# The TESSERACT direct dark matter experiment at LSM

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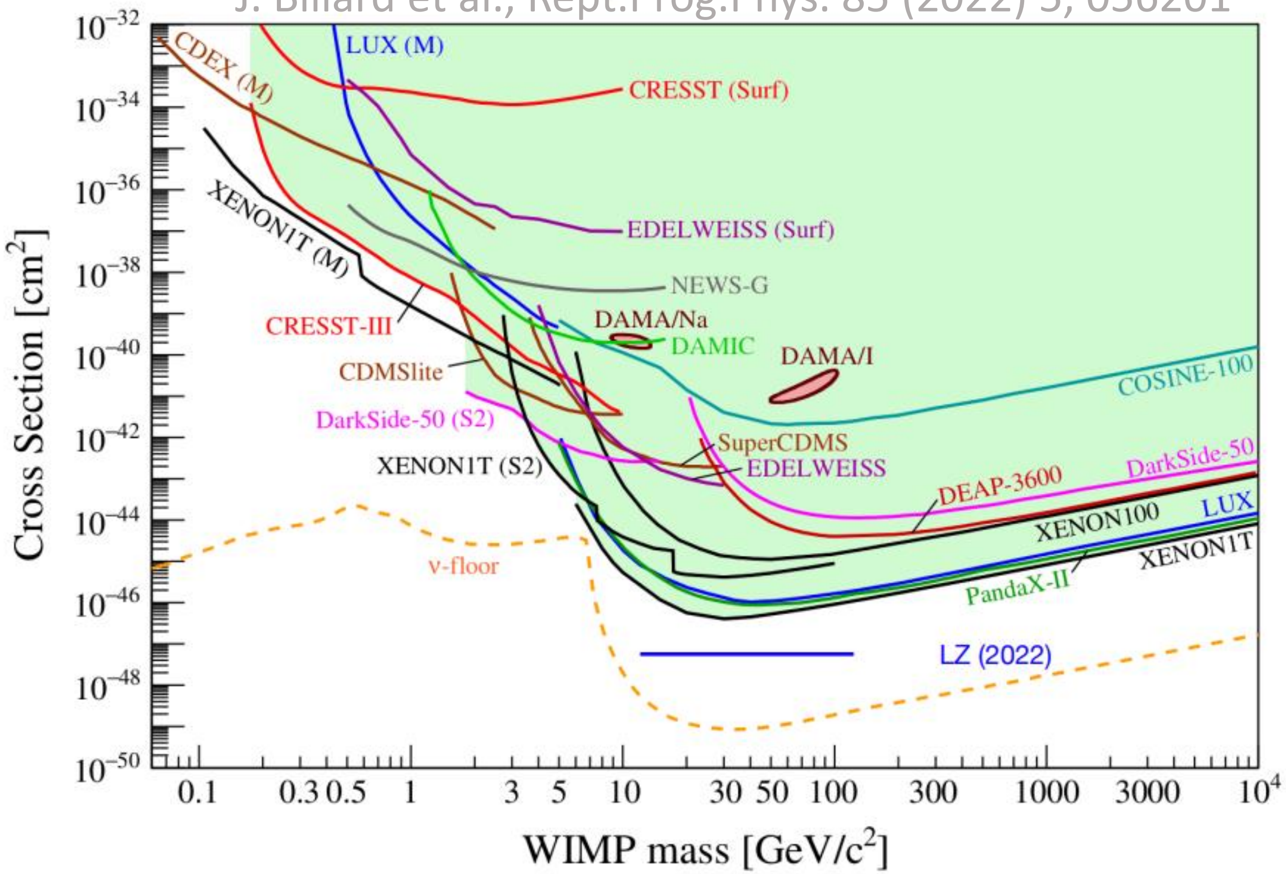
# Direct Dark Matter Search Status

- Direct Dark Matter (DM) searches have been mostly focused around the standard WIMP mass (10 GeV - TeV)
  - Better limits reached by few tons experiments (liquid target)
- Still no evidences, now reaching neutrinos floor

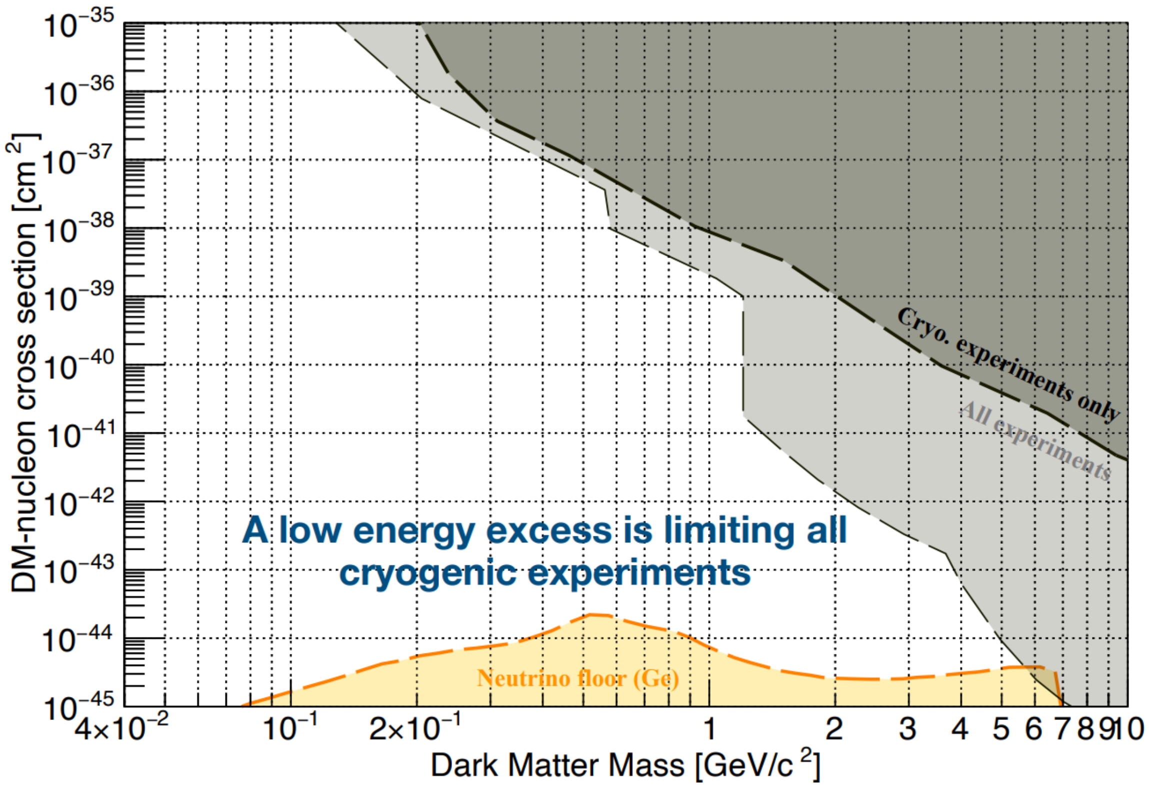
Need to broaden DM searches including masses below the GeV

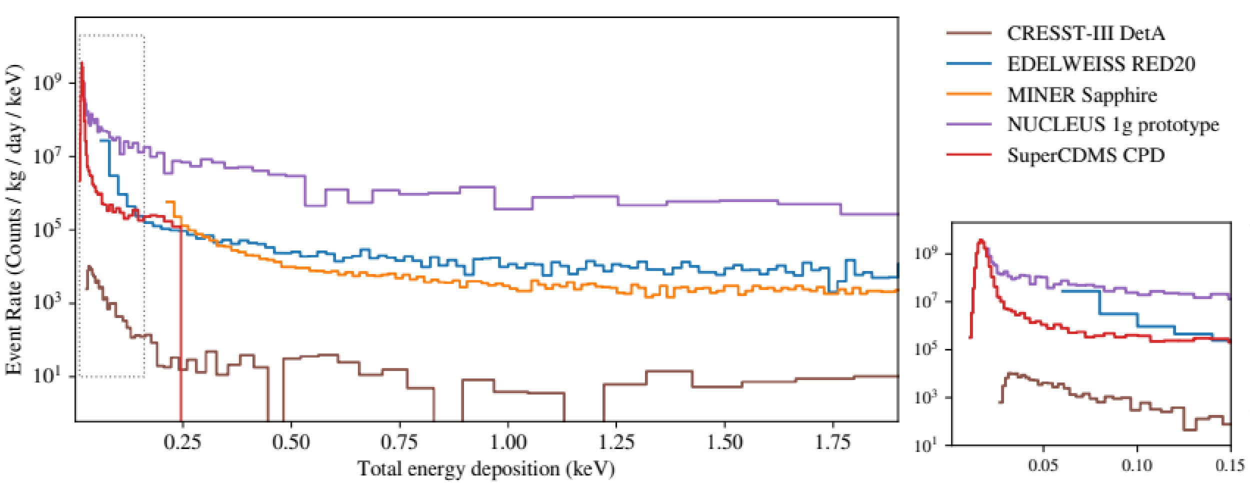
J. Billard et al., Rept.Prog.Phys. 85 (2022) 5, 056201




