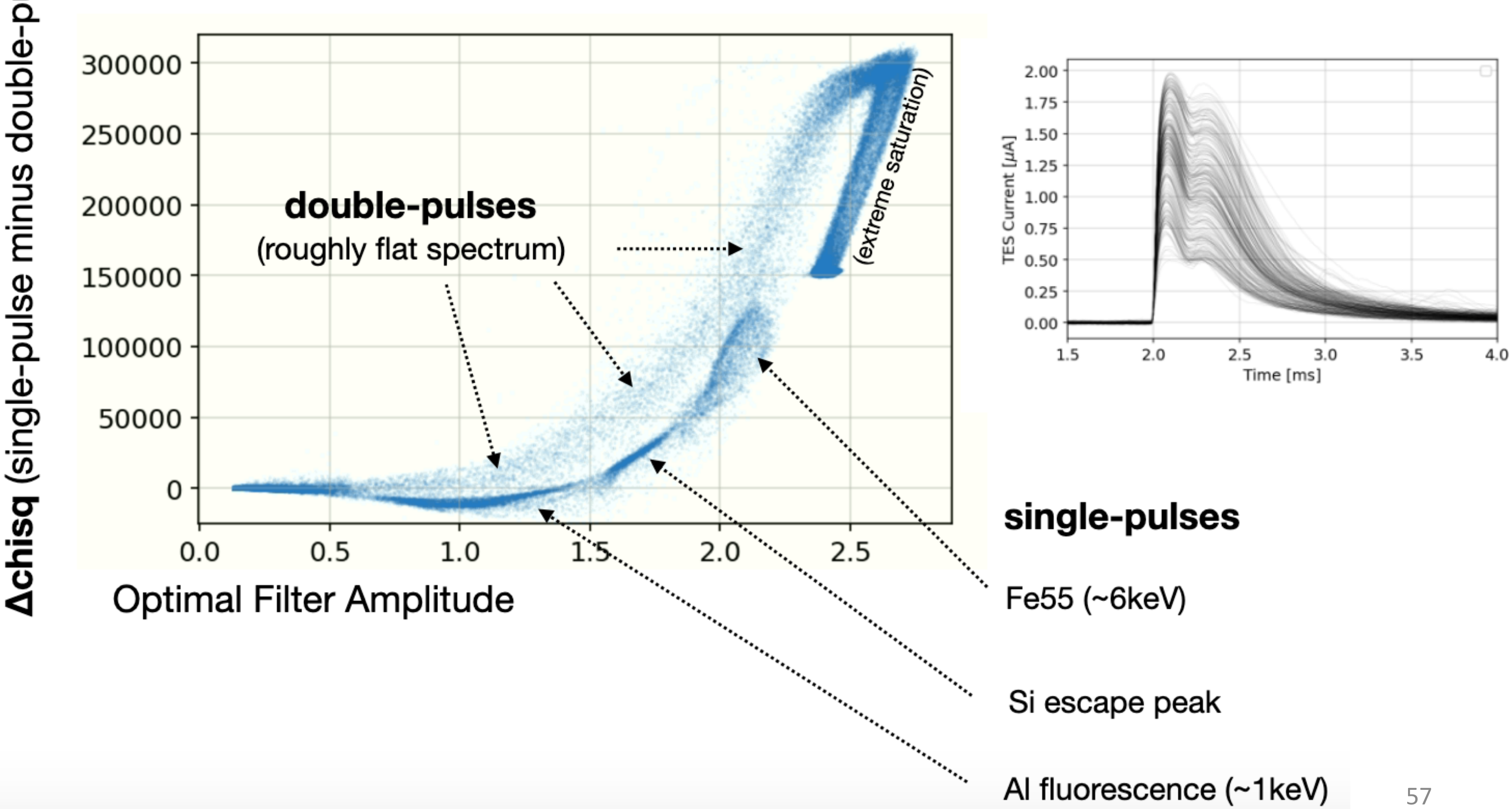
A number of expected features appear:

- Increase in 55Fe rate relative to dry CPD
- Rise at low energy from 55Fe scatters in 4He
- Disappearance of aluminum peak



Progress on Superfluid Helium

First TESSERACT measurements of quantum evaporation signals in liquid helium, done at U Massachusetts (group of S Hertel).



