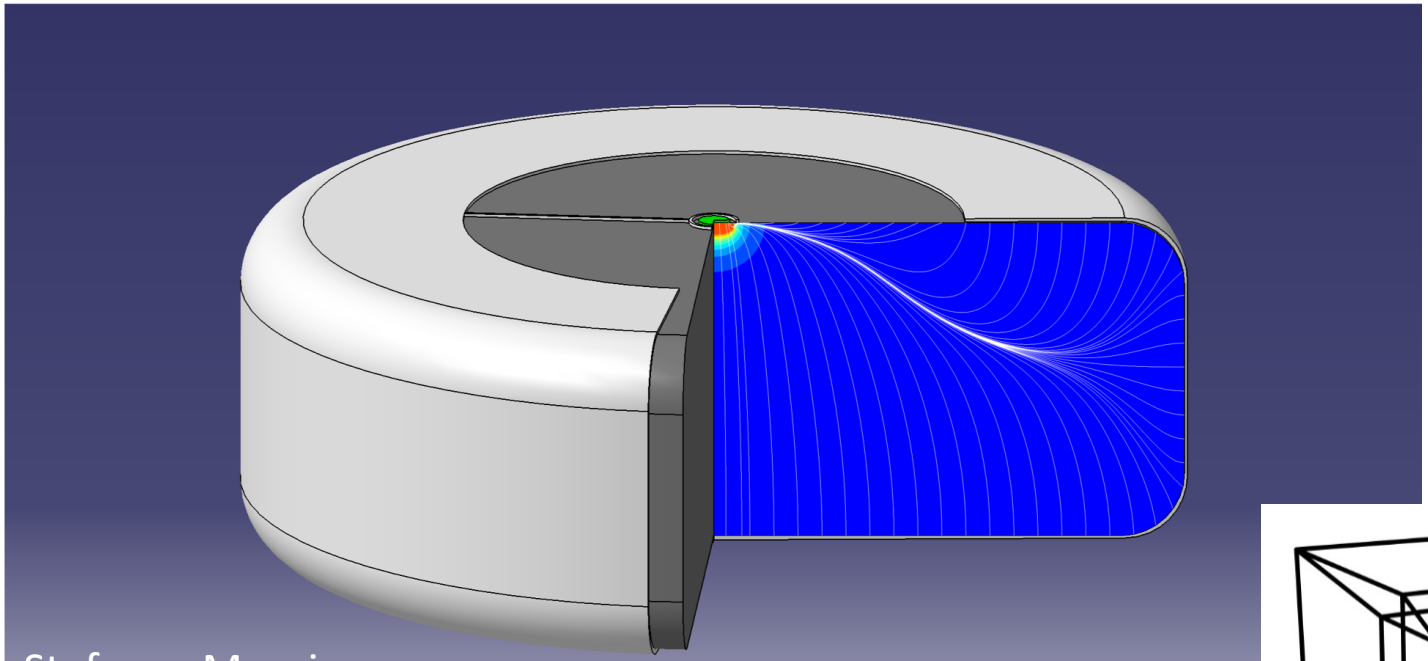
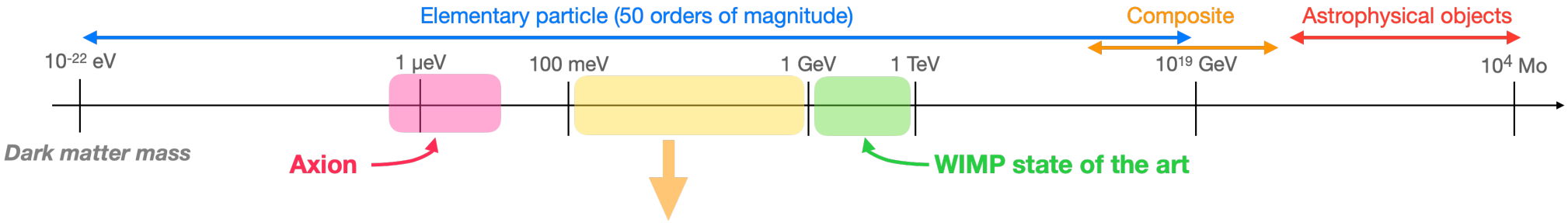
TESSERACT @ LSM
Direct Dark Matter Detection



Stefanos Marnieros
Astroparticle Solid State Detector group (ASSD) - IJCLab

TESSERACT Collaboration

TESSERACT project



Explore the meV-to-GeV dark matter mass
using phonon-mediated cryogenic detectors (T = 10 – 50 mK)

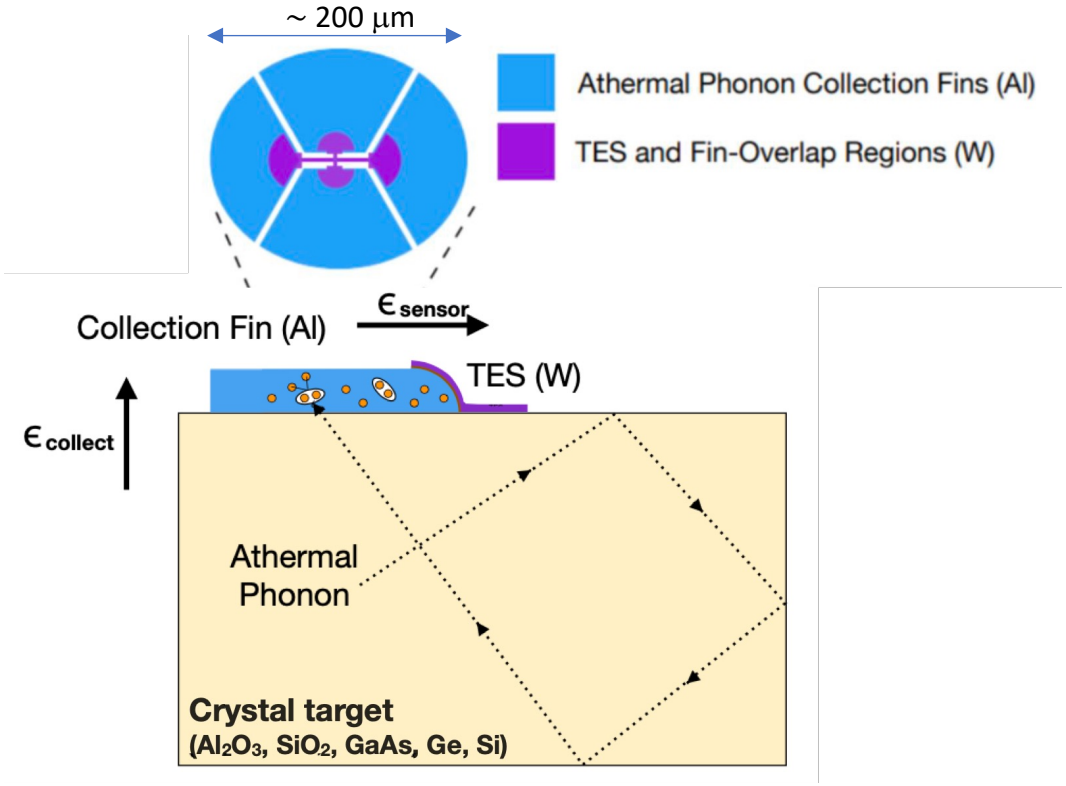
1. Cryogenic detectors with eV energy-threshold : Transition Edge Sensors (TES)
2. Diverse target materials : sensitivity to various DM candidates and couplings (dark photon mediators, direct DM absorption…)
3. Background rejection capabilities : dual detection, pulse shape …
4. Low background underground cryogenic infrastructure at LSM

