TESSERACT

The TESSERACT Project for Sub-GeV Dark Matter Detection

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The TESSERACT Project

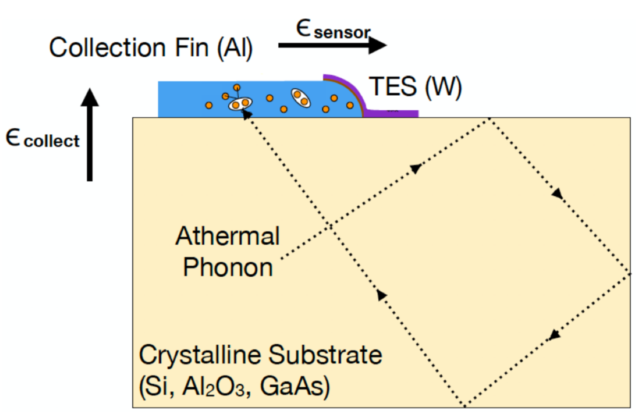
DMNI Project Planning

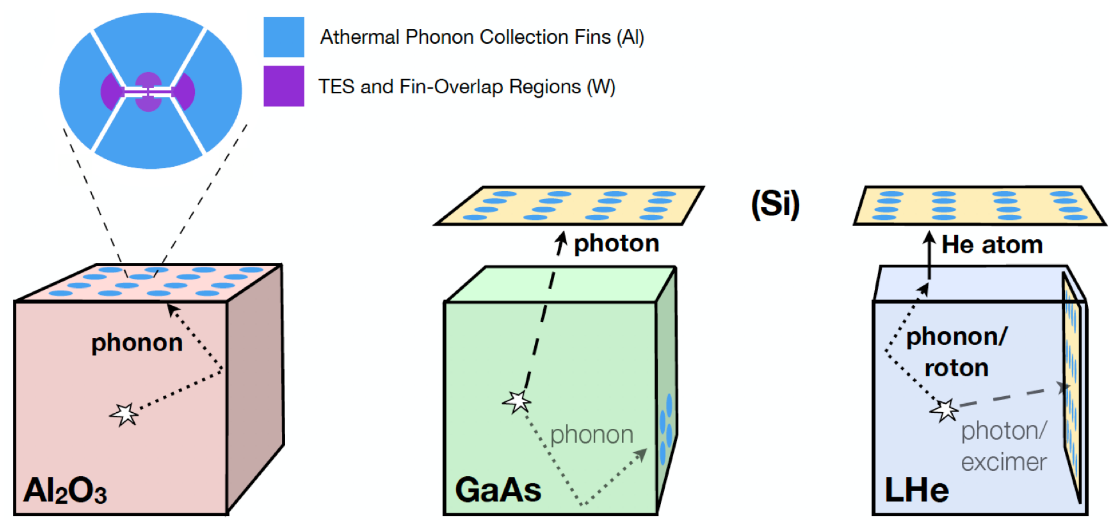
Would be a DOE-HEP small project; Managed by LBNL; contributions all US.

Uses extremely sensitive Transition Edge Sensor readout, state-of-the-art noise suppression, and multiple materials as dark matter targets.

TESSERACT chosen to be one of the 6 DMNI small projects (one of ~30 DMNI proposals)
Pre Conceptual Design Phase: from July 2020 through Sept 2024.
Project phase: planned for FY2025

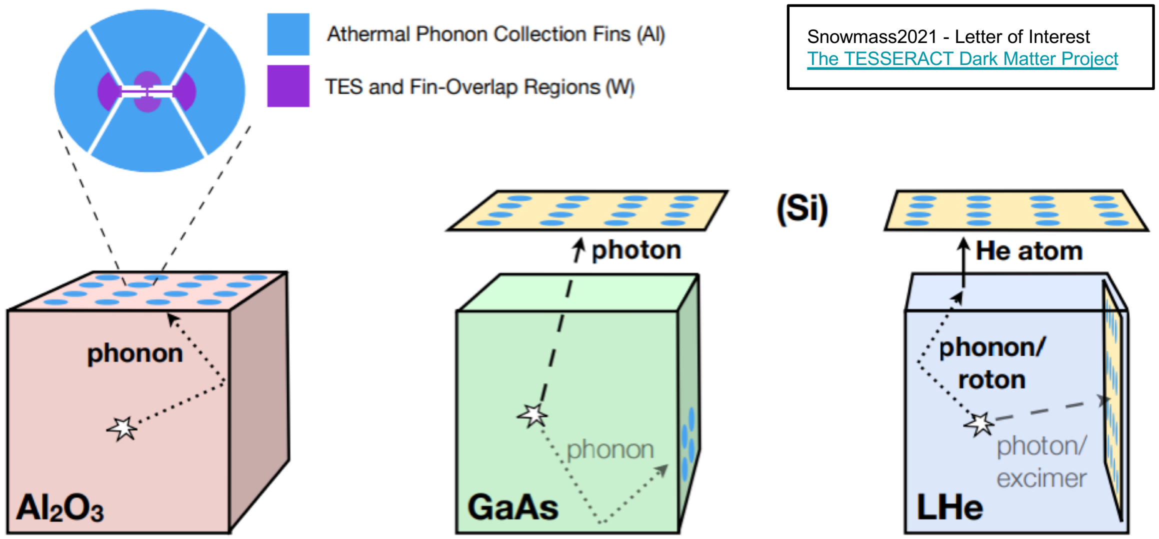
R&D: Coupling different target materials to TES, and optimizing this coupling. Target materials include sapphire, gallium arsenide, superfluid helium. Testing detectors to quantify noise performance. Calibrating different targets





TESSERACT project

- Managed by LBNL
- 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

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Dark matter target complementarity

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

= World-leading sensitivity

= Competitive sensitivity

Al_2O_3 and SiO_2 have sensitivity across the board. But only a phonon signal channel, and TES coupled directly to the crystal, so no intrinsic instrumental background suppression.,