Progress on Superfluid Helium

Superfluid He detector being designed in Berkeley based on Cs-based film blocking

Will be first operated at LBNL using existing dilution refrigerator

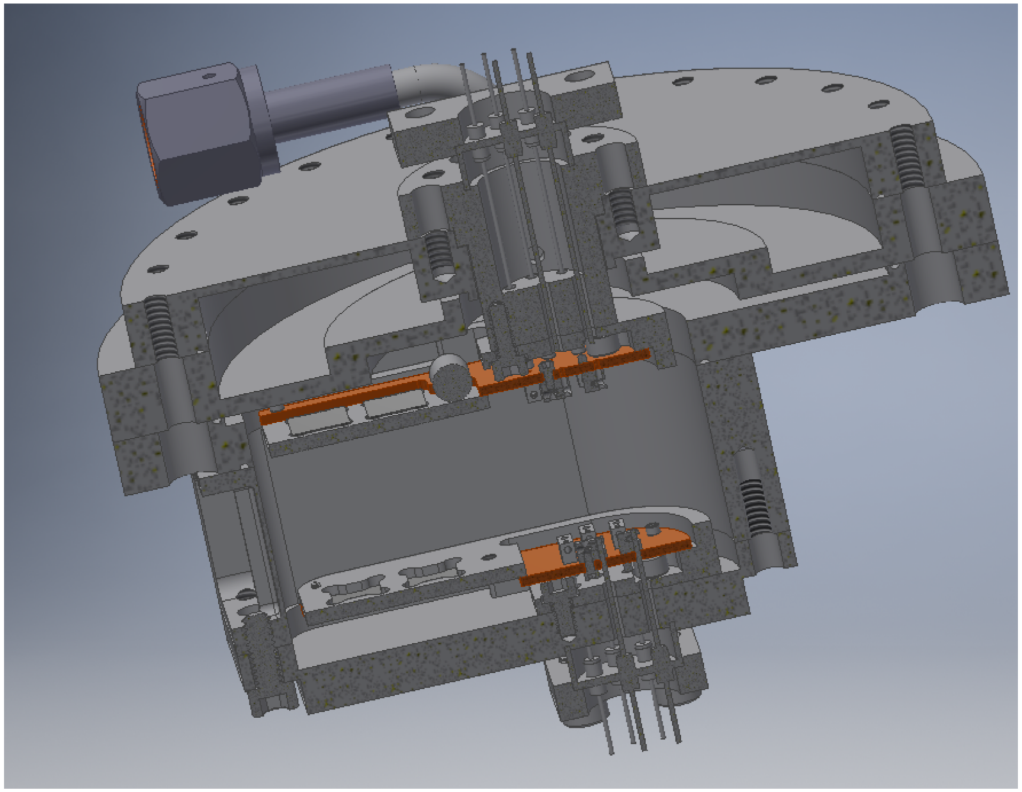
in^3 of active liquid helium

Will use very latest TES-based detectors, with < 1 eV resolution

Calibrations to be performed using x-rays, gamma-rays, and new SbBe 24 keV neutron beam (UCB)

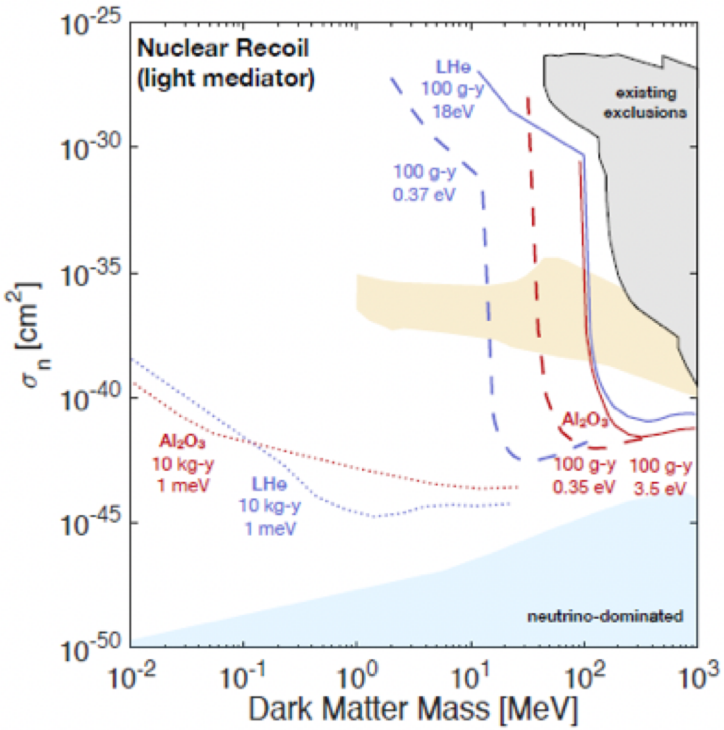
Prototype for future TESSERACT detectors