TESSERACT Transition Edge Sensors (TES)

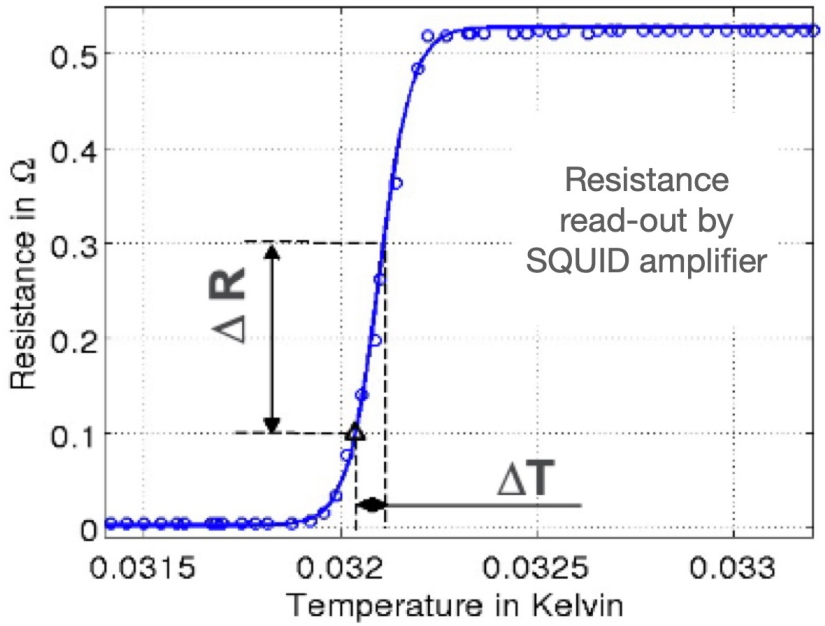
TESSERACT use a common phonon sensor technology integrated to a variety of cryogenic detector targets

TES size is small, but coupled to a large superconducting Al layer that will efficiently trap athermal phonons (”QET structure”)

Athermal phonons produce quasiparticle excitations in the Al layer that diffuse and get trapped into the TES inducing a measurable signal