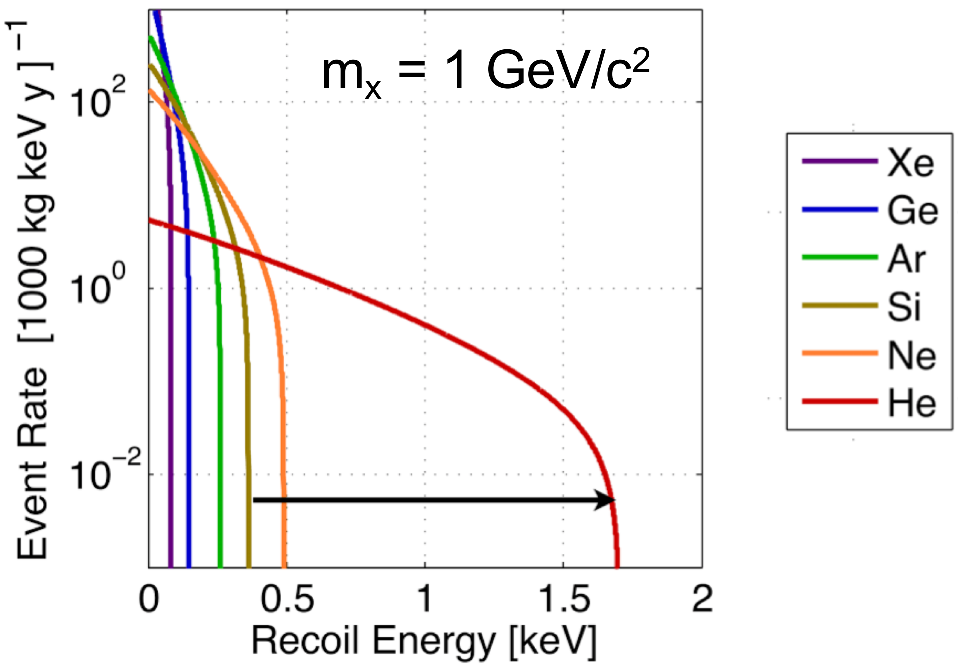
GaAs and superfluid helium have significant advantages in background rejection: multiple signal channels and multipixel coincidence-based instrumental background rejection.

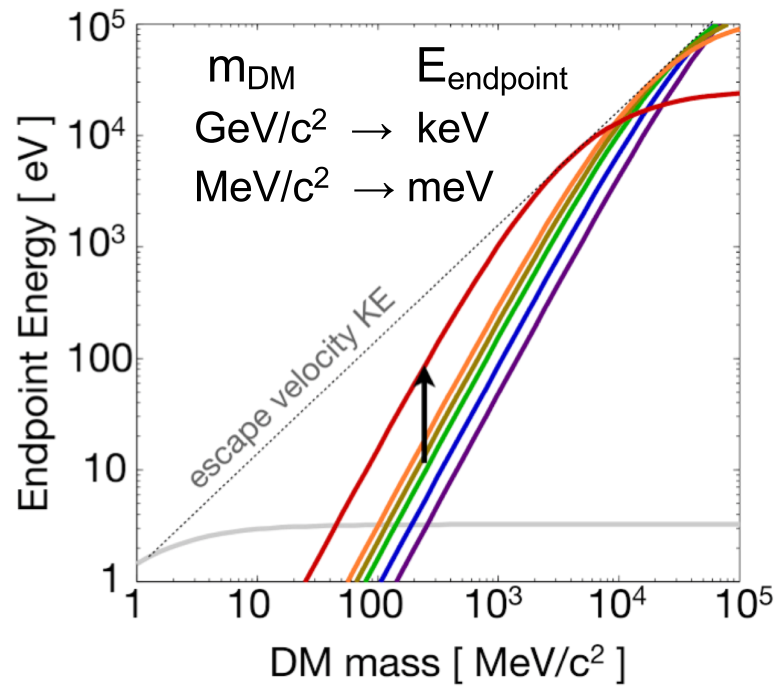
Targets are not the dominant cost: any target materials that make specification will be included.

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)

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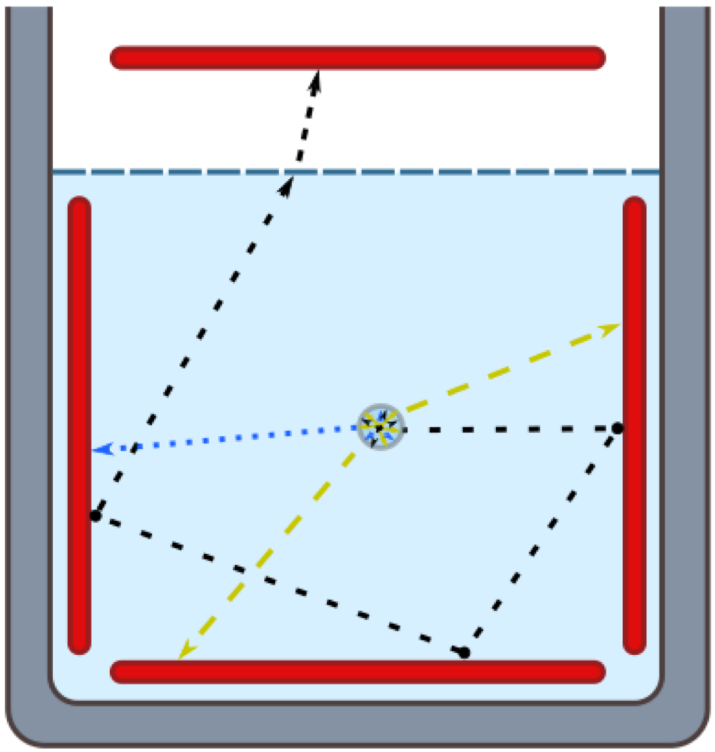
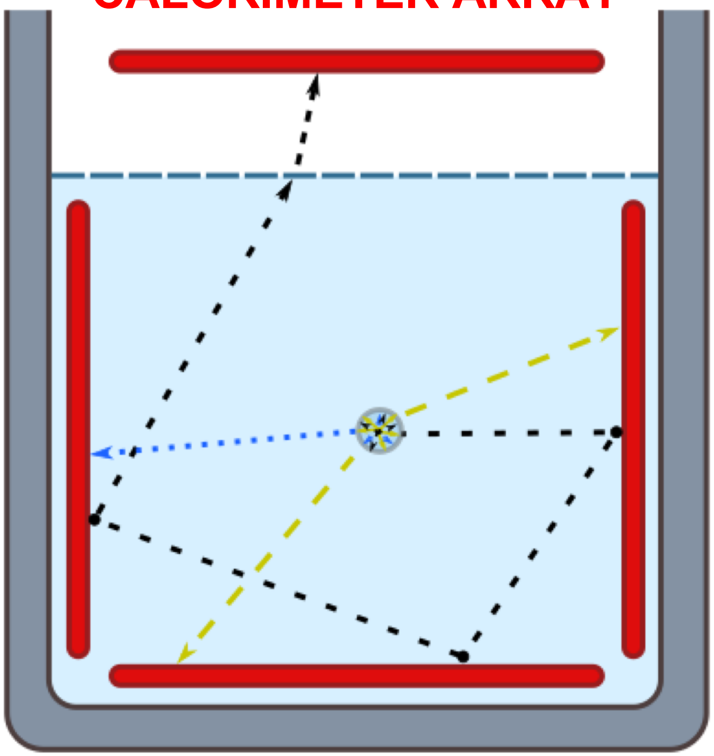
Superfluid Helium as a Dark Matter Target