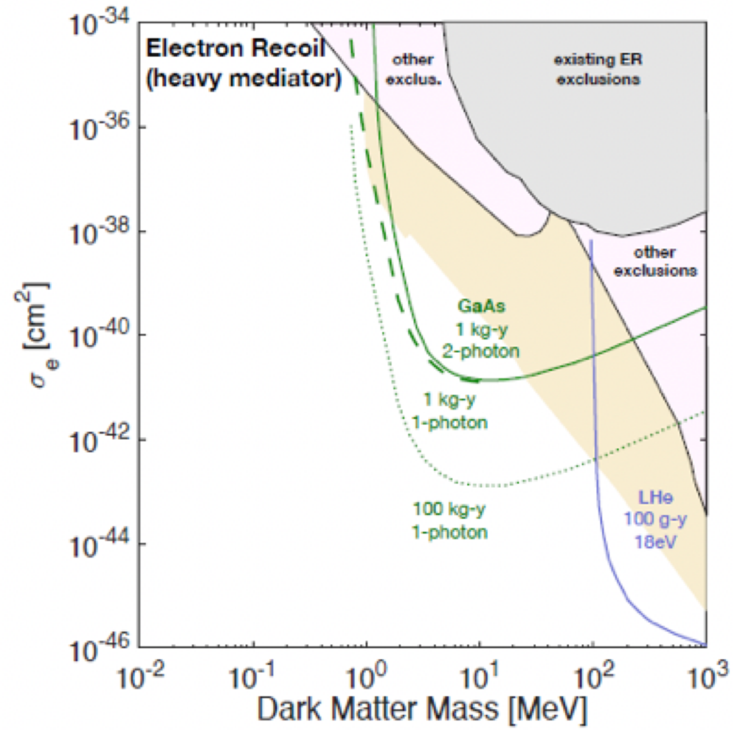
Investigate heat-only backgrounds – are they eliminated by using LHe?



SPICE and HeRALD - projected sensitivity

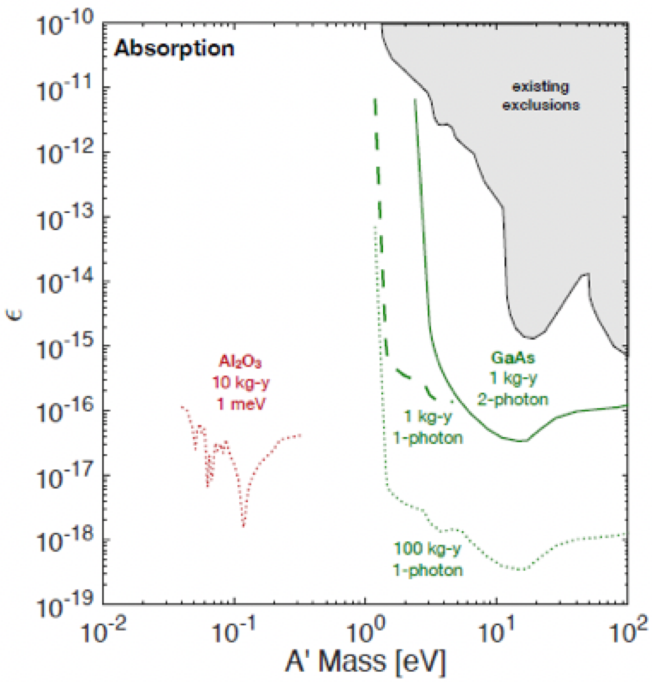
Snowmass2021 - Letter of Interest
The TESSERACT Dark Matter Project

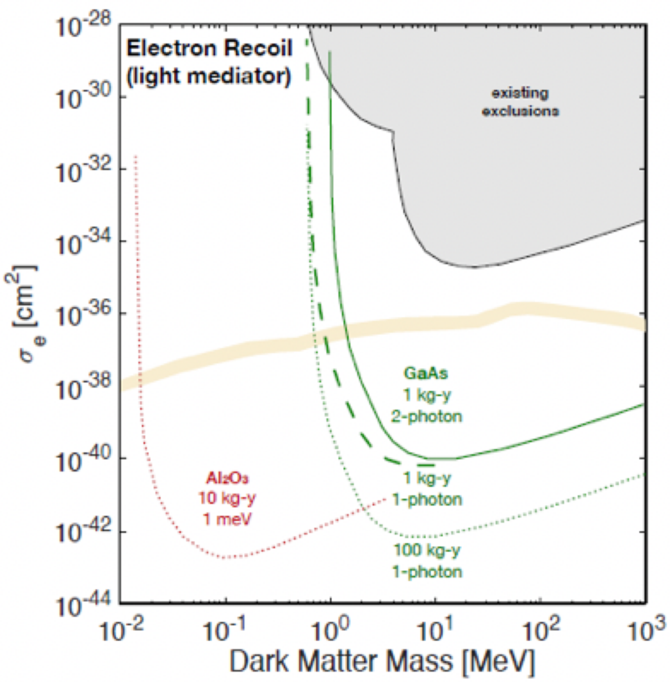




SPICE and HeRALD - projected sensitivity

Snowmass2021 - Letter of Interest
[The TESSERACT Dark Matter Project]