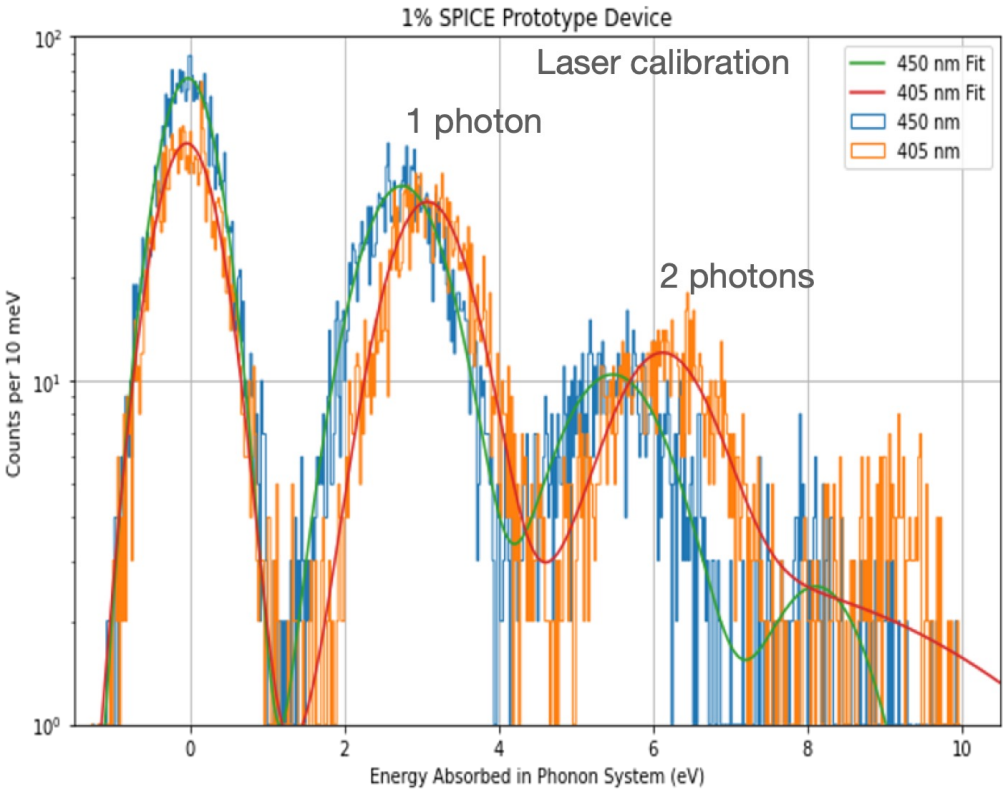


Typical TES transition

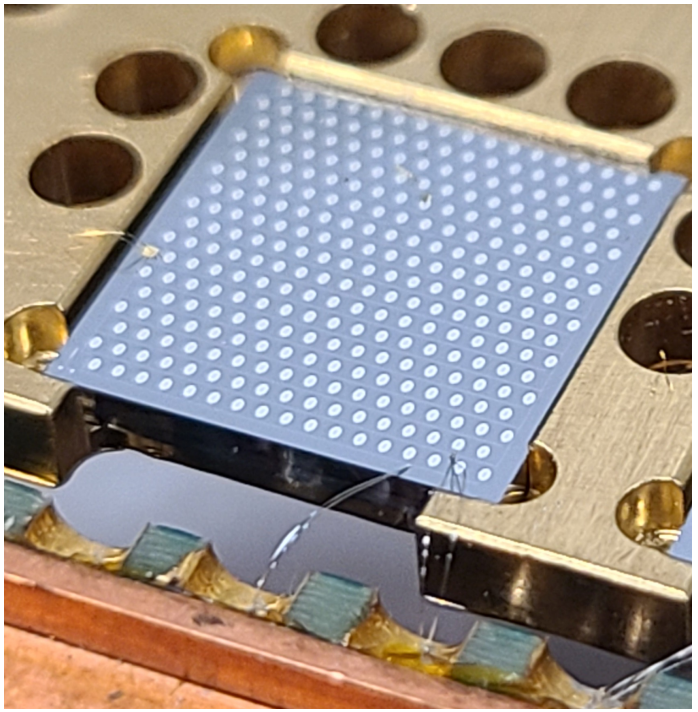


TESSERACT Transition Edge Sensors (TES)

QET sensors : **Q**uasiparticle-trap-assisted **E**lectrothermal-feedback **T**ES



273 meV (RMS) leading to eV-scale threshold with a 0.2 g Si detector

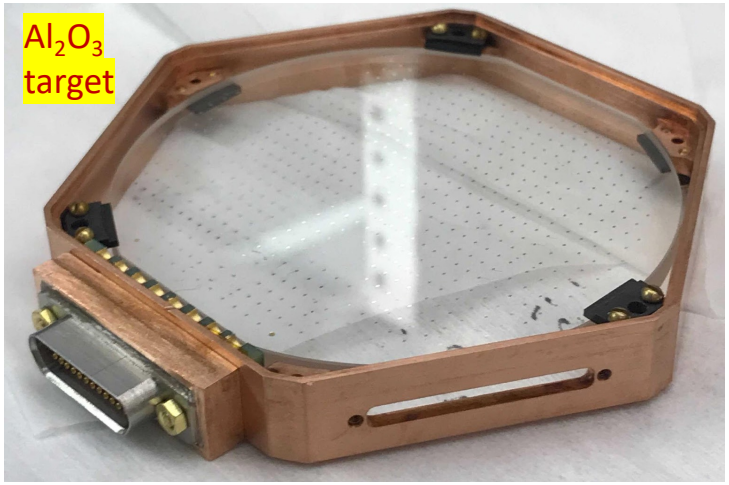


1 cm^2 x 1 mm (0.2 g) Si substrate with TES array.

Many TES connected in parallel to improve athermal phonon sensing

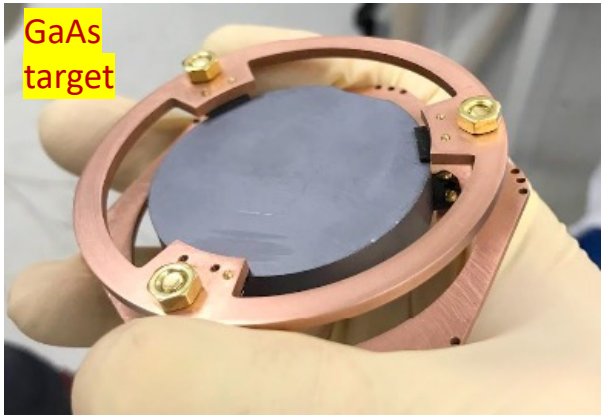
TESSERACT SPICE detectors - US

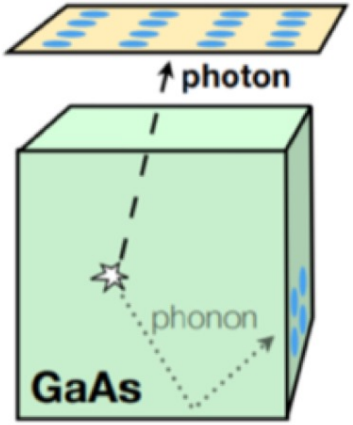
- Polar crystals (positively and negatively charged ions in the primitive cell) such as Al_2O_3, SiO_2 and GaAs may exhibit strong coupling to a dark photon mediator (optical-phonon scattering channel, arXiv: 1910.10716)
- Possibility to explore 100 meV DM masses for DM absorption on phonon



