TESSERACT Experiment at the Modane Underground Laboratory

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TESSERACT

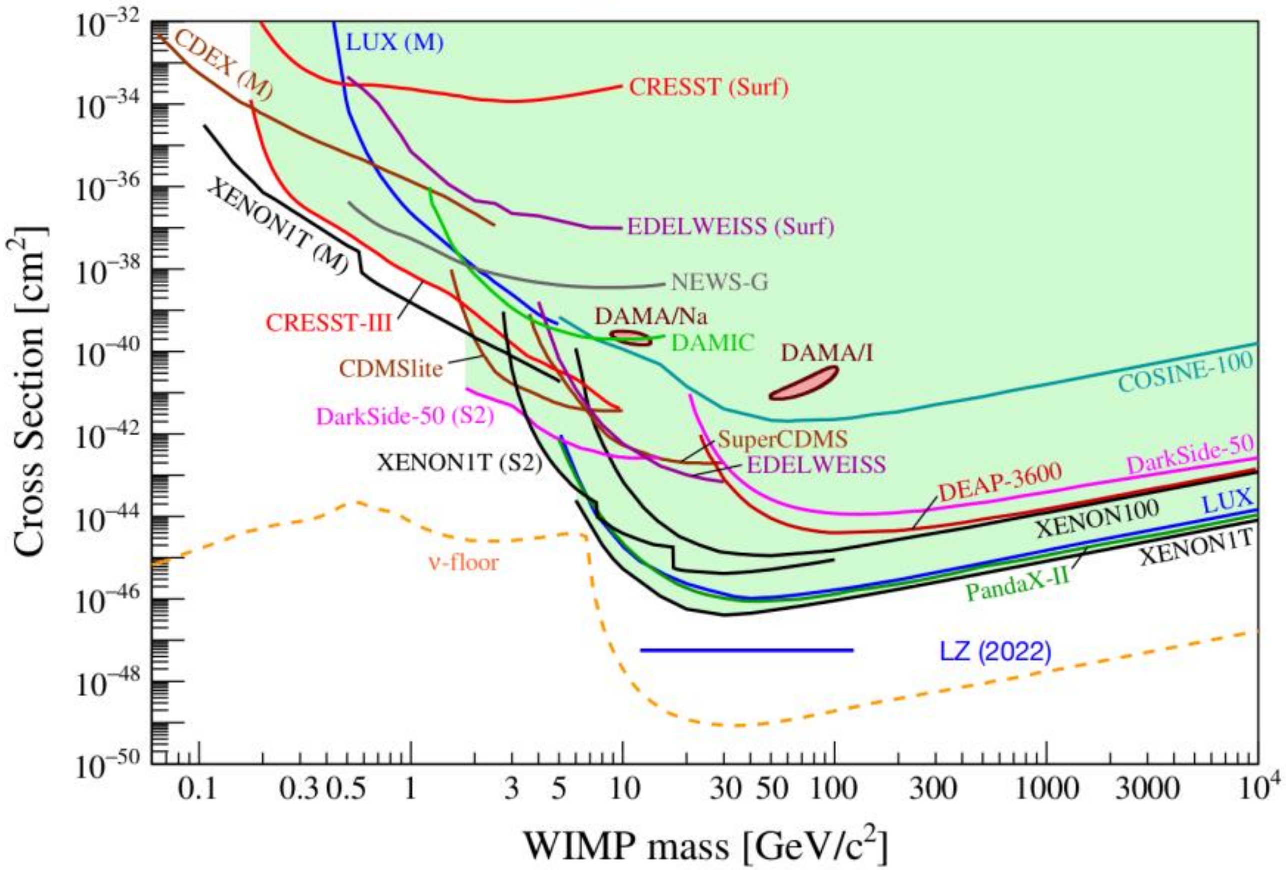
LPSC GRENOBLE | MODANE

GRENOBLE INP UGA

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)