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

Proposed Detector: HeRALD



Helium **R**oton **A**pparatus for **L**ight **D**ark Matter

O(1 kg) cubic mass of helium, operated at ~50 mK in dilution refrigerator

5 calorimeter arrays immersed in helium, instrumented with transition-edge sensors (TES's)

- Detect UV photons, triplet excimers, IR photons

Vacuum layer between helium and 6th TES array

- Detect quasiparticles via quantum evaporation

arXiv:1810.06283

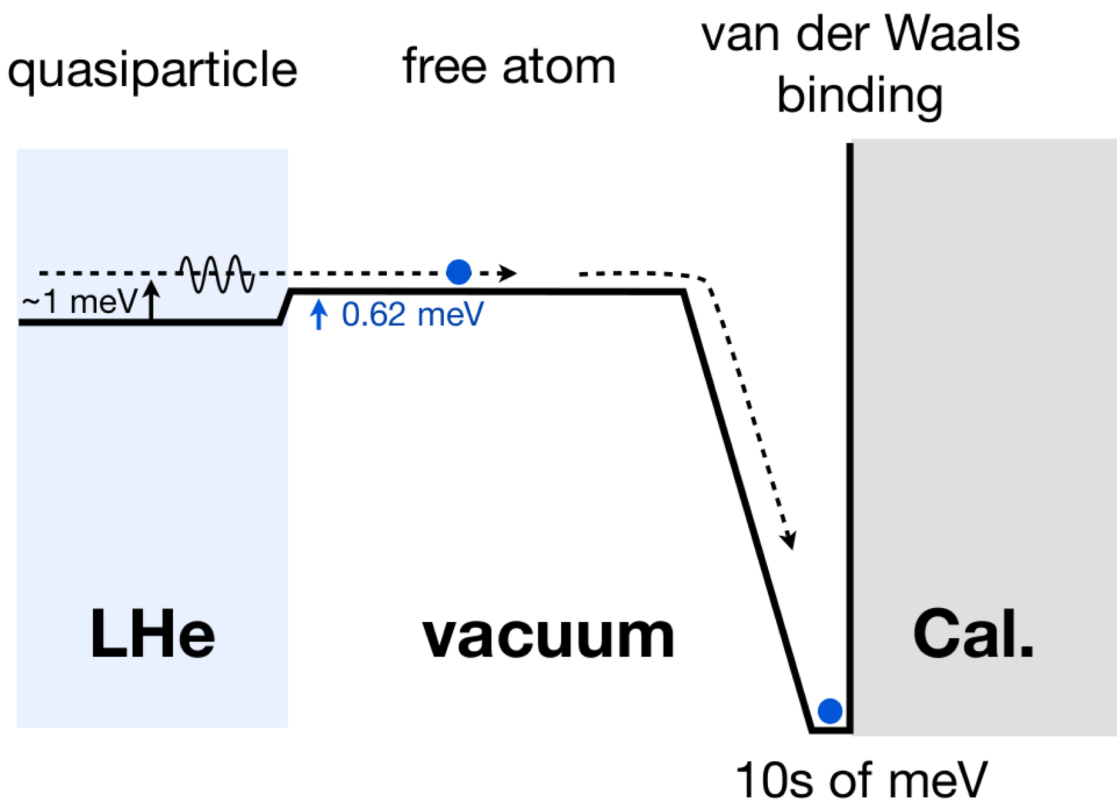
Detecting Quasiparticle Signal

Binding energy between helium and solid amplifies signal

1 meV recoil energy → up to 40 meV detectable energy

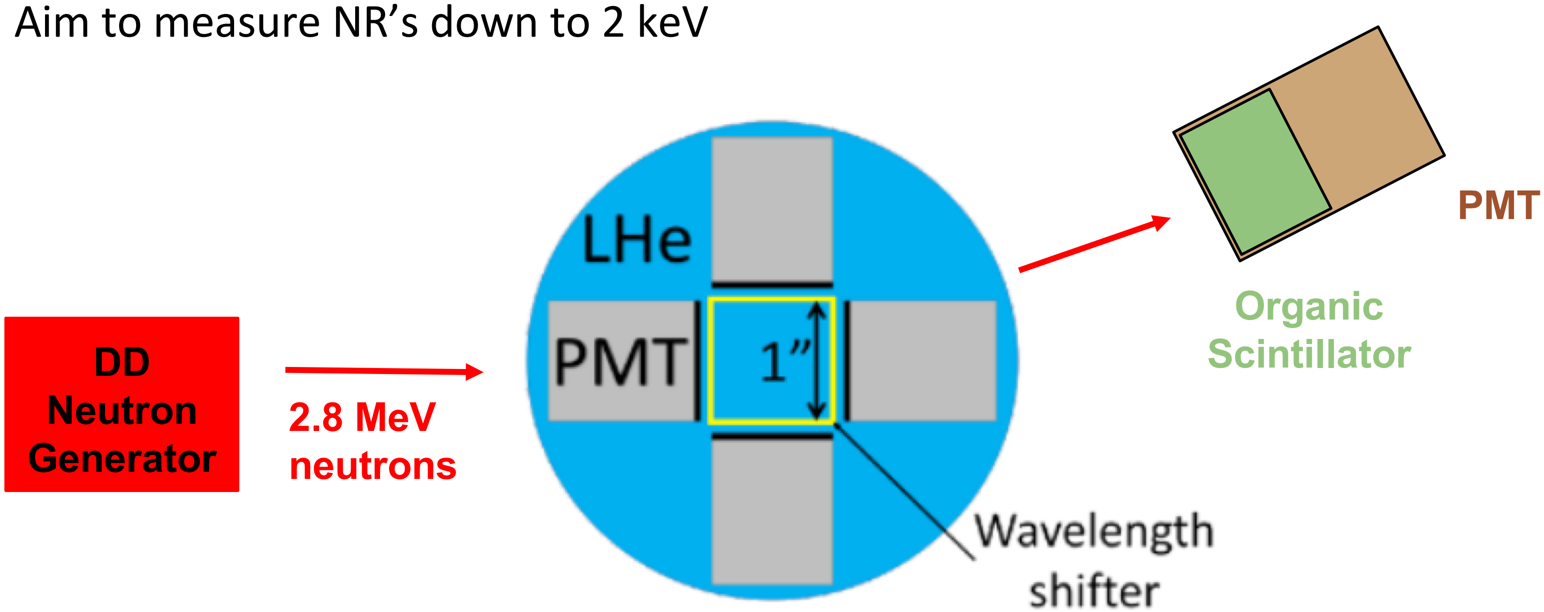
Thermal energy negligible (µeV)

Film burner to remove helium from calorimeter



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

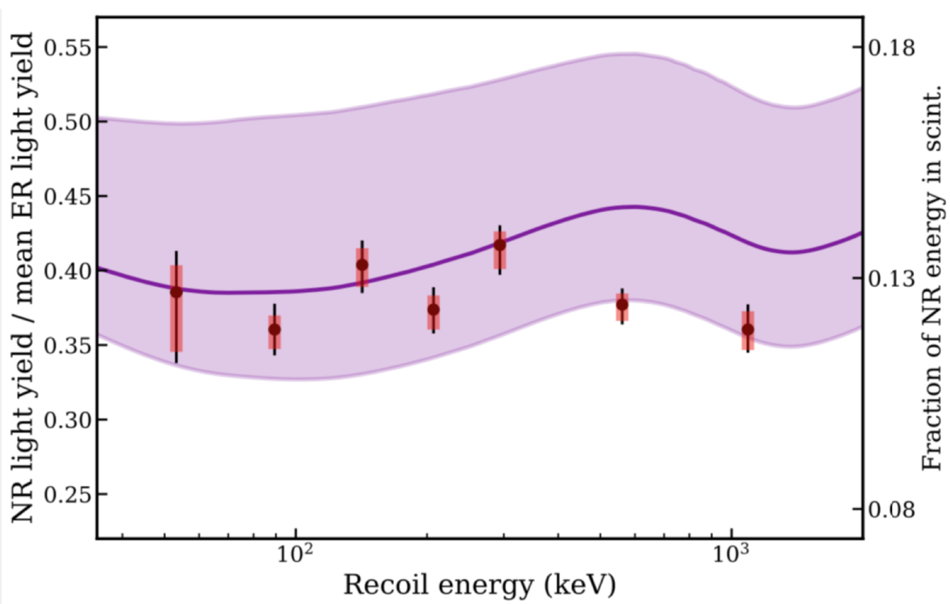
- Will be first measurement of the ^{4}He nuclear recoil light yield!
- Aim to measure NR’s down to 2 keV