R&D on a sapphire crystal with W-TES array

Limited by a Low Energy Excess (LEE) background





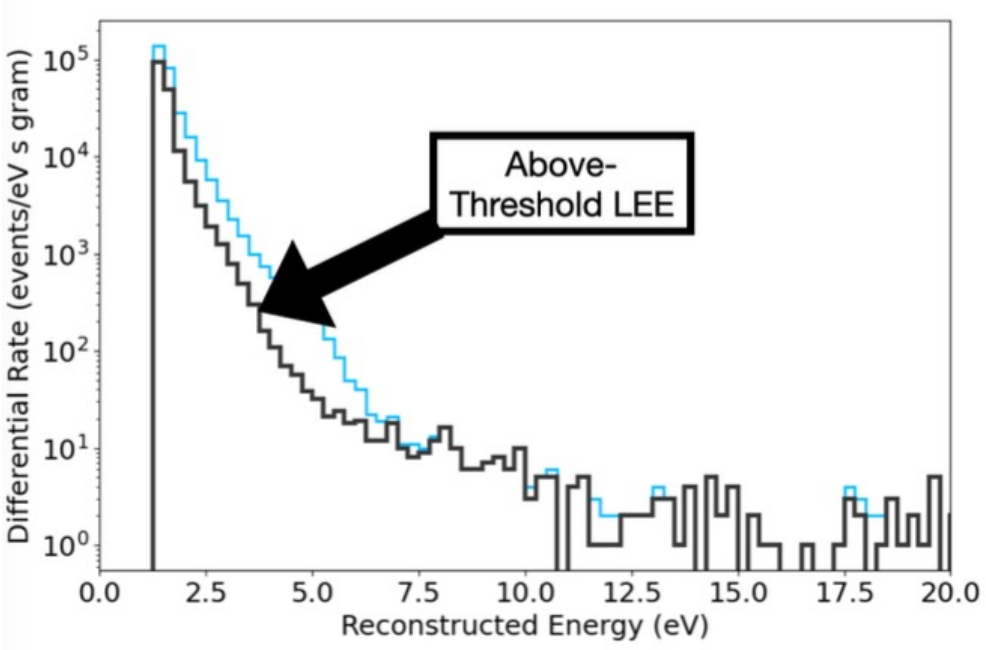
Dual detection: Scintillation + Phonon

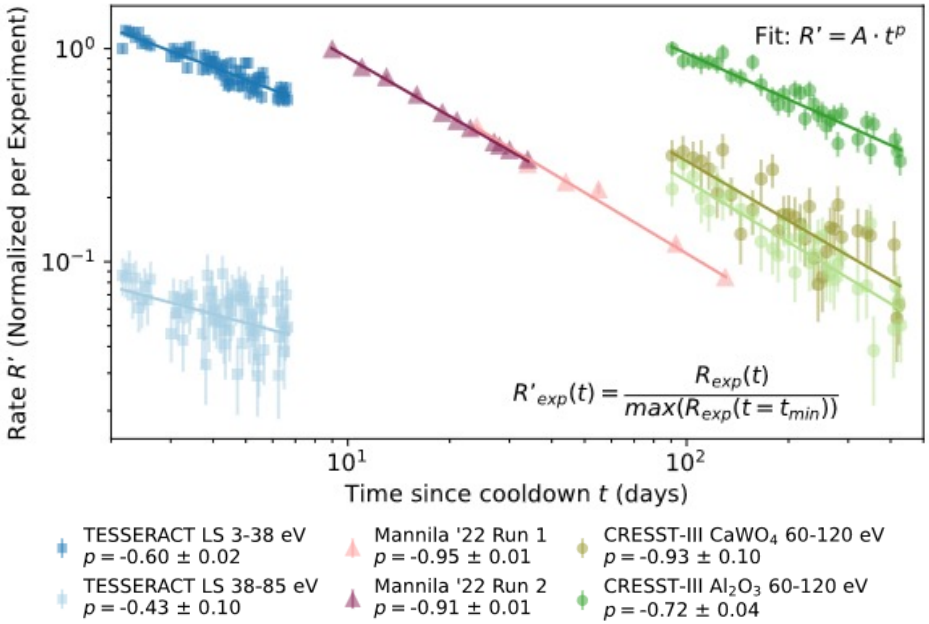
- NR/ER discrimination (≈10 eV scale)
- Active LEE discrimination (10 eV scale??)

Si:P doped GaAs has very high scintillation yield (125 ph/keV, arxiv:1904.09362)

Low Energy Excess (LEE) background in cryogenic detectors

arXiv: 2503.08859





LEE background rate is decreasing over time

All cryogenic experiments using phonon sensors observe an excess background rising below 1 keV

- Far exceeding all other backgrounds at low E → strongly limiting DM detection
- Most probably related to stress-release of the detectors after cooling-down
- No ionizing, no scintillating background

Low Energy Excess (LEE) background in cryogenic detectors

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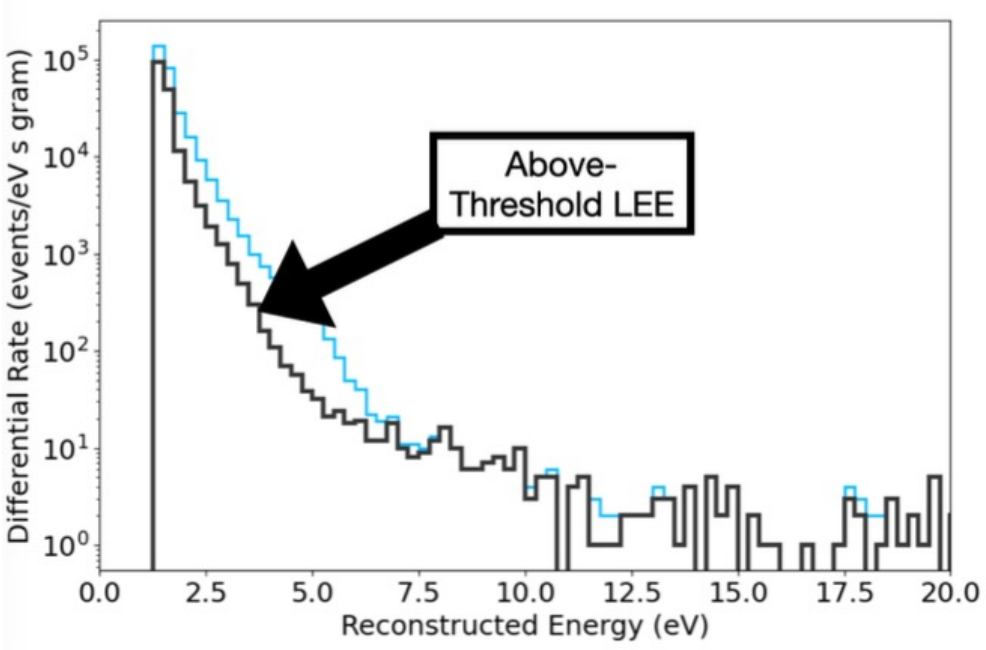
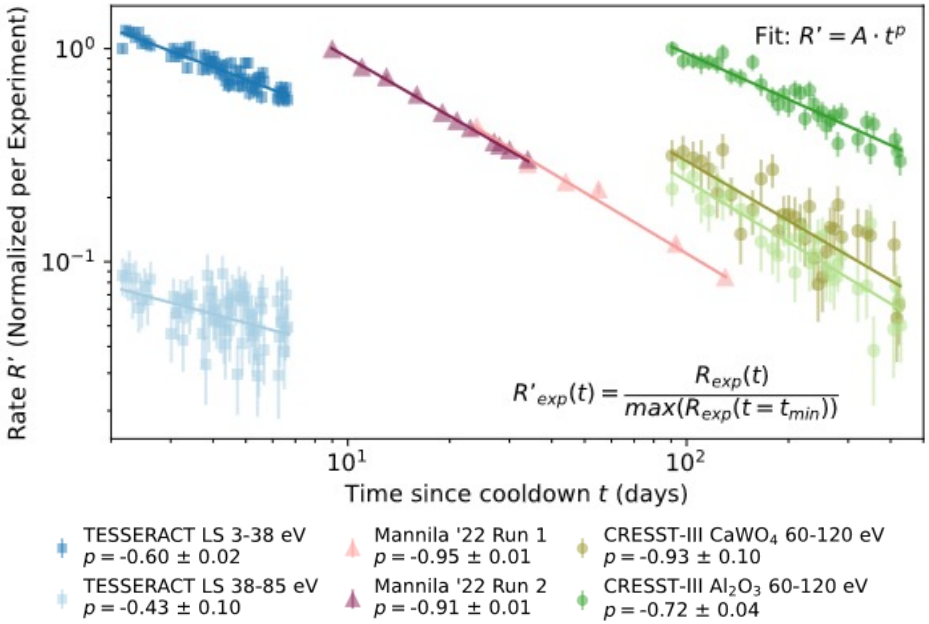