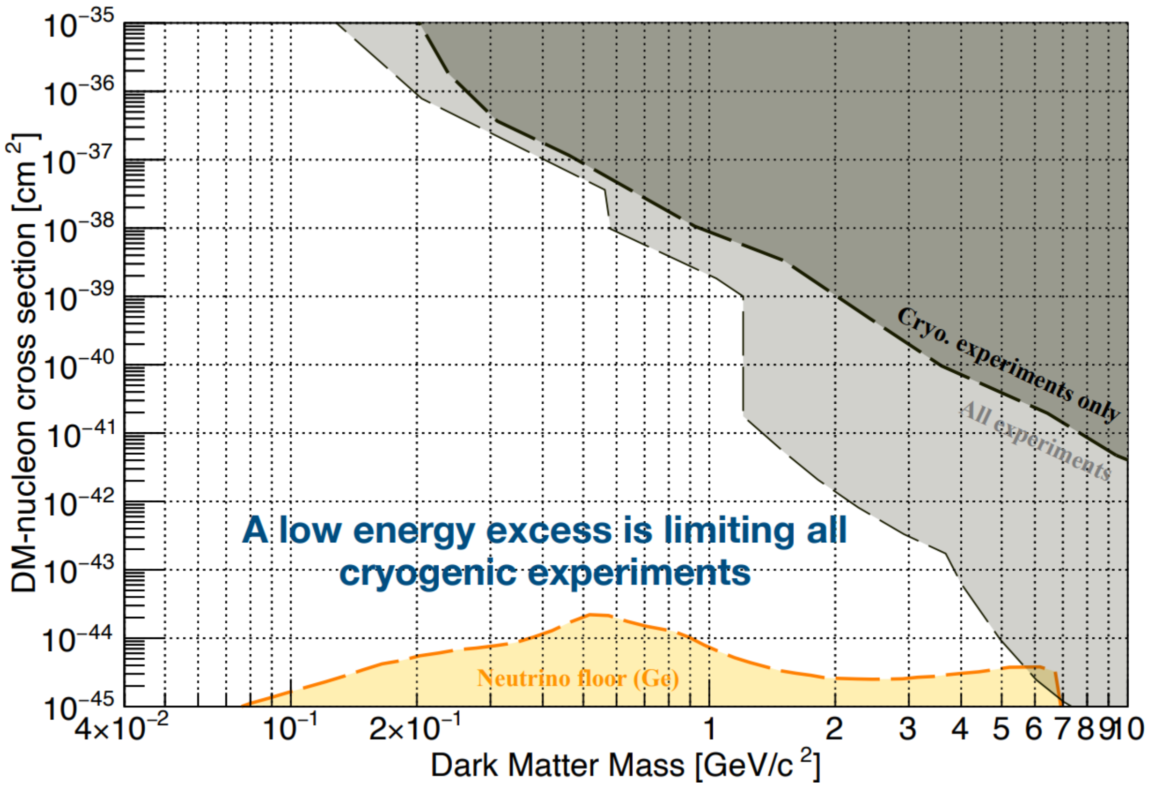
- Still no evidences, now reaching neutrinos floor