LHe light yield measurements

V2: DD neutrons scattering in 4He *liquid* (~1.75K), observed via PMTs

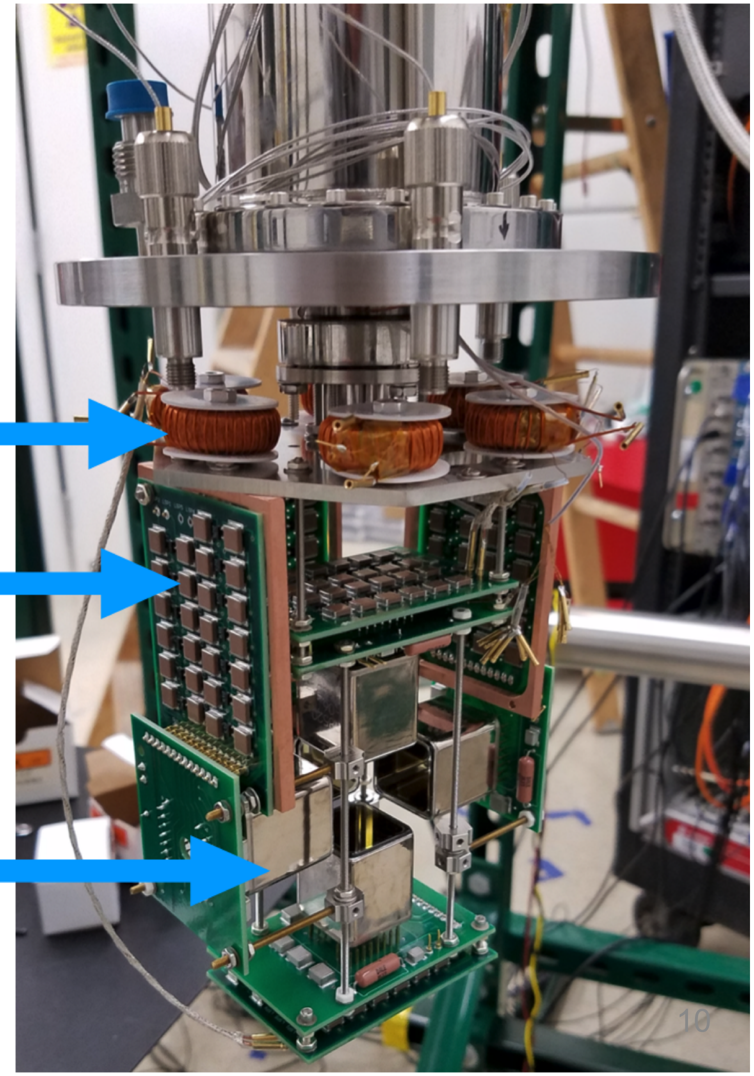
See arXiv:2108.02176.



transformer

cockroft-walton

1” PMTs



24 keV neutron beam from 124Sb-Be

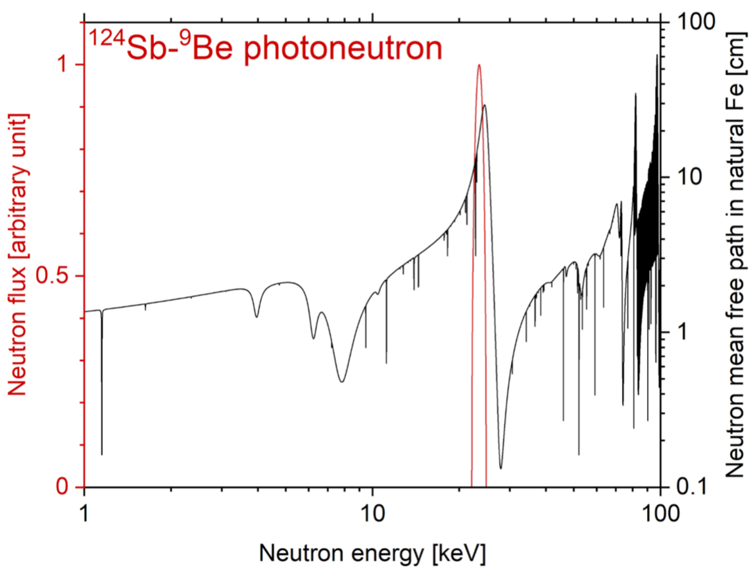
Photoneutron source: 124Sb gammas on Be target, producing quasi-monoenergetic 24keV neutrons

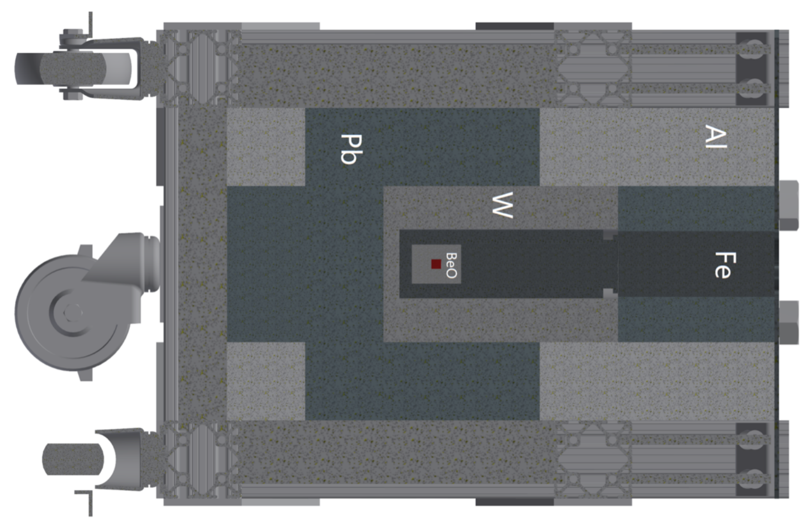
24keV neutron, ~10 degree scattering angle: ~100eV deposited   (sweet spot for the next few years of studies)

Main challenge is to shield order-GBq of 124Sb gammas.

Powerful trick: Fe is transparent to 24keV neutrons! (Coincidental alignment of of 24keV with Fe56 cross section 'notch')