Solid state and cryogenic detectors are best suited for low mass DM detection

# Cryogenic DM Experiments and Low Energy Excess (LEE) Limiting DM Search




P. Adari, SciPost Phys. Proc. 9, 001 (2022)

LEE Characteristics:
Non ionising (« Heat Only »), mostly independant of site, unknown origin

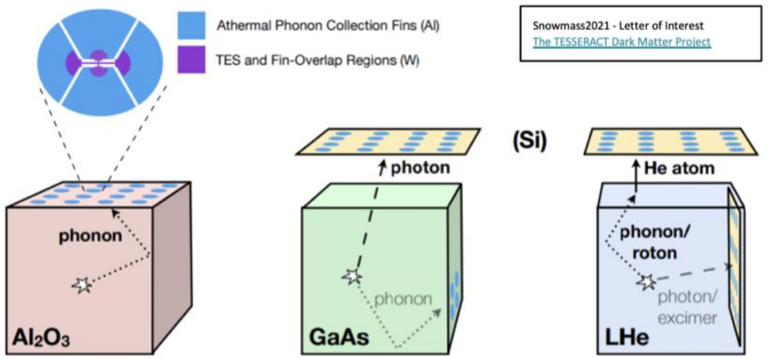
Need to understand, mitigate LEE and develop new technology to reject it

# The TESSERACT Experiment

**T**ransition **E**dge **S**ensor with **S**ub-**E**v **R**esolution **A**nd **C**ryogenic **T**arget

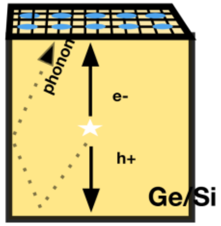
*<u>Goal:</u> extending the Dark Matter mass search window from meV-to-GeV with ultra low-threshold cryogenic detectors with multiple targets and particle identification capabilities*

## US contribution




One design, several targets leading to different DM sensitivities

## French contribution




Add the Ge/Si semiconductors calorimeter technology and benefit from RICOCHET and EDELWEISS experiences

Deploy TESSERACT experiment @ LSM

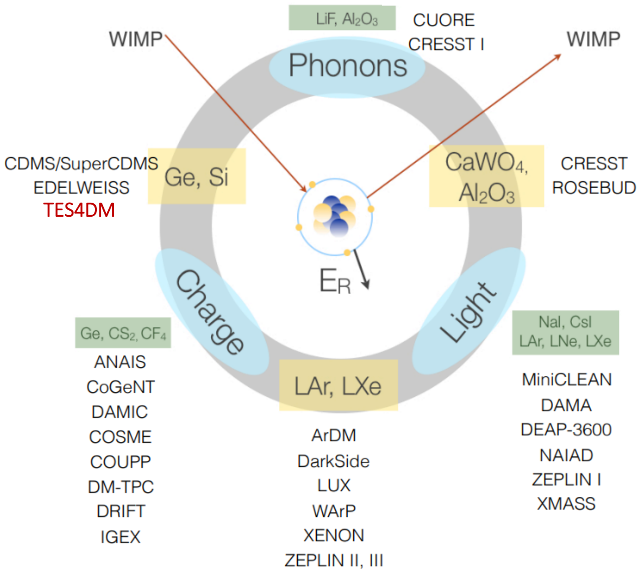
**$\mathbf{RI^2}$ project: TES4DM**

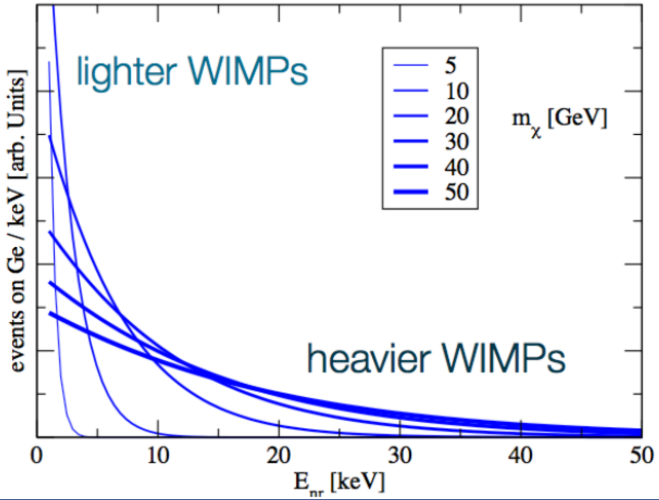
# Dark Matter Detection Wishlist

- **Discrimination between signal and background**
    - Simultaneous readout of signals induced from energy deposition to distinguish NR/ER
    - Fiducialization of detectors for background rejection

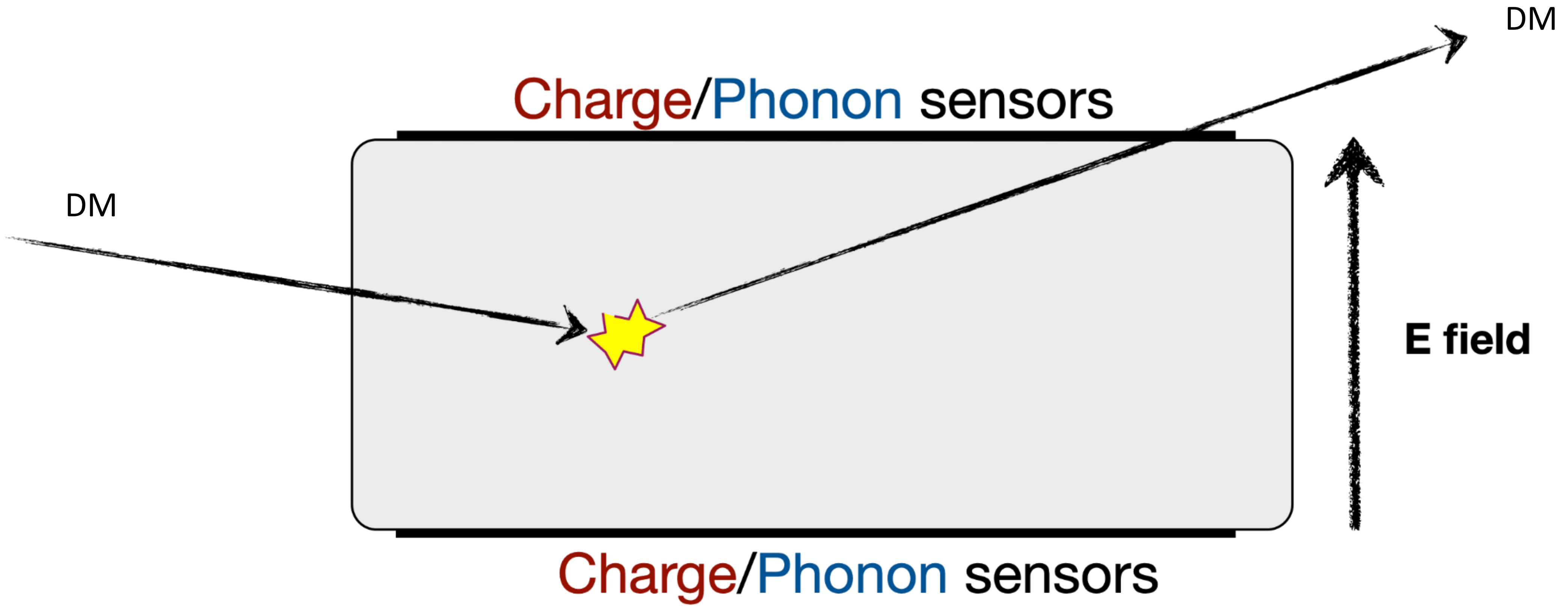
- **Low energy threshold**
    - Elastic scattering of light DM particle deposits few keV in the detector