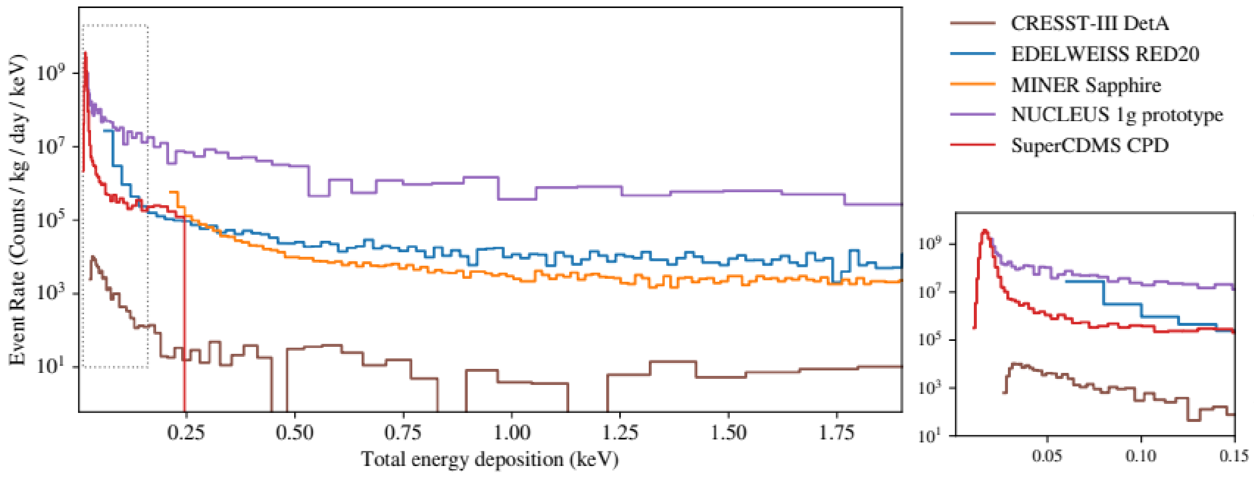


Need to broaden DM searches including masses below the GeV

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

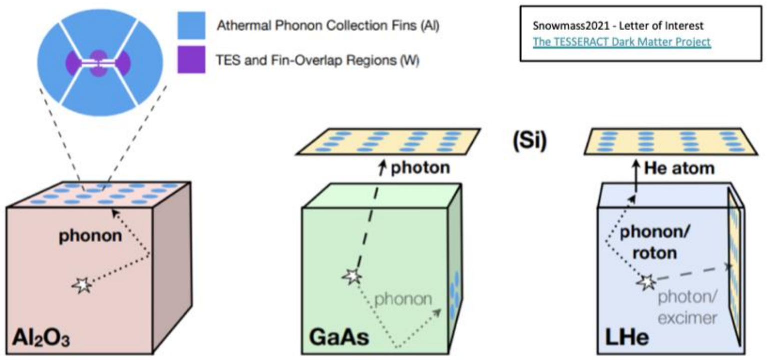
Need to understand, mitigate LEE and develop new technology to reject it

The TESSERACT Experiment

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

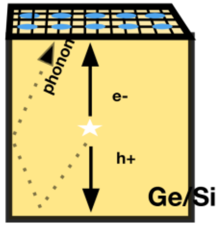
Goal: extending the Dark Matter mass search window from meV-to-GeV with ultra low-threshold cryogenic detectors with multiple targets and particle identification capabilities

US contribution



One design, several targets leading to different DM sensitivities

French contribution

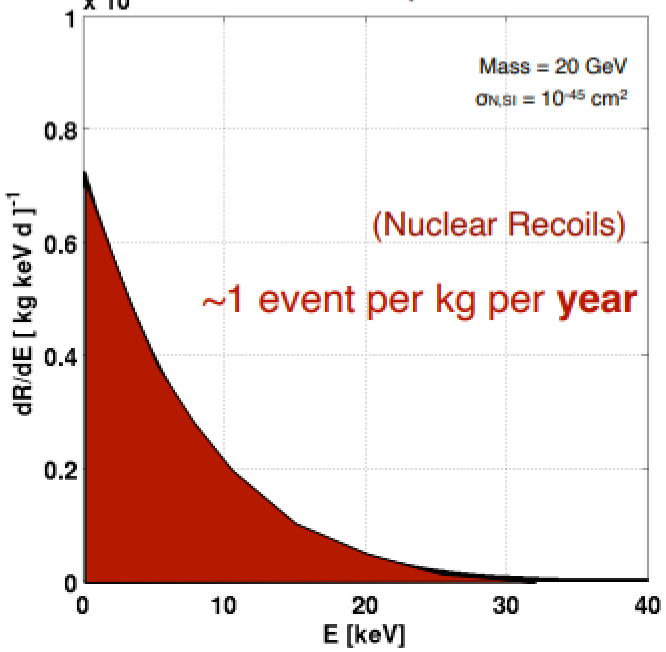


Add the Ge/Si semiconductors calorimeter technology and benefit from RICOCHET and EDELWEISS experiences