Data collected, paper in preparation

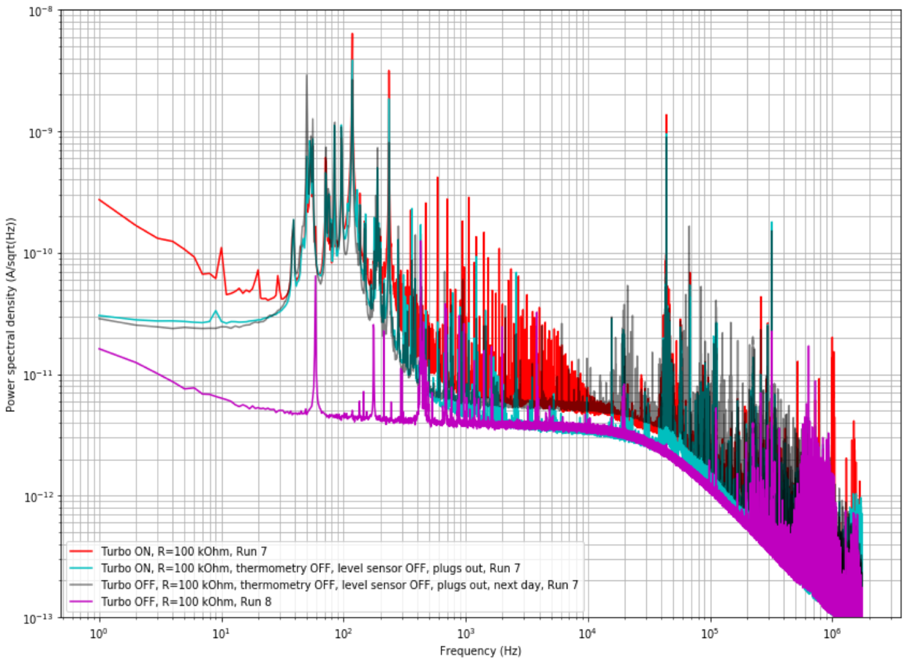


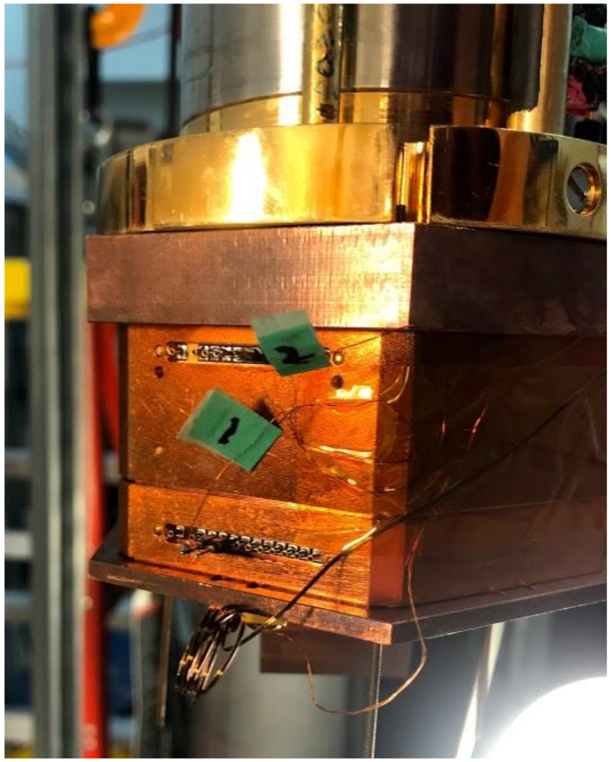


Next step: light yield via calorimetry

Wet dilution fridge in McKinsey space . Now in process of commissioning/practicing calorimetry readout. Currently have a liquid helium-filled cell at ~ 50 mK, testing athermal phonon detectors immersed in LHe.