Use Ge/Si semiconductor calorimeter

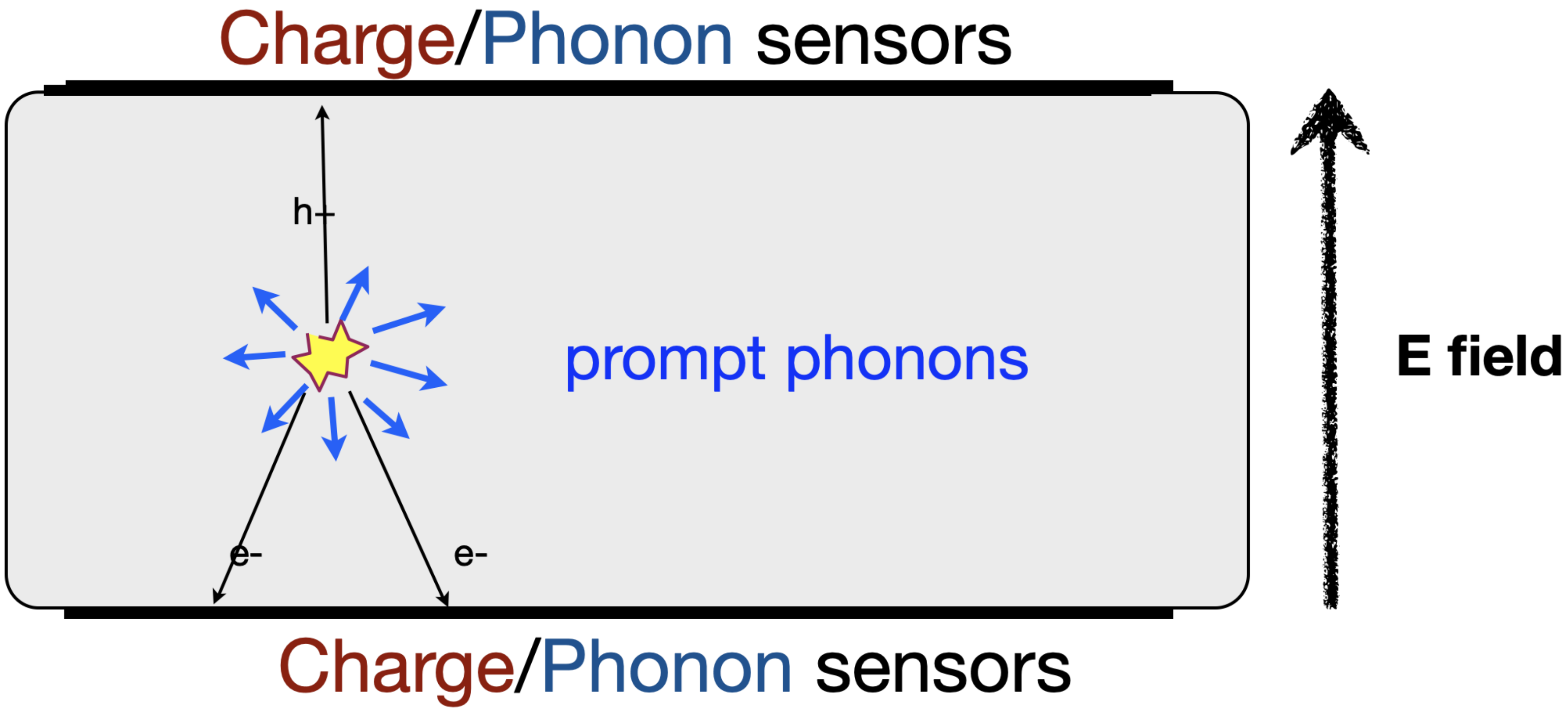


# Ge/Si semiconductors

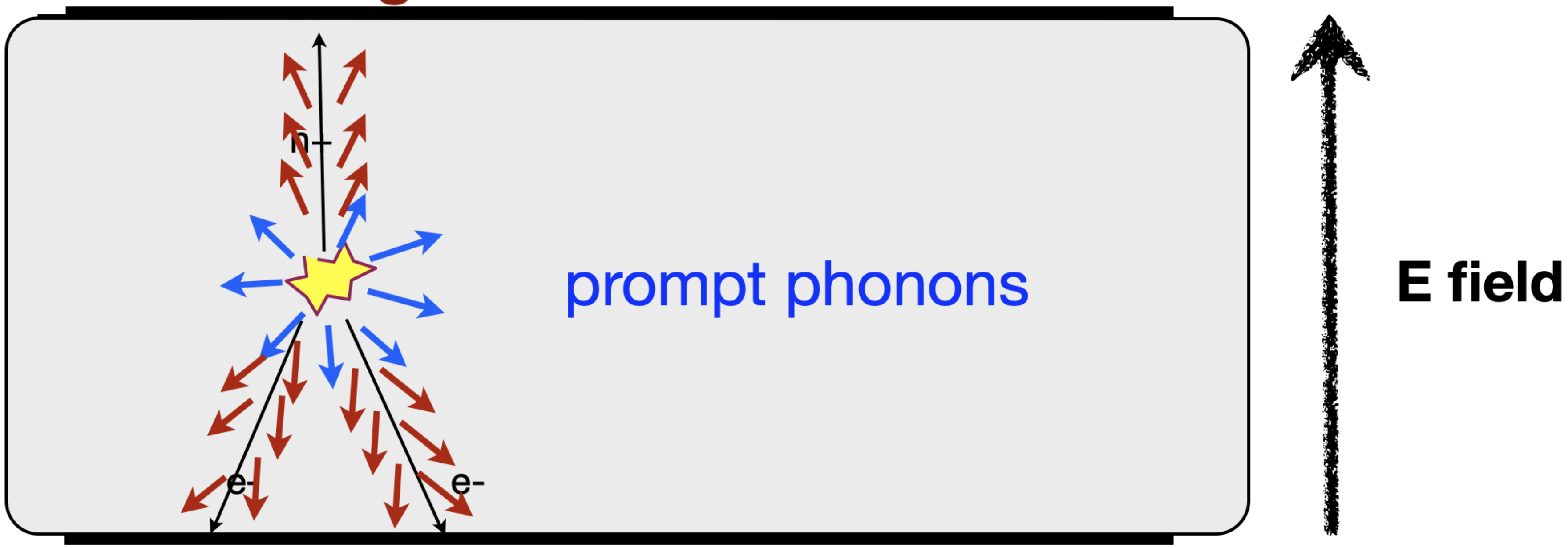


# Ge/Si semiconductors



# Ge/Si semiconductors

Charge/Phonon sensors




Charge/Phonon sensors

$$E_{total} = E_{recoil} + E_{luke}$$

$$= E_{recoil} + \frac{1}{3\ eV} E_{ion} \Delta V$$

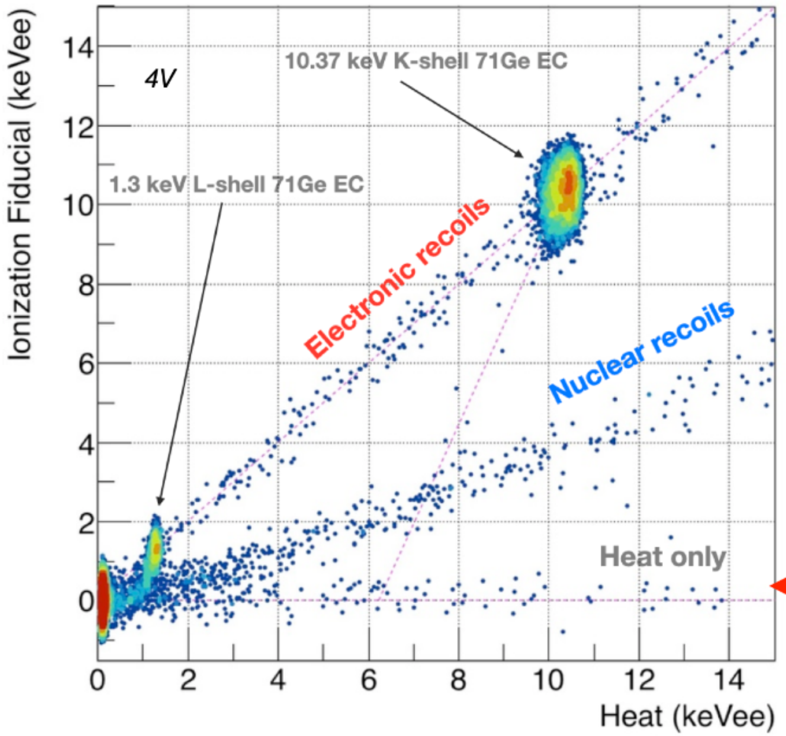
# Ge/Si semiconductors

Two working modes:

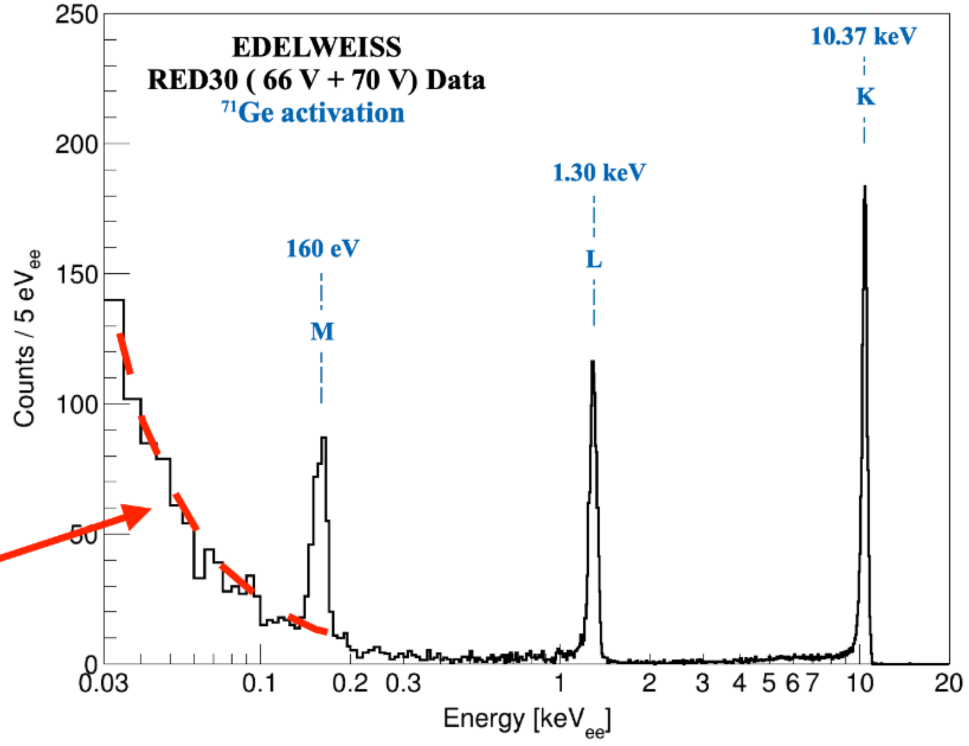
$$E_{total} = E_{recoil} + E_{luke} = E_{recoil} + \frac{1}{3\ eV} E_{ion}\Delta V$$

**Low Voltage mode**
Part. ID + Fid

**High Voltage mode**
single e/h - No PID

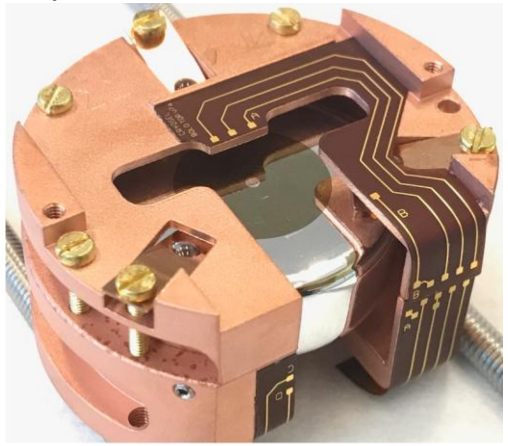


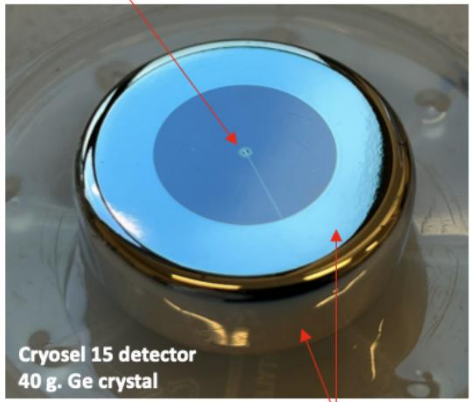

LEE



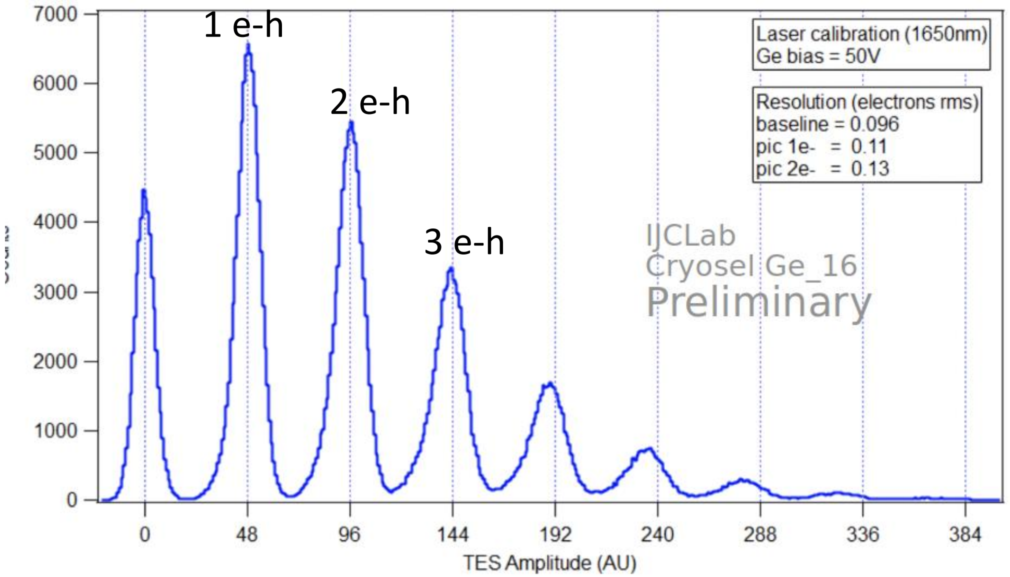
# Ge/Si semiconductors : High Voltage mode

Optimal for **ERDM** sensitivity






**First observation of a single-electron sensitivity in a massive (40g) Ge cryogenic detector !**




**CRYOSEL performance goals**: 200 V bias + single e-h sensitivity + SSED LEE tagging efficiency > 1000

**First R&D results shown at TAUP2023:**

- Stable operation up to 60 V
- Confirmation that first NbSi SSED acts as efficient LEE veto
- New prototype currently being tested with significantly improved performance

**For TESSERACT:**

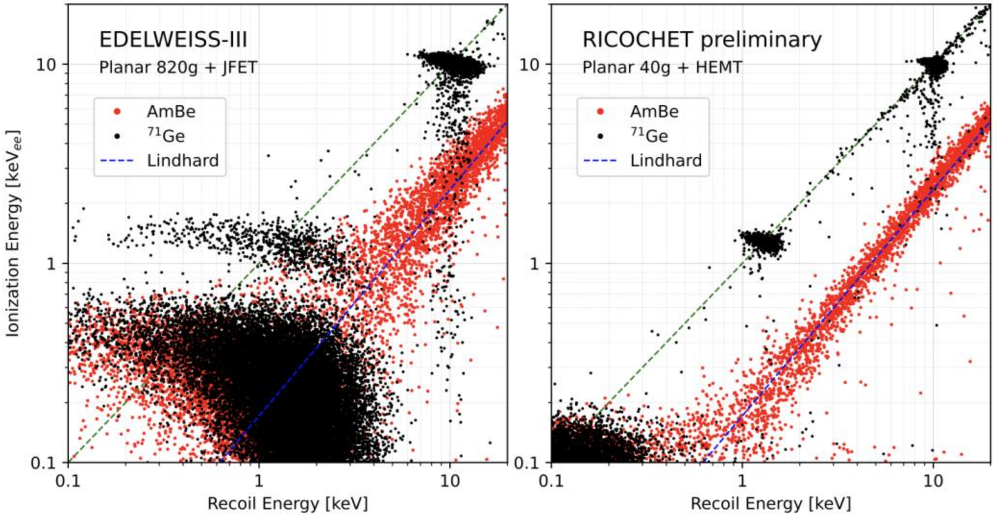
- Switch to low-imp. TES for sub-eV SSED energy threshold
- LEE discrimination down single e-h pair
- Exquisite sensitivities to ERDM with LEE discrimination