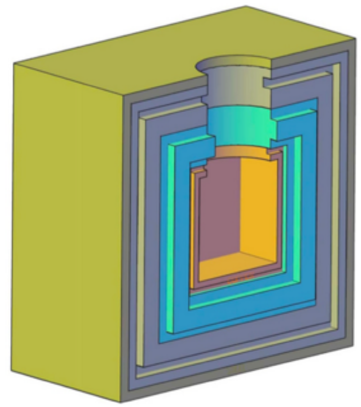


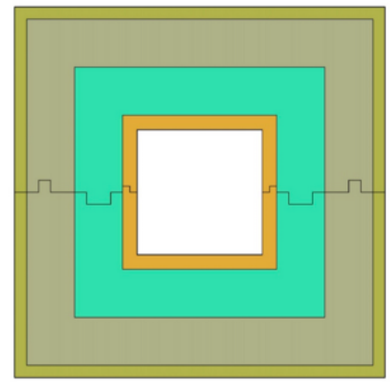
Progress on Shielding Design

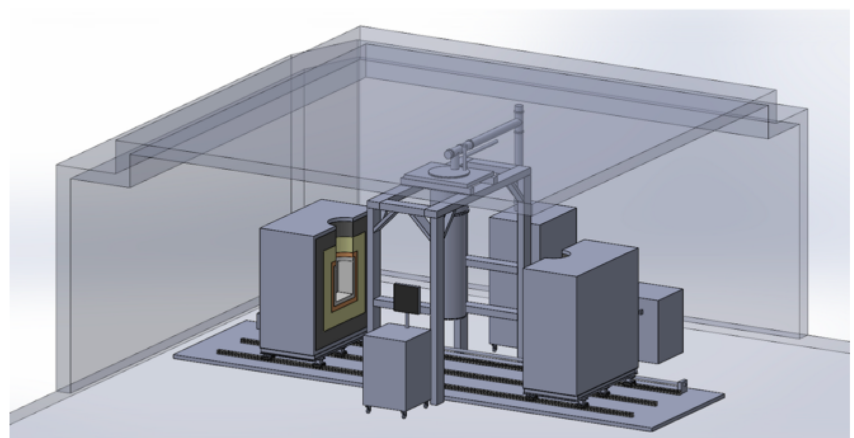
The experiments will be operated in an underground laboratory (not yet chosen). Discussions are just beginning with underground labs.

The shielding design has converged on a compact lead/polyethylene approach. Shielding will come off on rails so as to enable quick and straightforward access to the cryostat. There will be two copies of the setup, for enabling both SPICE and HeRALD.

Significant emphasis on vibrational and EM noise suppression. Substantial R&D effort is being devoted to reducing these instrumental backgrounds, and this R&D will feed into the engineering design.