Then: onto combining light and quantum evaporation

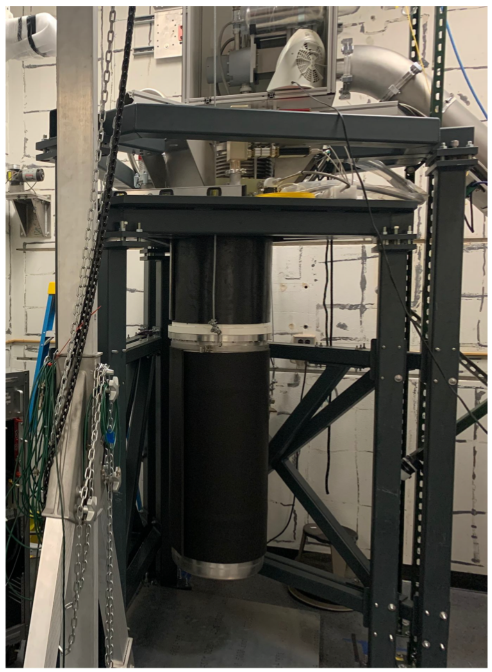




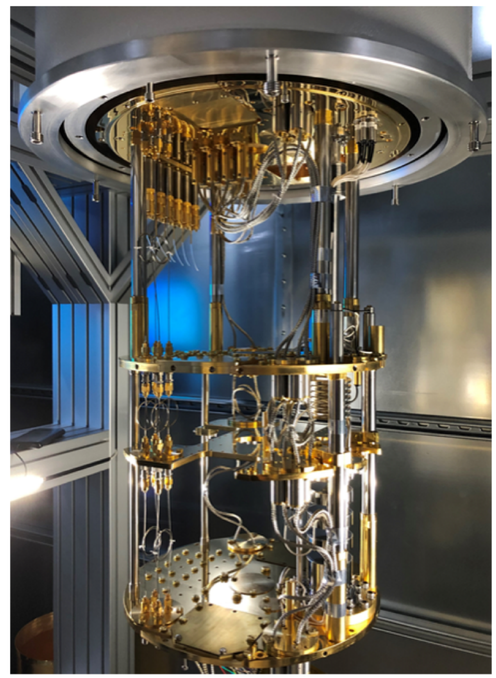
TESSERACT testbeds

Leiden MNK126-500
McKinsey Group @ UCB

CryoConcept UQT-B 200
Pyle Group @ UCB



BlueFors LD-400
Detector R&D @ LBNL



CryoConcept HEXADRY UQT-B 400
Hertel Group @ UMass

R&D Progress

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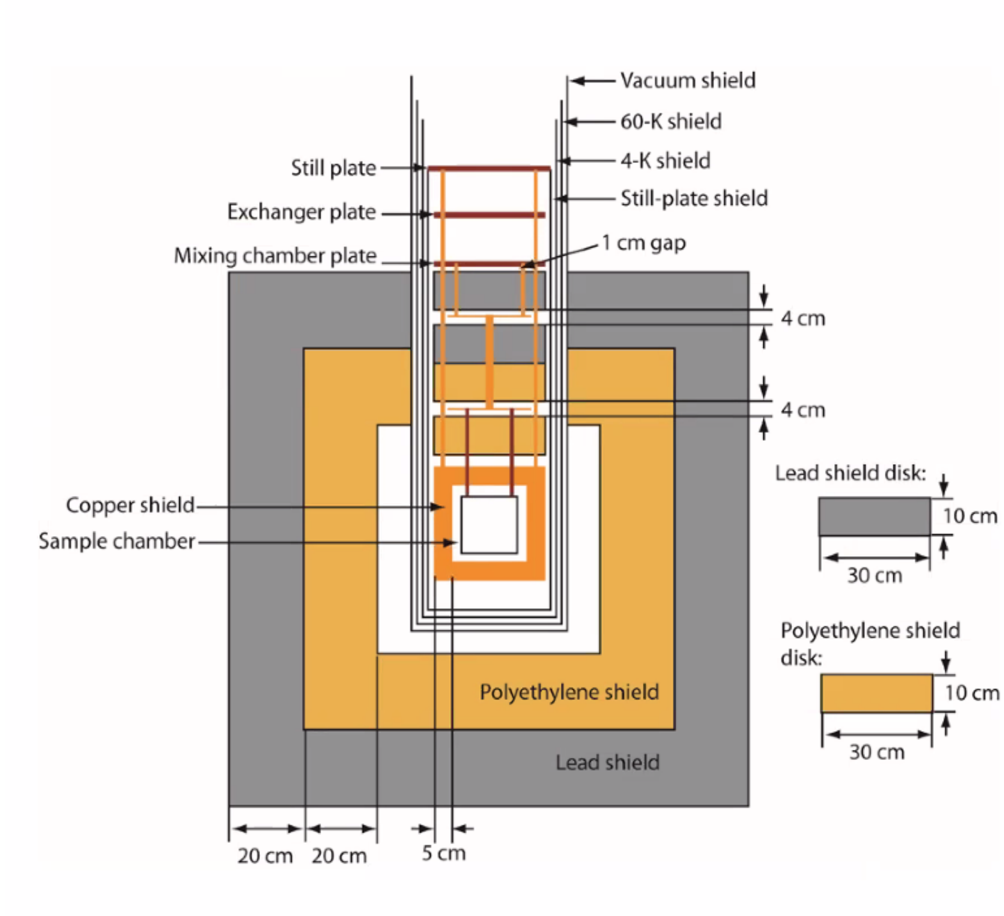
We already have made significant progress on R&D, including:

- Tungsten TES films demonstrated with extremely low critical temperature (down to 19 mK).
- IrPt bilayer films produced at ANL with 25 mK critical temperature
- First superfluid helium scintillation measurements from nuclear recoils (see SPICE/HeRALD collaboration, arXiv:2108.02176)
- First demonstration of portable iron-filtered SbBe photoneutron beam

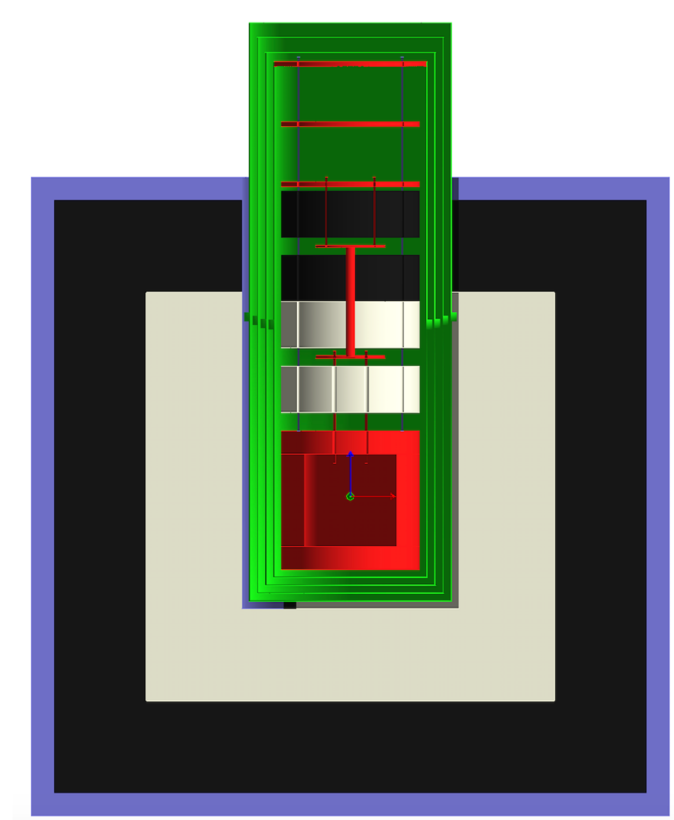
TESSERACT engineering and simulation

Cryostat and shielding engineering design commencing, in parallel with GEANT background simulations