# Ge/Si semiconductors : Low Voltage mode

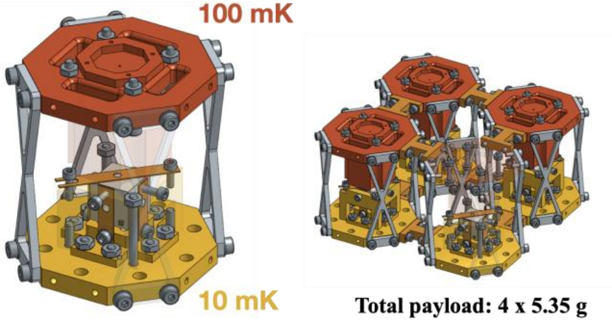
Optimal for **NRDM** sensitivity

Energy thresh.: 4.5 keVnr
Ion. thresh.: 700 eVee

Energy thresh.: 300 eVnr
Ion. thresh.: 160 eVee




Presented at: TAUP2023, IDM2023, Nobel Symposium 2023 (NS-182 « Dark Matter »)




•ER/NR discrimination threshold has been **improved by about one order of magnitude** w.r.t EDW and SuperCDMS
•Ricochet can now probe reactor neutrinos (CEvNS) and equiv. 3 GeV WIMP with highly efficient LEE and ER rejection

**Ricochet resolution goals:** 20 eV (heat) + 20 eVee (ionisation) - almost achieved (by a factor of ~2)

**For TESSERACT:**

•Switch to TES for sub-eV heat energy threshold and reduced LEE, and aiming for <10 eVee ion. resolution
•ER/NR identification down to 10s of eVnr + LEE discrimination down to 50 eVnr (Lindhard)
•Ideal for low-mass NRDM with PID

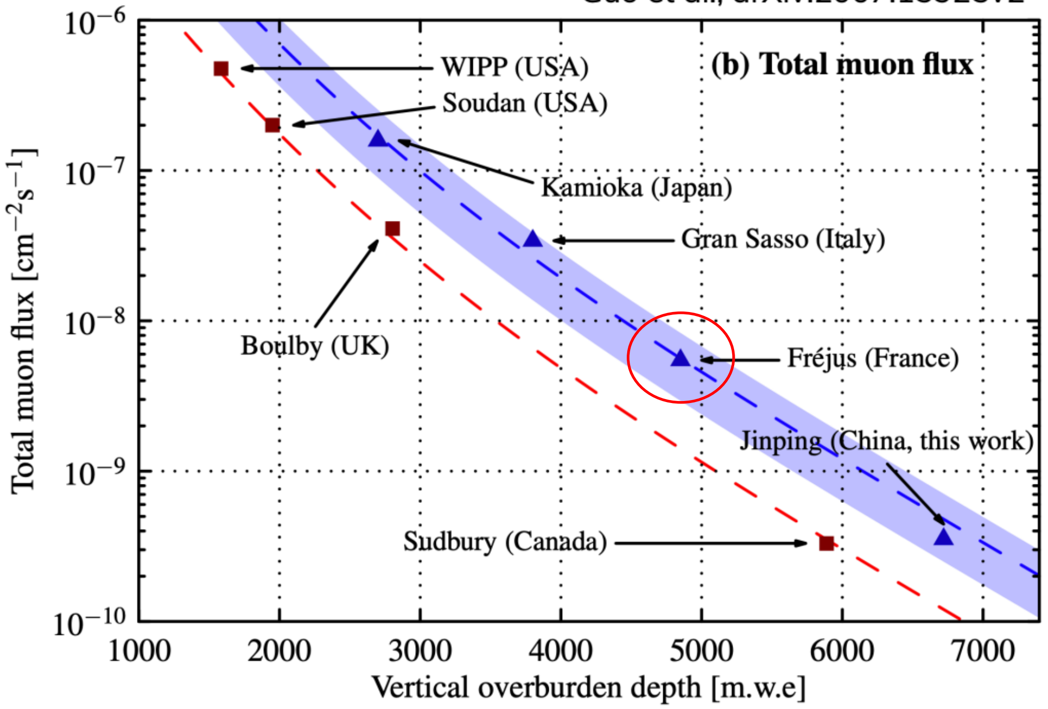
# Dark Matter Detection Wishlist

- **Discrimination between signal and background**
  - Simultaneous readout of signals induced from energy deposition to distinguish NR/ER
  - Fiducialization of detectors for background rejection
- **Low energy threshold**
  - Elastic scattering of light DM particle deposits few keV in the detector
- **Low and controlled backgrounds**

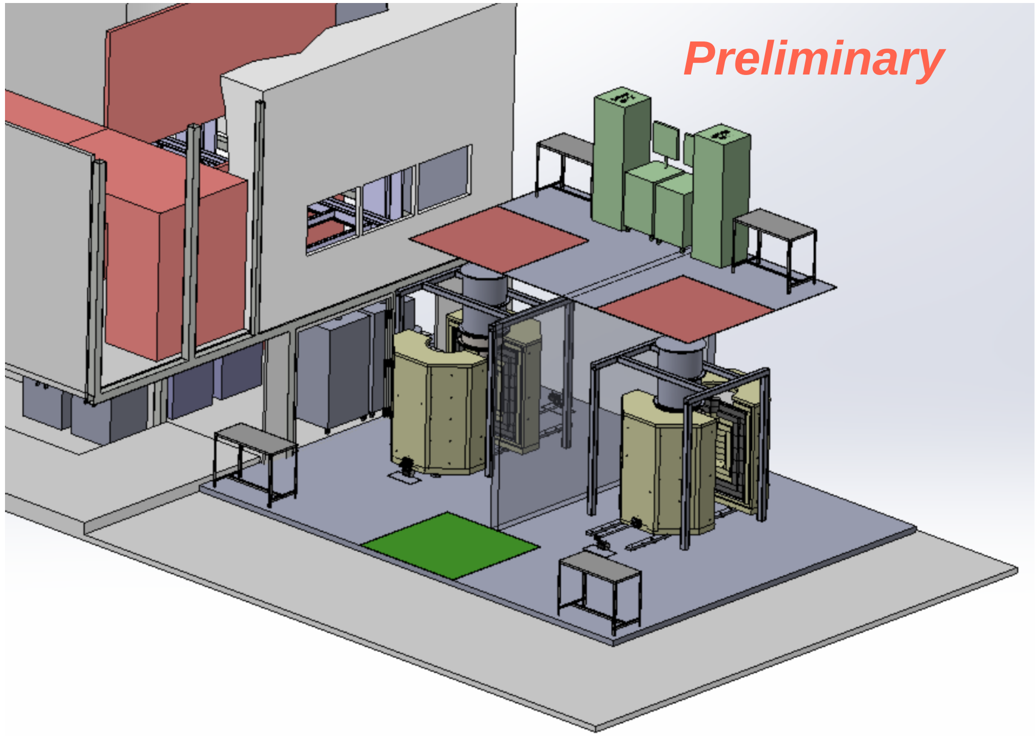
# Background Mitigations

- **Cosmic rays + cosmogenic activation of detectors & shielding materials**
  - ✓ Low Background Environment: TESSERACT integration in Modane Underground Laboratory