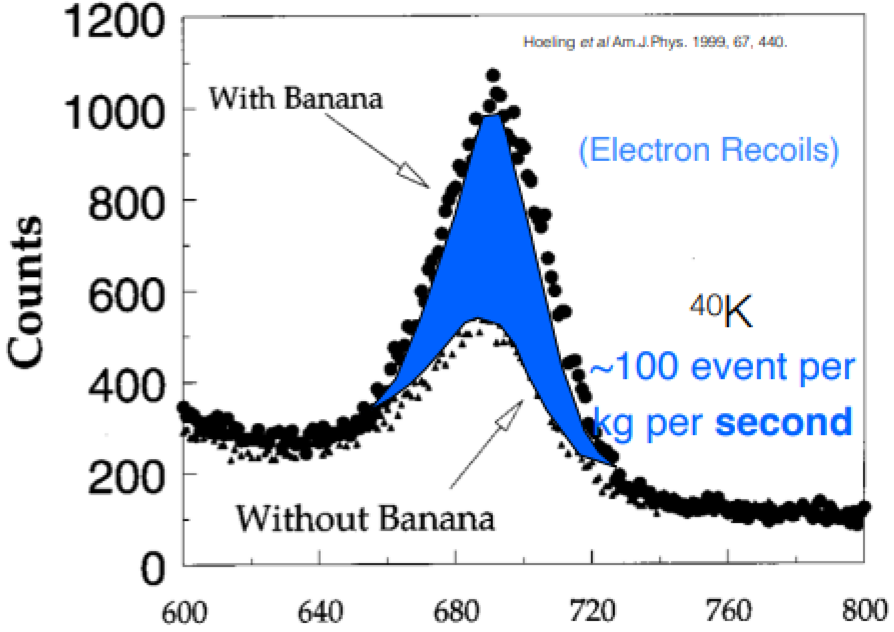
Deploy TESSERACT experiment @ LSM

The Dark Matter Interaction Rate

Expected
Dark Matter Spectrum



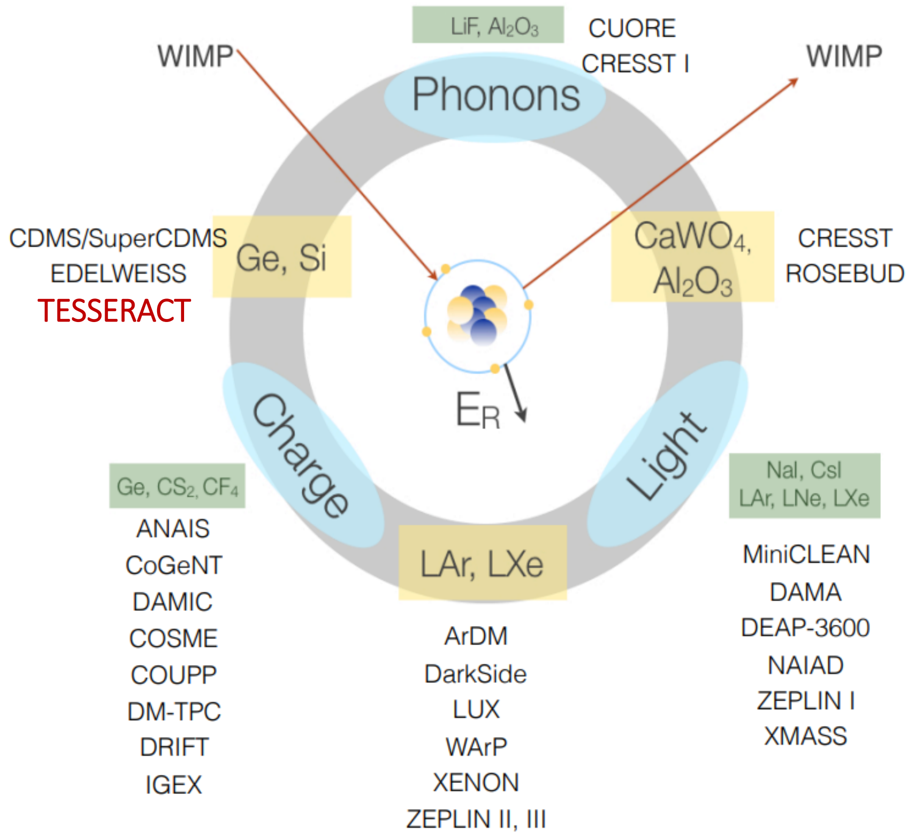
Measured
Banana Spectrum



We need ~~to stop eating bananas~~ low background environment and effective strategies of background rejection.