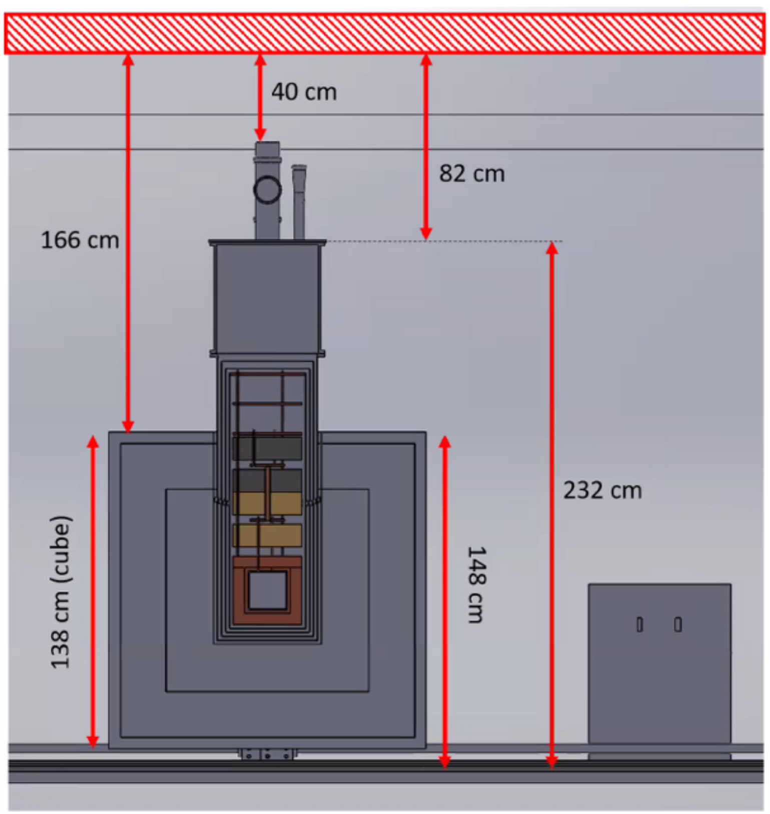




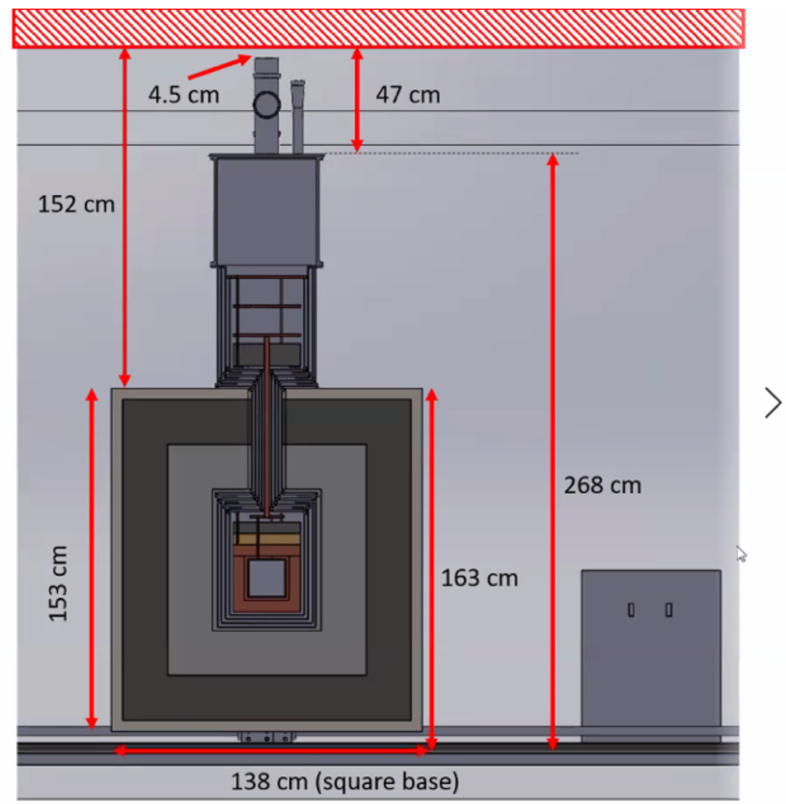


Two shielding designs were studied, to understand engineering and radioactive background tradeoffs. Both designs were simulated using GEANT. The cylindrical design has a simpler cryostat, but simulations showed a gamma-ray background that was a factor 10 too high because of gamma rays and neutrons coming down the gaps between cryogenic layers.

Cylindrical design



Nested cryostat design



Possible TESSERACT Low-Background Cryogenic Facility at Modane

Idea: The Modane lab could be the future home of TESSERACT, starting with a **TESSERACT low-background cryogenic facility**, leveraging the combined technical and operational expertise in the US and France, plus experience from EDELWEISS, SuperCDMS, RICOCHET.

- This could replace the EDELWEISS experiment.
- Two sets of lead-polyethylene shielding and dry cryostats, with 15 mK detector platforms
- The facility would be dedicated to cryogenic detectors for sub-GeV dark matter direct detection
- Focus on quick access, replacement of detectors, flexibility
- Shared SQUID electronics, DAQ, slow control
- State-of-the-art suppression of vibrational and electromagnetic backgrounds
- Cryogenic active veto (NaI?) to further reduce backgrounds
- Detector materials: superfluid helium, silica, sapphire, GaAs, Ge, Si, others?
- **Grenoble participation would be essential**

Visiting EDELWEISS this January

Summary

- TESSERACT is developing different targets for DM searches
- DM targets include polar crystals (SPICE) and superfluid helium (HeRALD), and could include others.
- R&D has begun on TES, athermal phonon sensors, and coupling these to multiple targets. First R&D accomplishments have already been achieved!
- First R&D results on superfluid helium light yield, SbBe neutron beam.
- In parallel, TESSERACT design, engineering, and project management is ramping up
- There could be a TESSERACT facility in Modane, taking advantage of technical and operational expertise in both the US and France.