Guo et al., arXiv:2007.15925v2




Muon flux reduced by $\mathbf{10^6}$ relative to surface



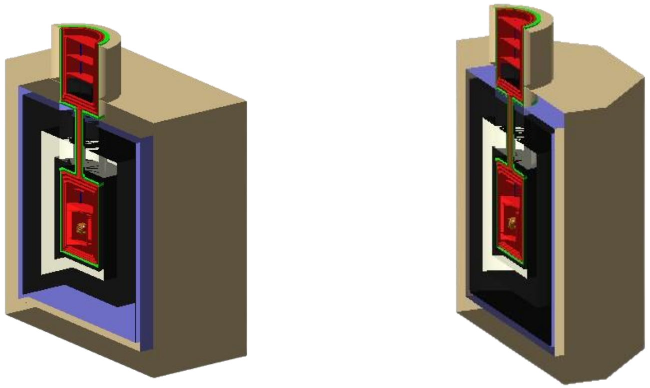
# Background Mitigations

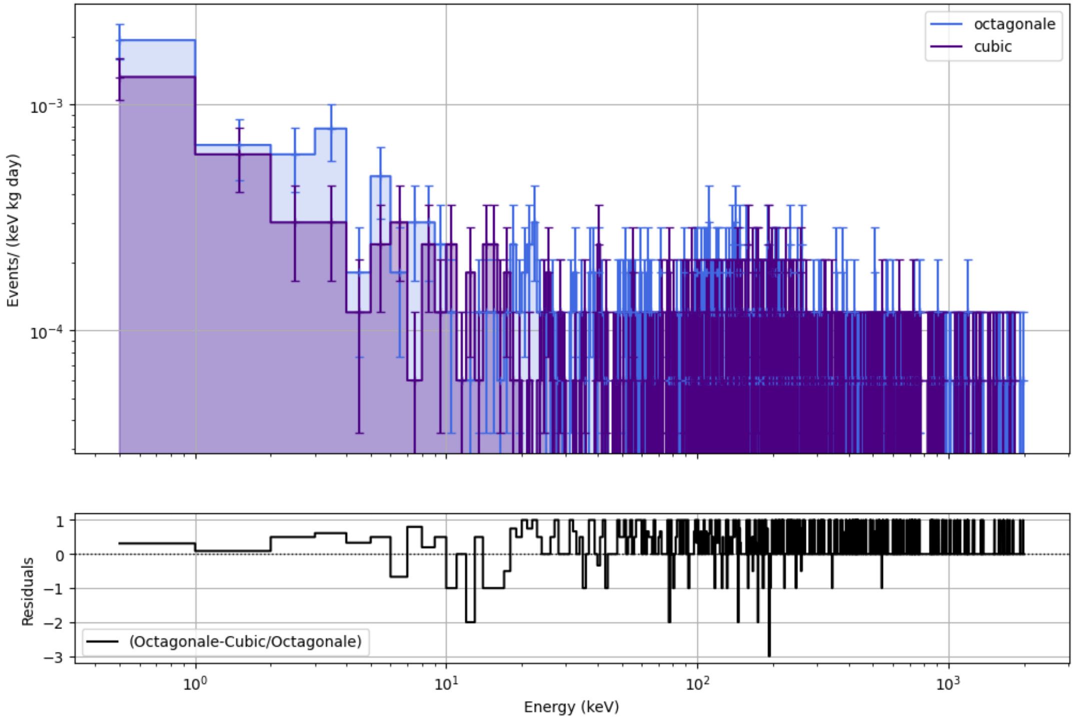
- Cosmic rays + cosmogenic activation of detectors & shielding materials

- **Natural radioactivity from Modane rock (U, Th, K)**
  - ✓ Passive/Active shielding

- **Internal radiogenic contamination (U, Th, K, Cs …)**
  - ✓ Radiopurity specifications with screening and material assay with HPGe

Ongoing simulation work essential for geometry design

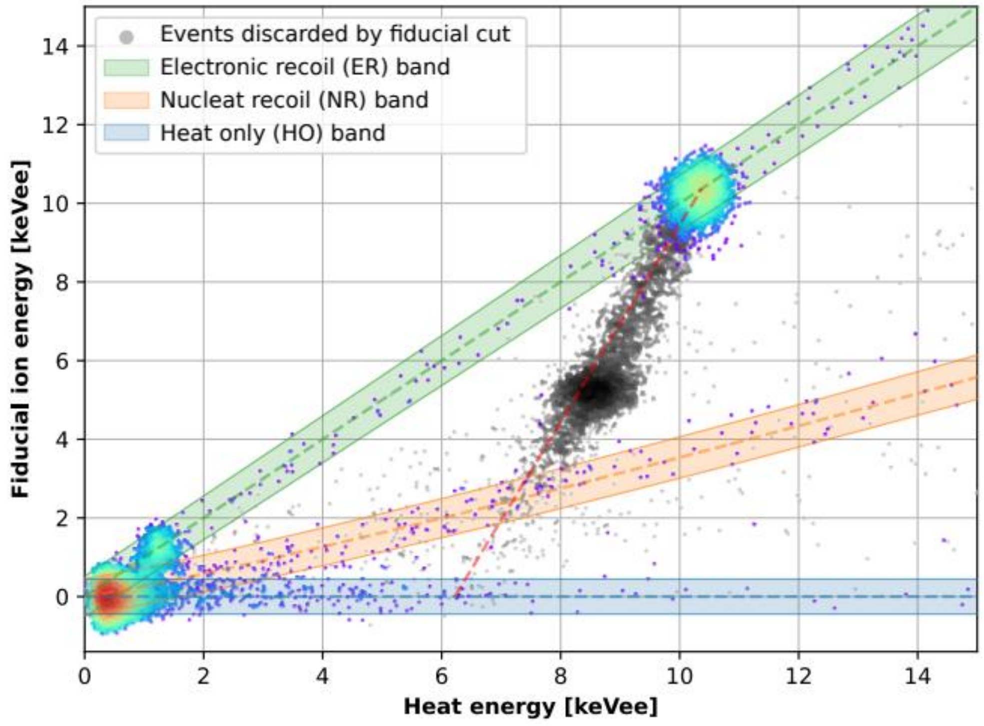





Simulation of octagonal vs cubic geometry to assess the protection from the rock

# Background Mitigations

- Cosmic rays + cosmogenic activation of detectors & shielding materials
- Natural radioactivity from Modane rock (U, Th, K)
- Internal radiogenic contamination (Cs, U, K, …)
- **Radon dust leading to contamination of detector surfaces**
  - ✓ Detector technology to reject surface events contamination




Salagnac & al: arXiv:2111.12438

# Conclusion

- TESSERACT will use **ultra-low threshold cryogenic detectors** with **multiple targets** (leading to different NR/ER sensitivities) and particle identification for light DM search down to meV

- TESSERACT will be deploy @ **LSM** to have a **ultra low background environment**

- Ongoing **simulations studies** for shielding design and material radiopurity requirement

- **Commissioning** of cryostat and shielding @LPSC soon!