Dark Matter Wishlist

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



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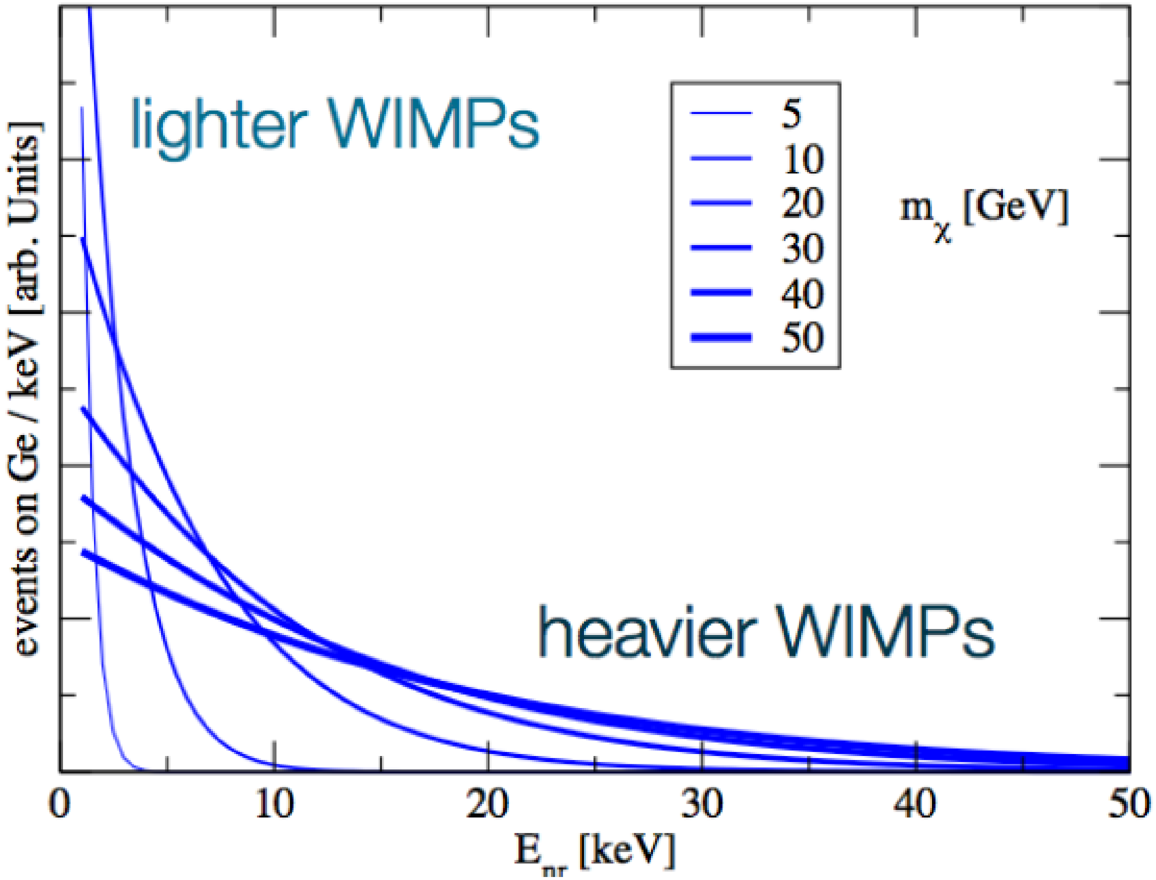