Engineering model

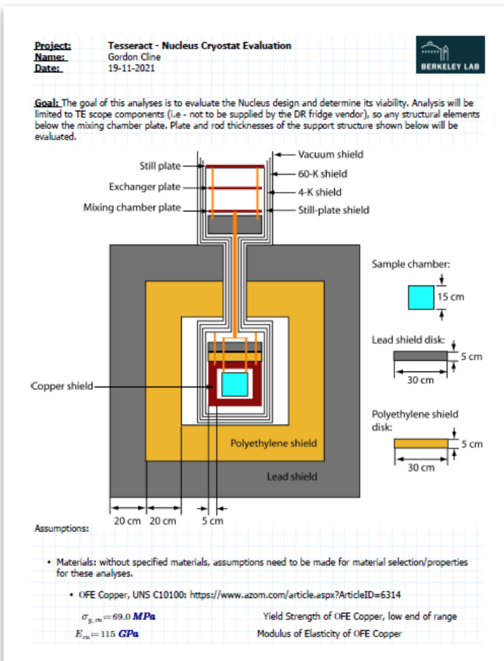


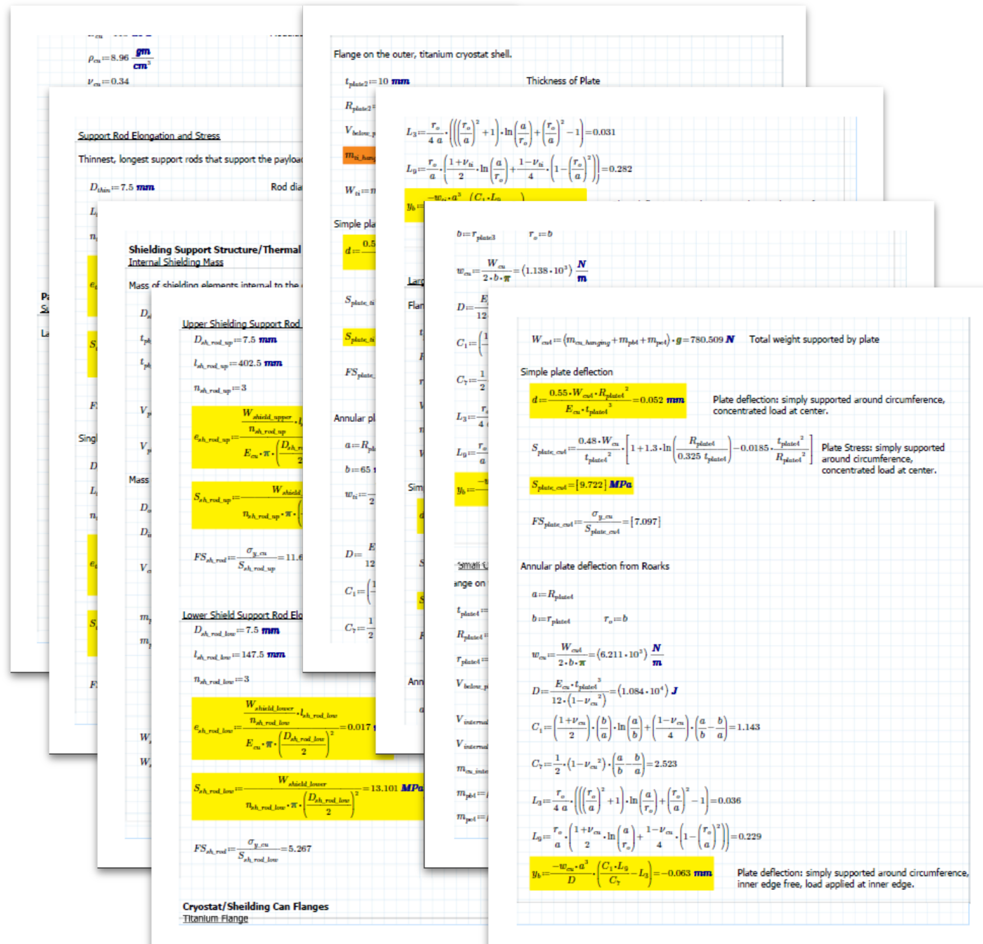
GEANT model (from Xinran)



Mechanical Analysis

Initial hand calculations to verify that reasonable plate and rod dimensions have been selected for the first round simulation models.





Progress on Shielding Design

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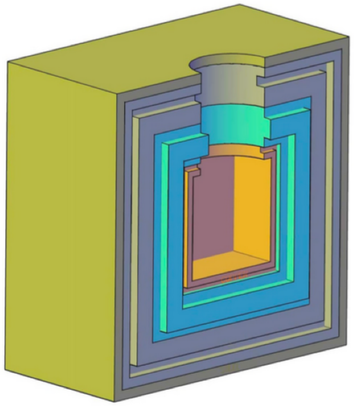
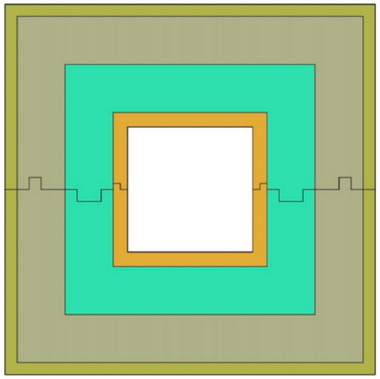
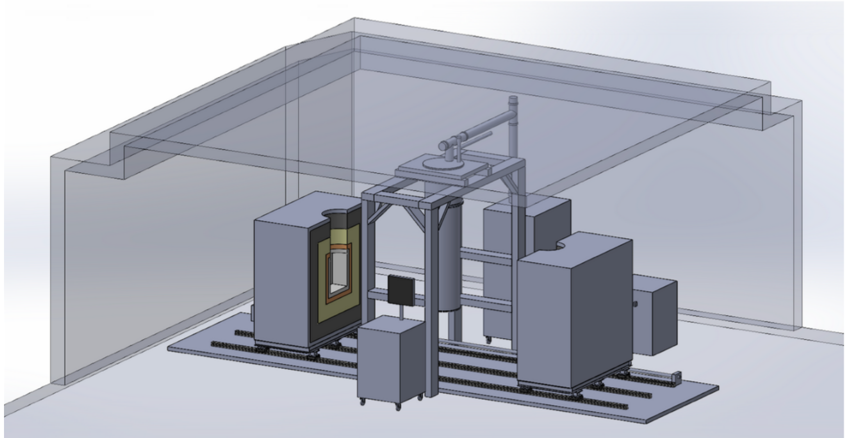
The experiments will be operated in an underground laboratory. Discussions are just beginning with underground labs.





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.

Dilution refrigerators are standard, off-the-shelf. Cryostat is simple.

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Summary

- TESSERACT is developing different targets for DM searches
- DM targets include polar crystals (SPICE) and superfluid helium (HeRALD)
- 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, should end pre-project phase by 2024.
- The TESSERACT project would begin in 2025. TPC estimated at $8.9M.
- There is competition, but TESSERACT already has a technical edge.