# Conclusion

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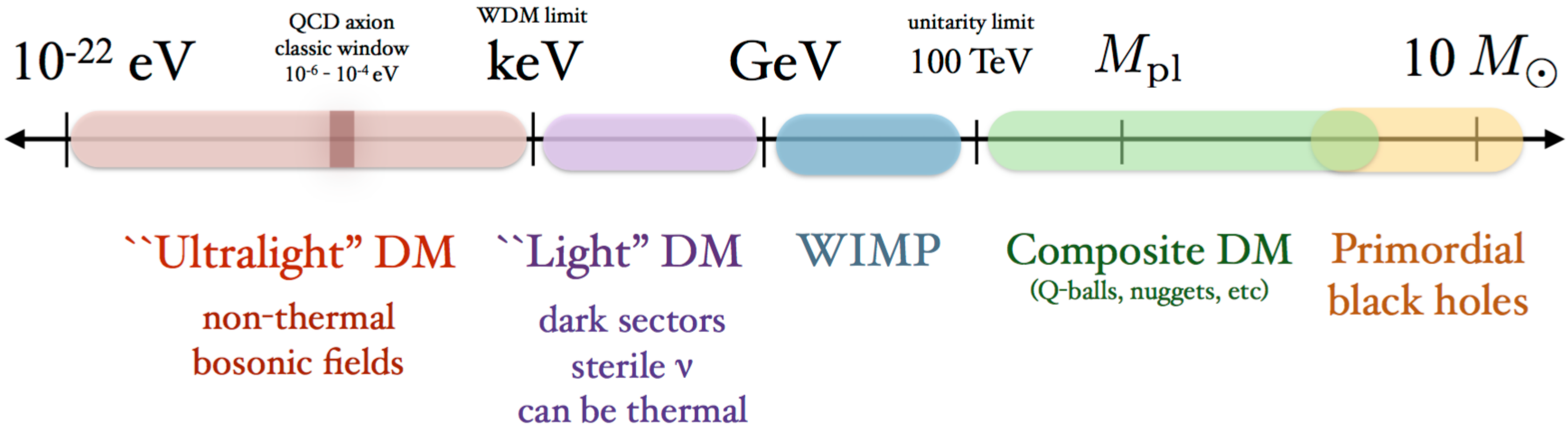
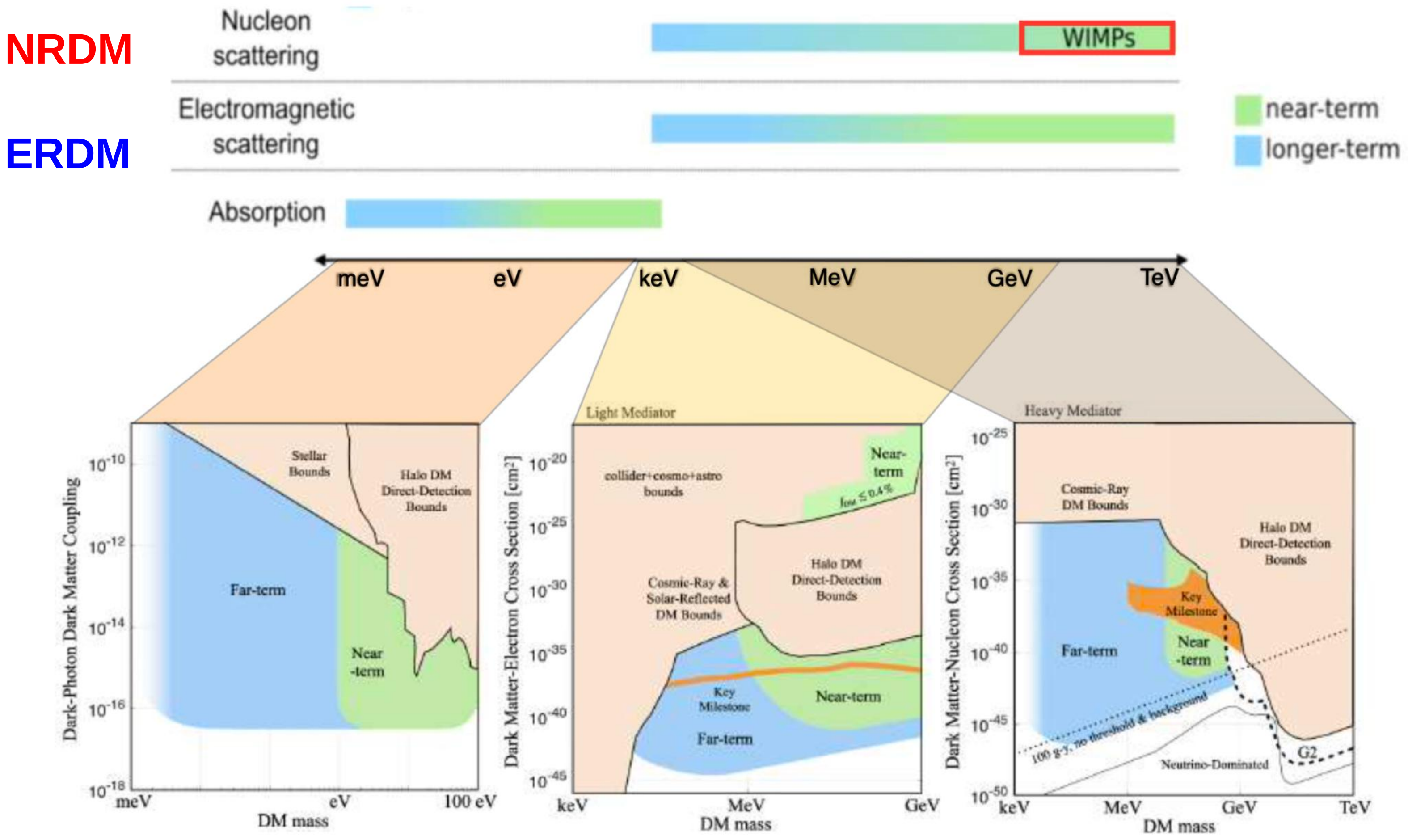
*Thank you!*

# BACKUP SLIDES

# DM candidates

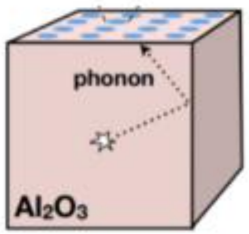


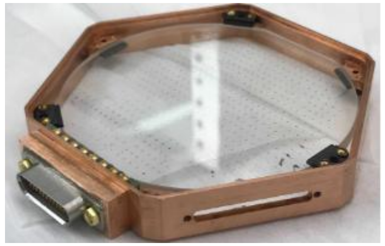
# DM candidates



# SPICE: Sub-eV Polar Interaction Cryogenic Experiment :

## $Al_2O_3$ :



Look for ERDM

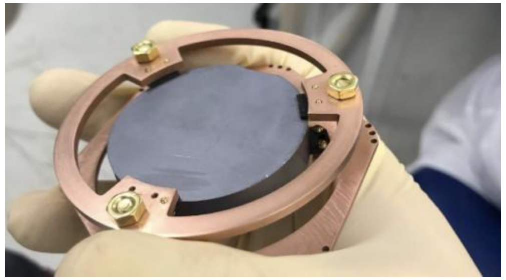
•mass range : 100 meV - MeV

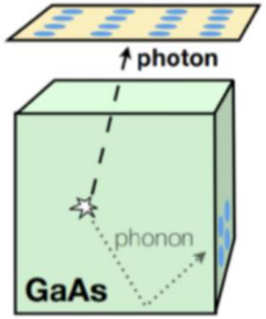
**•LEE mitigation method : use of two TES (pulse shape discrimination)**

•No particle identification

•Single Phonon sensitivity

## GaAs :






ERDM and NRDM

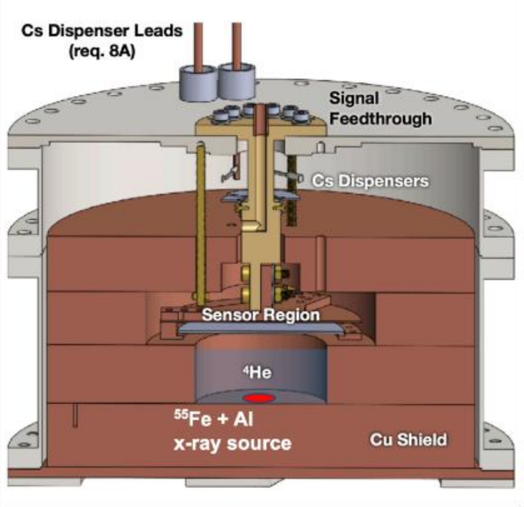
•mass range : eV - MeV and MeV - GeV

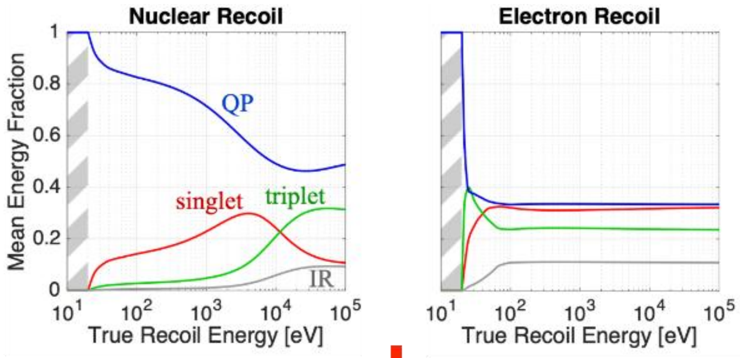
**•LEE mitigation method : photon / phonon coïncidence in two separate sensors** (~ eV scale)