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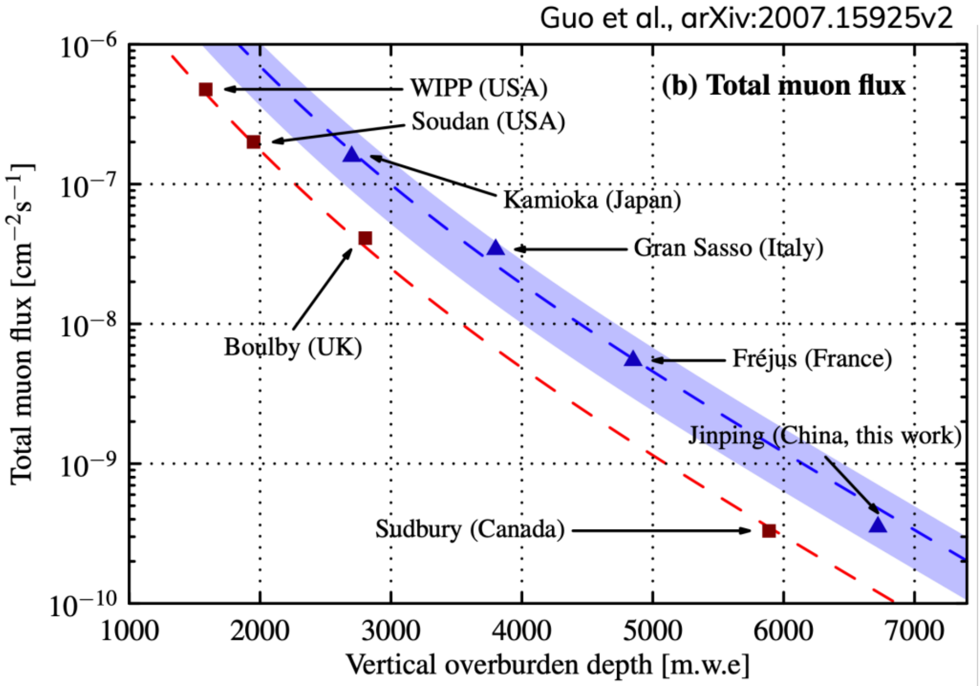
- **Low energy threshold**
  - Elastic scattering of light DM particle deposits few keV in the detector
- **Low and controlled backgrounds**

Background Mitigations

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



Muon flux reduced by 10^6 relative to surface

Background Mitigations

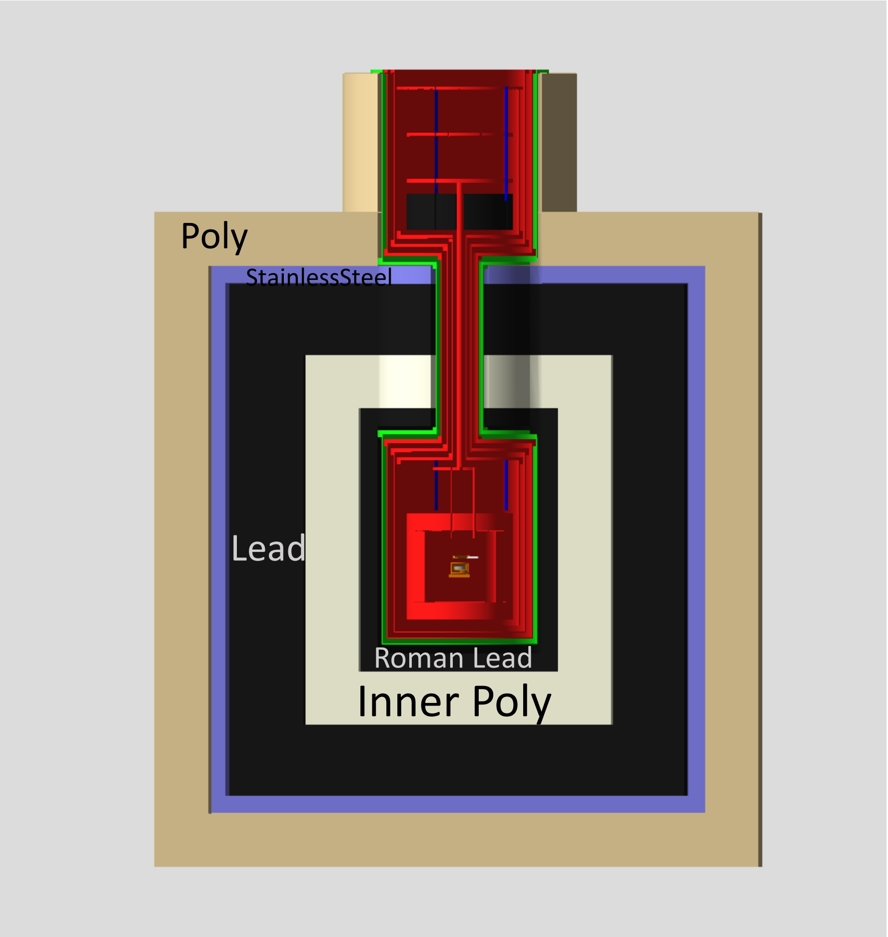
- Cosmic rays + cosmogenic activation of detectors & shielding materials