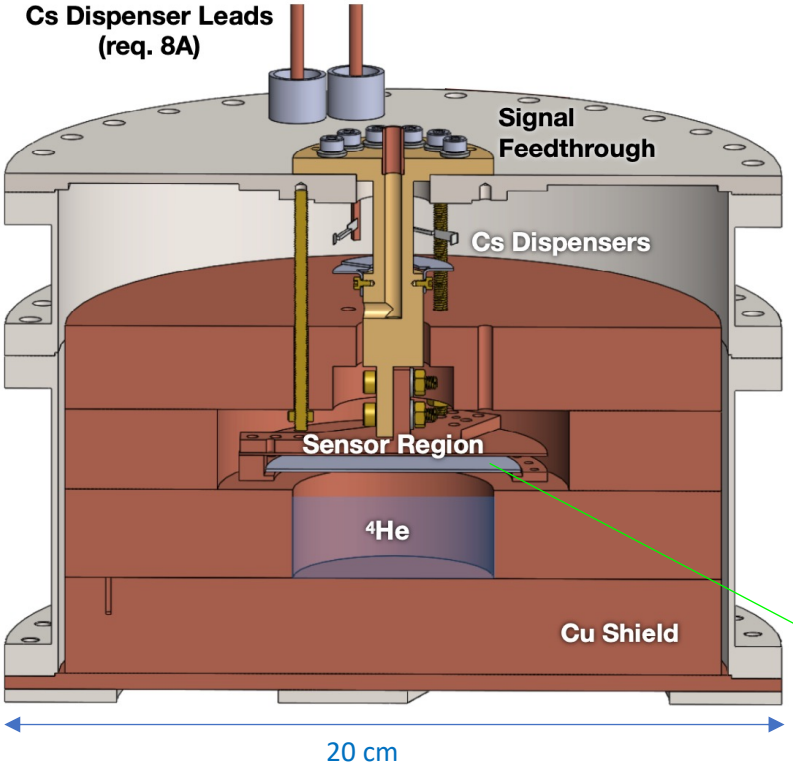


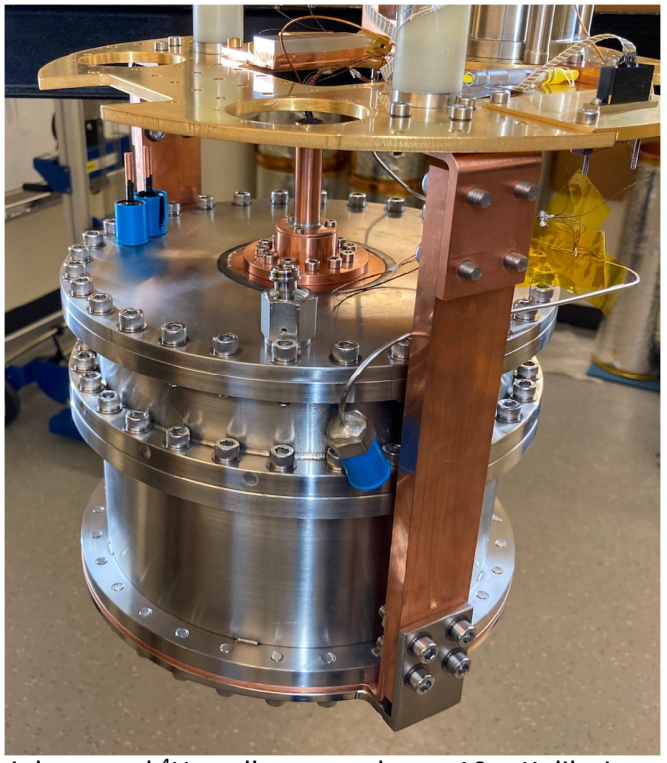
LEE background rate is decreasing over time

Design driver of TESSERACT:

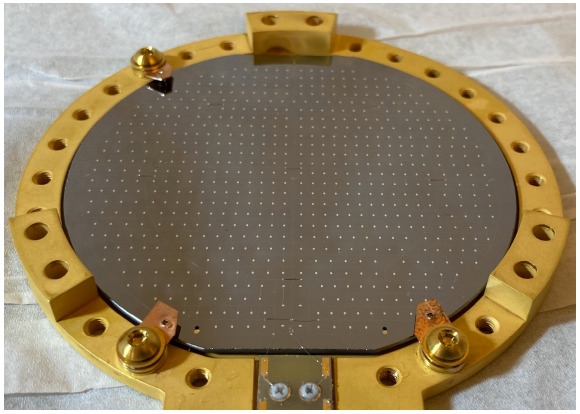
- *find the origin of the LEE to mitigate it*
- *develop detector technologies that can reject it*