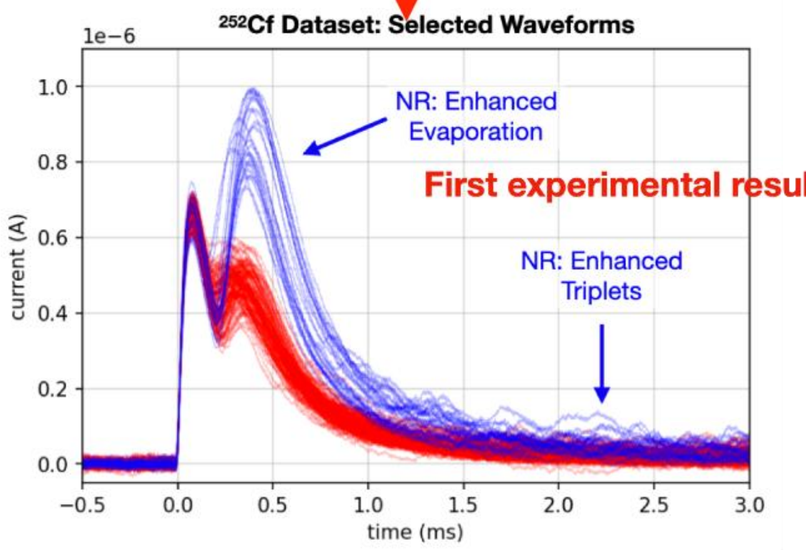
•Particle identification with dual Photon –

Phonon readout (~ 10 eV scale)

# HeRALD: Helium Roton Apparatus for Light Dark matter




**First experimental results !**

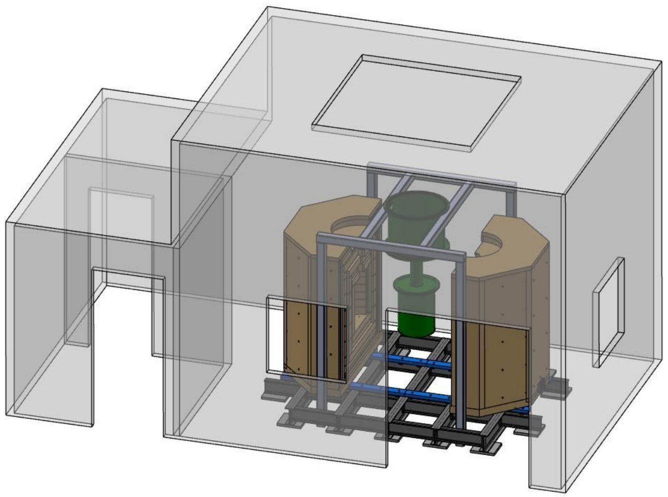
R. Anthony-Petersen et al., arXiv:2307.11877

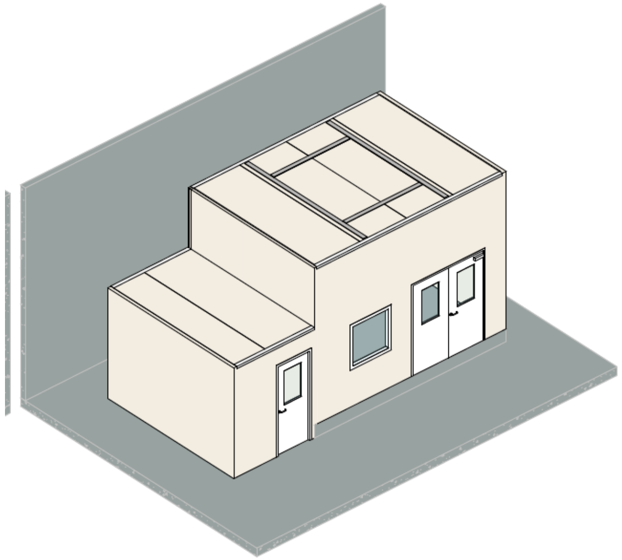
- Well kinetically matched to GeV-scale DM
- Easy to purify, intrinsically radio pure
- LHe cell operated at 20-50 mK with wafer-like cryogenic detectors with TES suspended in vacuum
  - UV/IR photons and **He atoms** from qp induced evaporation
- **First evidence of ER/NR discrimination @10 keV**
- **Already achieved ~170 eV threshold on He recoils (300 MeV DM)**

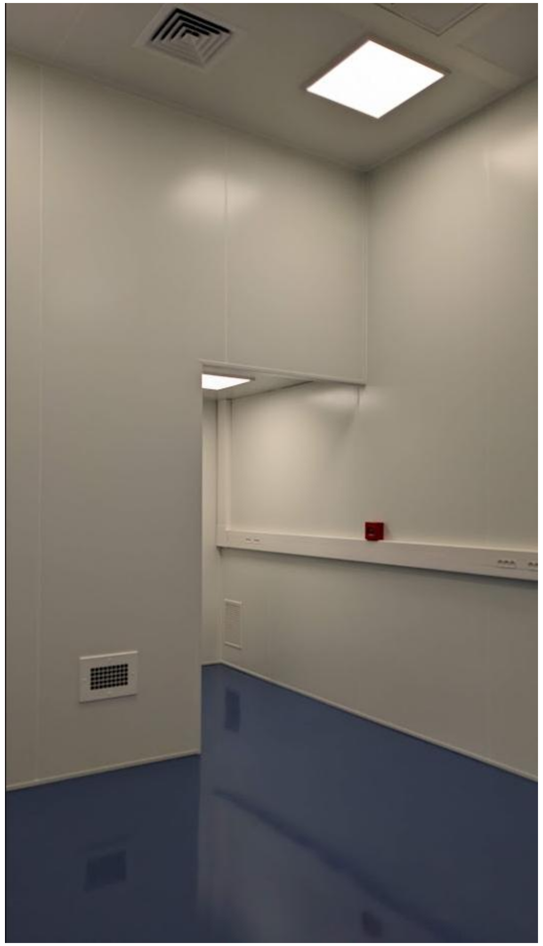
# Commissioning @ LPSC

The clean room for the cryostat is ready at LPSC

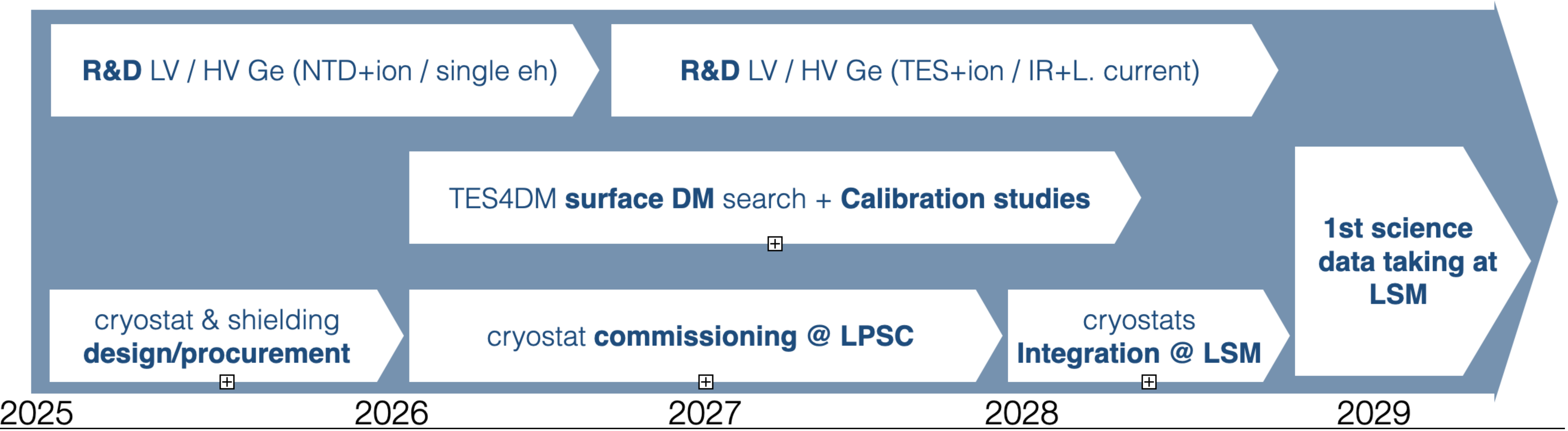
•Summer 2025: vibrational measurements
•Fall 2025: platform







# Planning


R&D LV / HV Ge (NTD+ion / single eh)
R&D LV / HV Ge (TES+ion / IR+L. current)
TES4DM surface DM search + Calibration studies
1st science data taking at LSM
cryostat & shielding design/procurement
cryostat commissioning @ LPSC
cryostats Integration @ LSM
2025
2026
2027
2028
2029