- **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

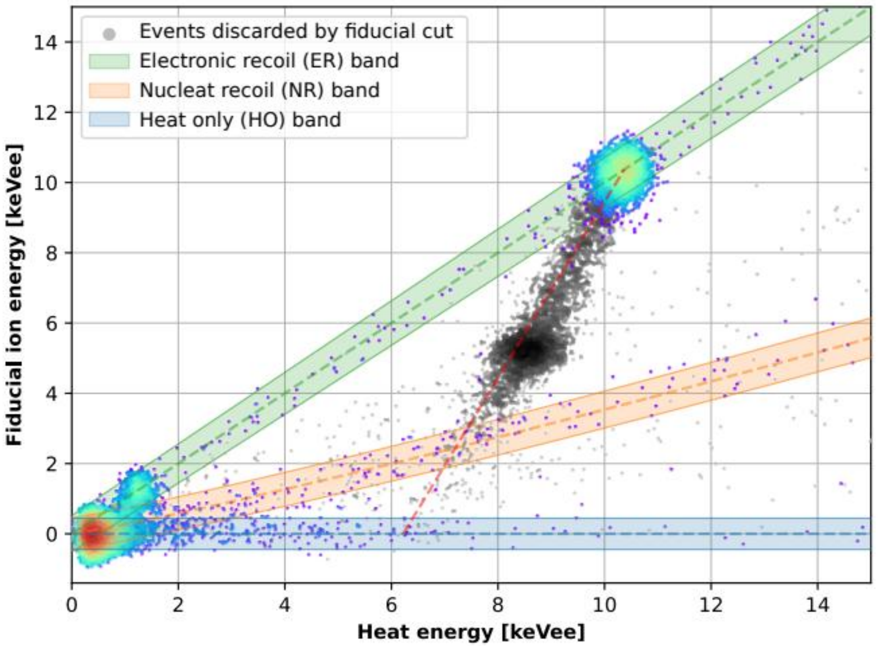
My work:
Geant4 simulations for
- Shielding optimization studies

- Background budget from Modane rock + material contamination (shielding & detector)



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

My work:
Estimate the semiconductor detector discrimination power of surface events for TESSERACT

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

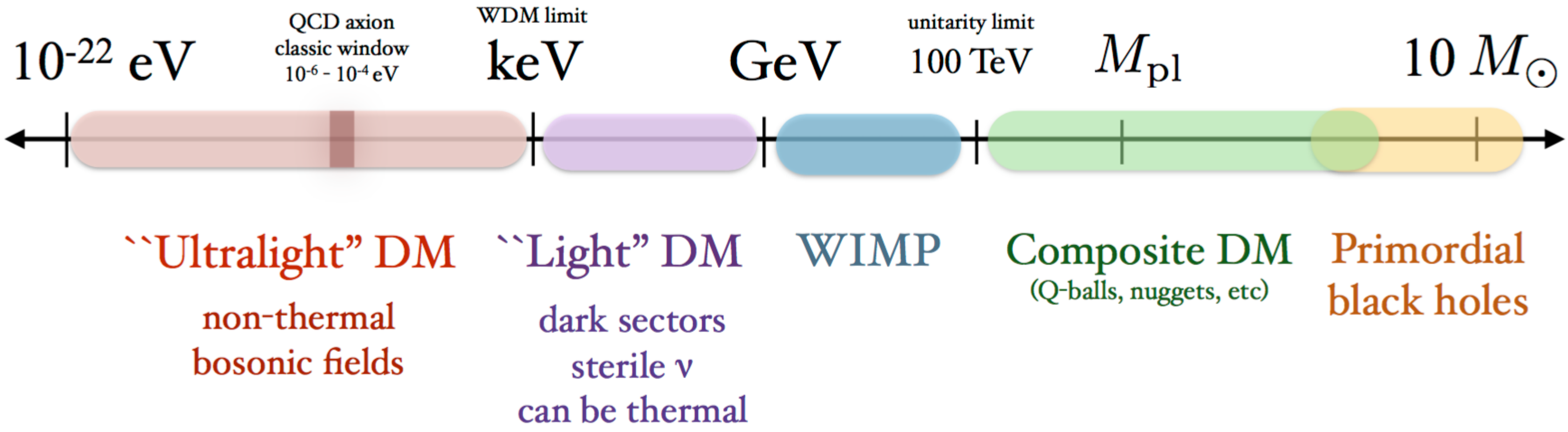
- Study of detector **discrimination power for surface events**