"HeRALD v0.1" R&D Hardware





Stainless steel ^{4}He cell mounted on a 10 mK dilution refrigerator

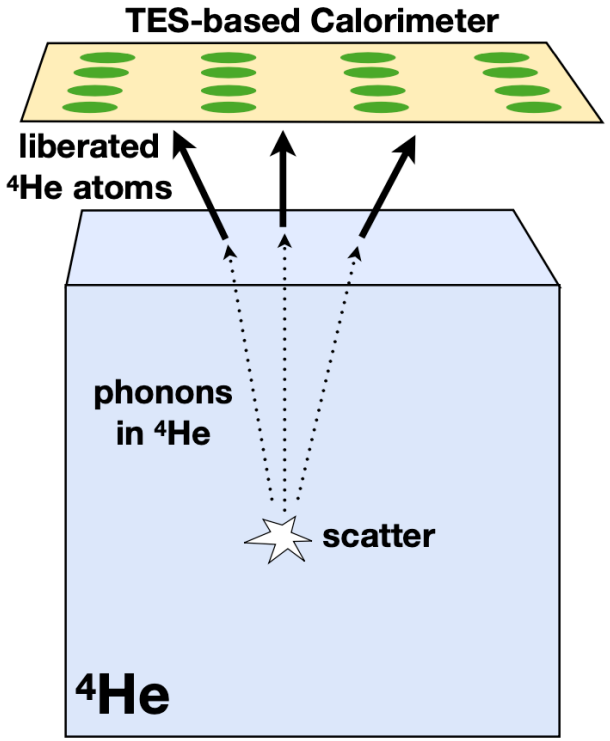


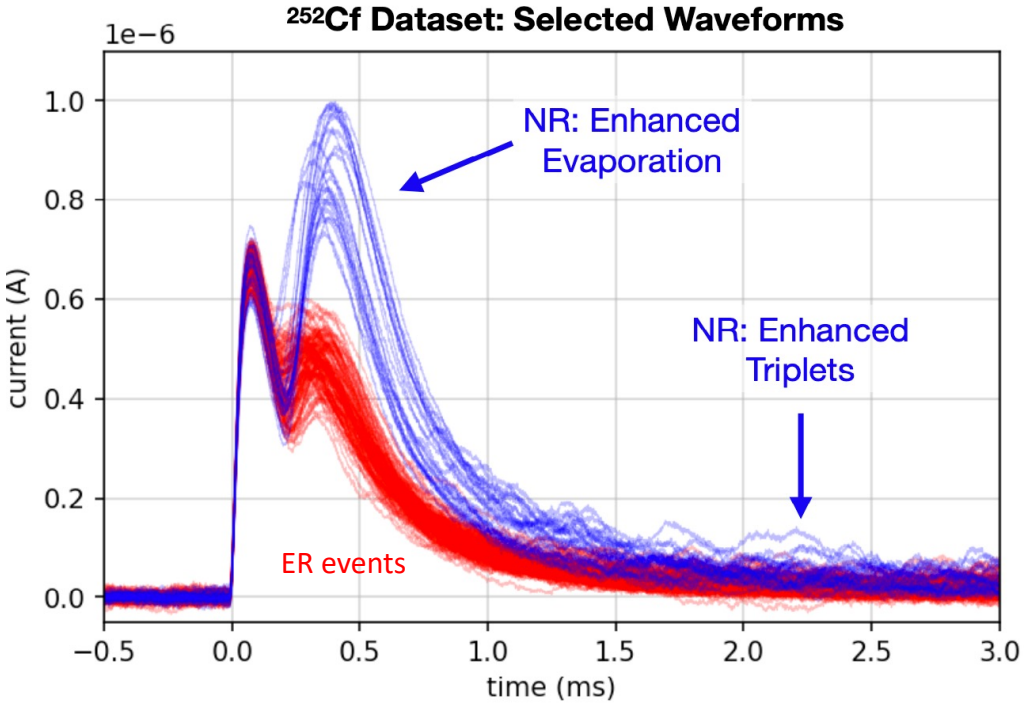
TES calorimeter for R&D v0.1:

- 3" Si wafer (10 g mass, 1mm thickness)
- Array of W based TES (Tc=55mK)
- 2.26 eV RMS resolution for energy on Si

arXiv:2009.14302
arXiv.org:2307.11877

Scintillation + Phonon signal via ^{4}He “quantum evaporation”





Already achieved 170 eV threshold on He recoils (300 MeV DM)
Possible ER/DM discrimination down to 20 eV

TESSERACT – France :

LSM site, radiopurity & background simulations

Ge and Si heat-ionization detector R&D

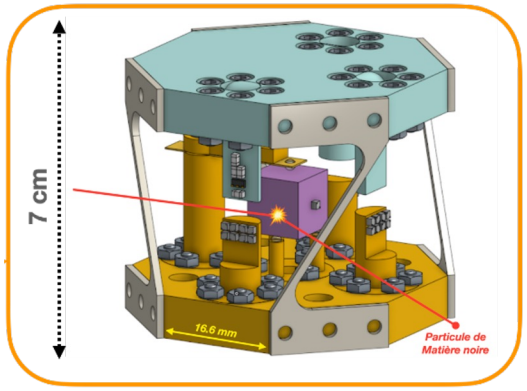
Direct DM detection with low threshold Ge and Si cryogenic technology

- Low ionization and heat threshold (critical)
- Reasonably high detector mass (~ 5 to 50 g)
- ER/NR discrimination
- LEE background mitigation (passive + active)

2 detector technologies are developed in parallel (TES4DM project)

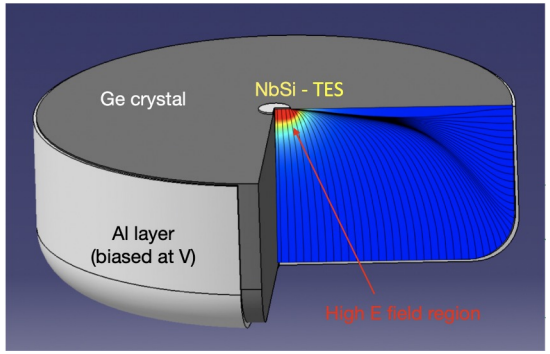
Detectors with HEMT charge read-out

HEMT : High Electron Mobility Transistor

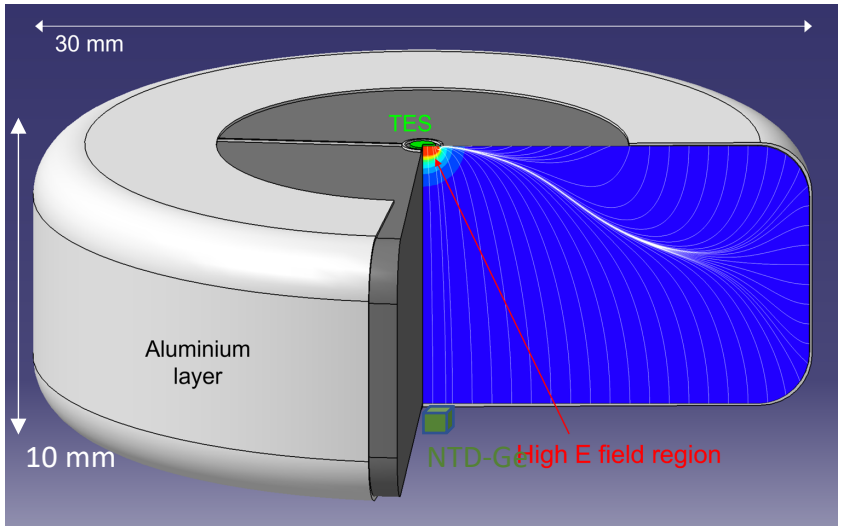


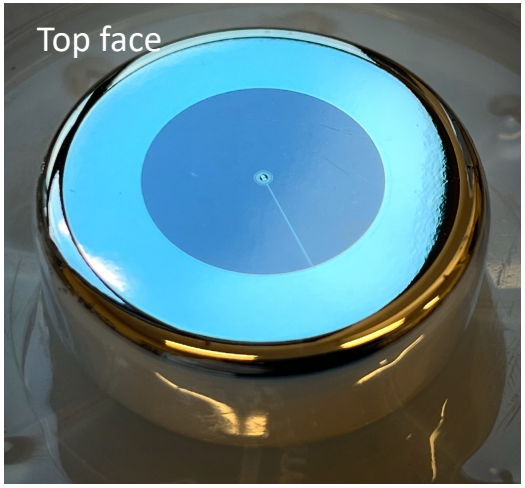
Detectors with NTL-amplification charge sensors

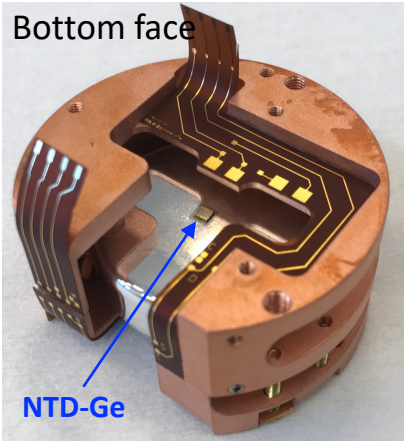
NTL : Neganov – Trofimov – Luke effect



Single-electron detection in a high-purity Ge device





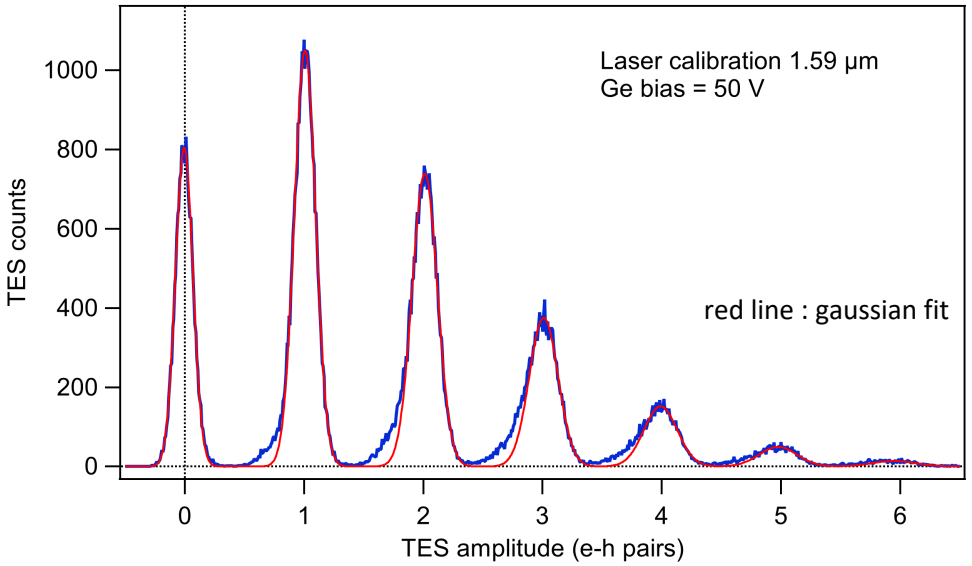


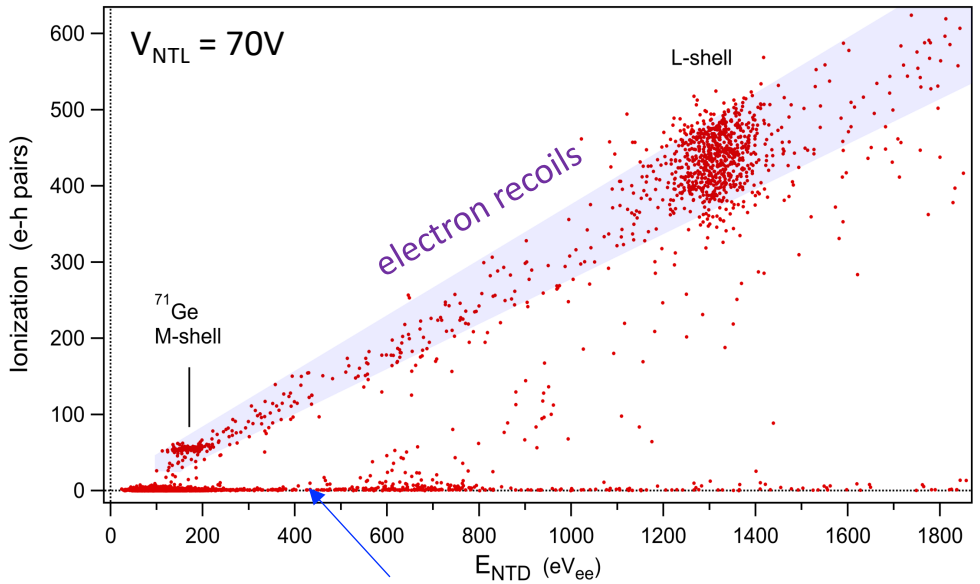
- NTD-Ge measures thermal signal
- TES measures athermal phonons

Point contact HPGe design:

- "Point contact" NbSi TES (biased close to 0 V)
- Large Al electrode on bottom + side + part of top face (biased at V_{NTL} in the 0 to +-100 V range)
- E-field shaping electrode around the TES (biased at V_{NTL})
- NTD-Ge thermistor glued at the bottom face (isolated from the detector by a glue layer)

Single electron-hole resolution – Active background discrimination





LEE background + events with substantial trapping

- Single electron resolution in a 40 g Germanium detector
- Active discrimination of the LEE background
- Possible ER – NR discrimination

TESSERACT@LSM: Getting ready for LSM

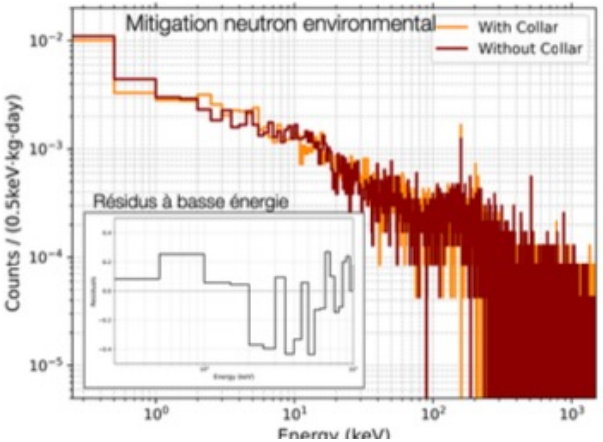
Designed around commercial cryostat and vertical layout.

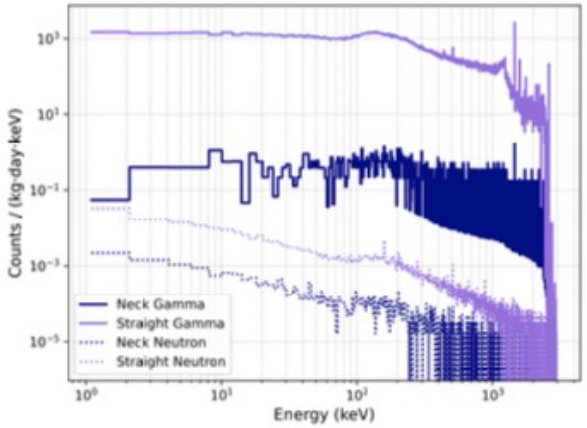
- Narrow 'neck' region, with Pb plug above at 1K
- Thick Cu at base temperature surrounds target region.

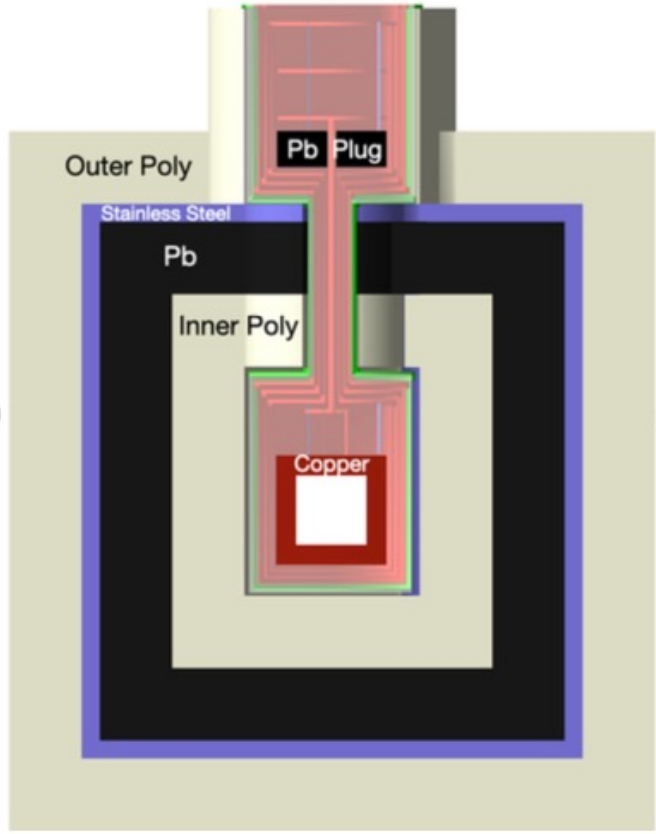
Material screening at LSM ongoing

Simulations predict **~1 DRU (ER)**
<1e-3 DRU (NR)

(possible future upgrade: cold inner veto)

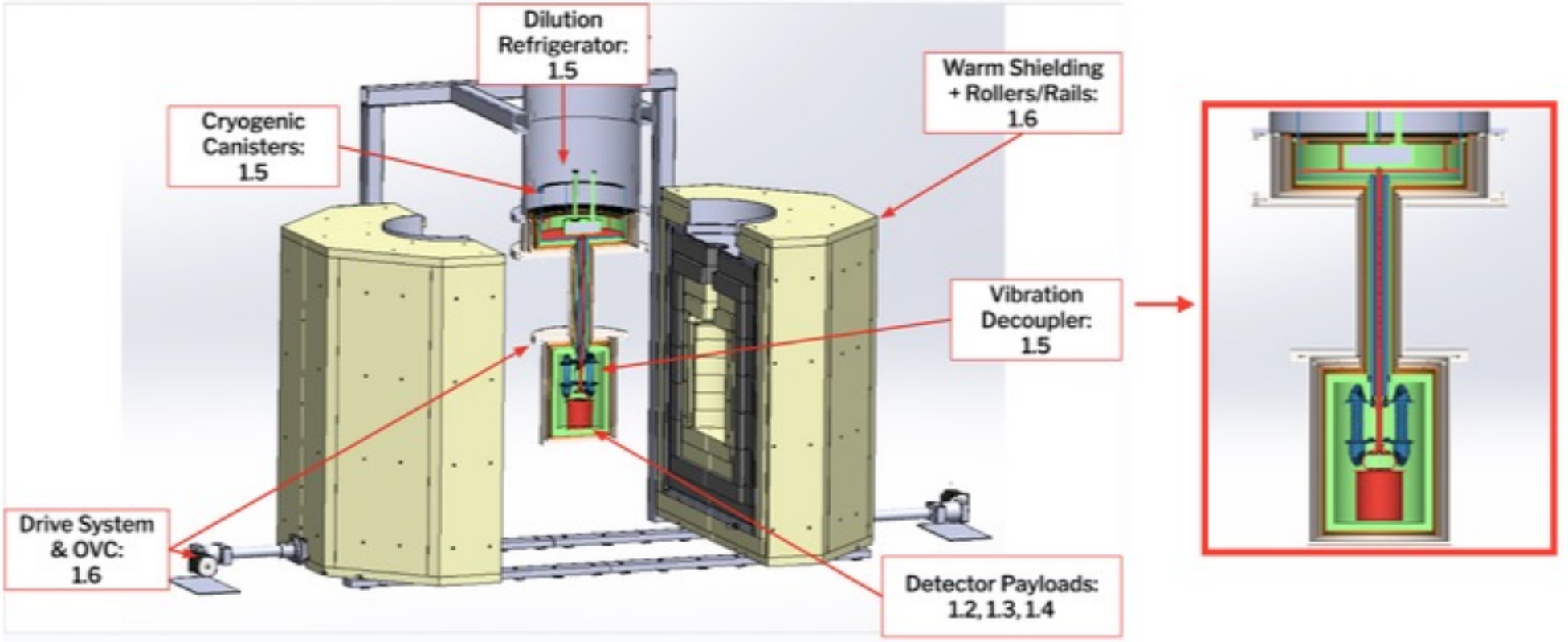






Moving to Modane in **2028** for low-background searches starting in **2029**

Two dilution refrigerators operating in parrallel.



TESSERACT at LSM : quite near-term, and very very long term…