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

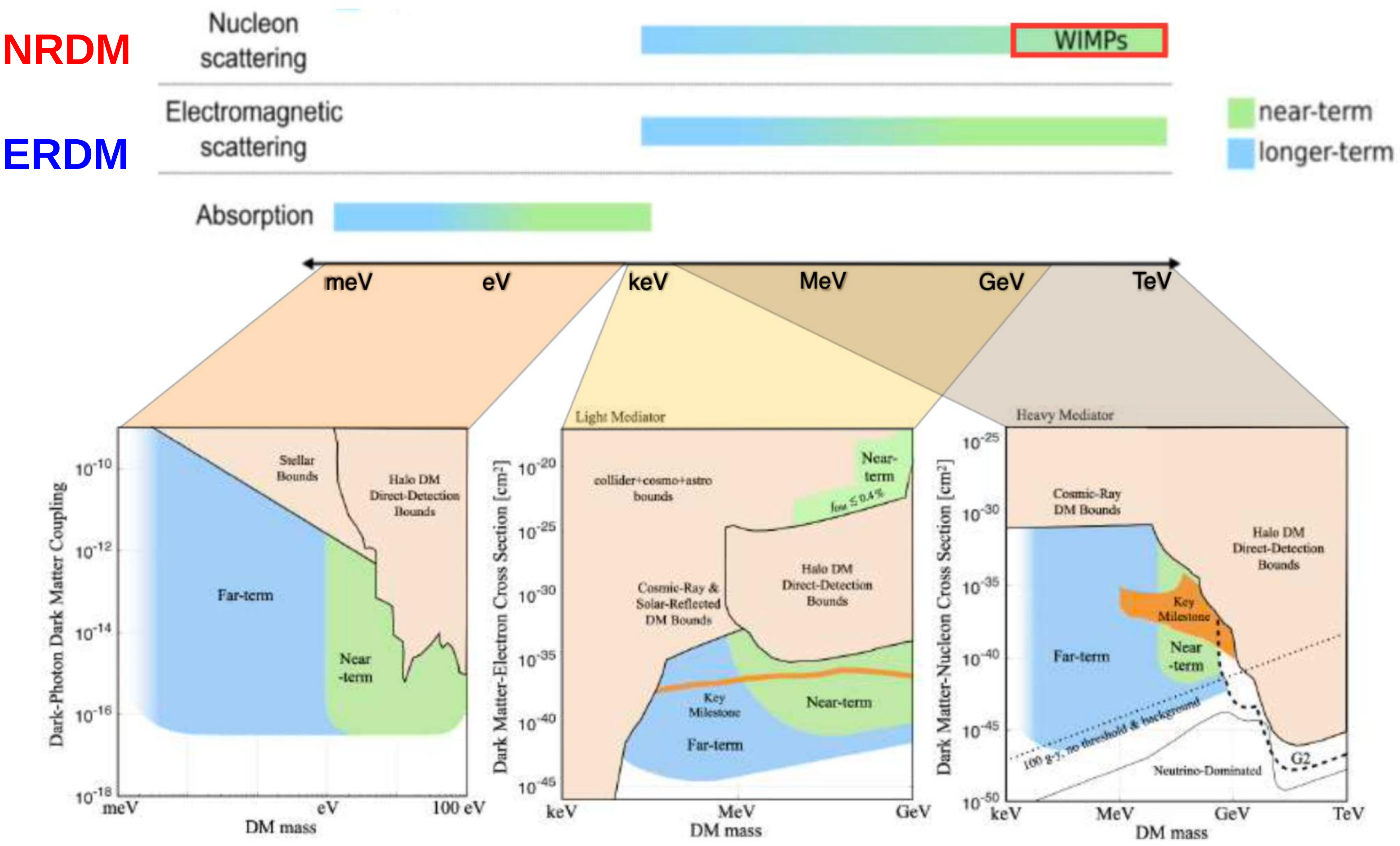
Thank you !

BACKUP SLIDES

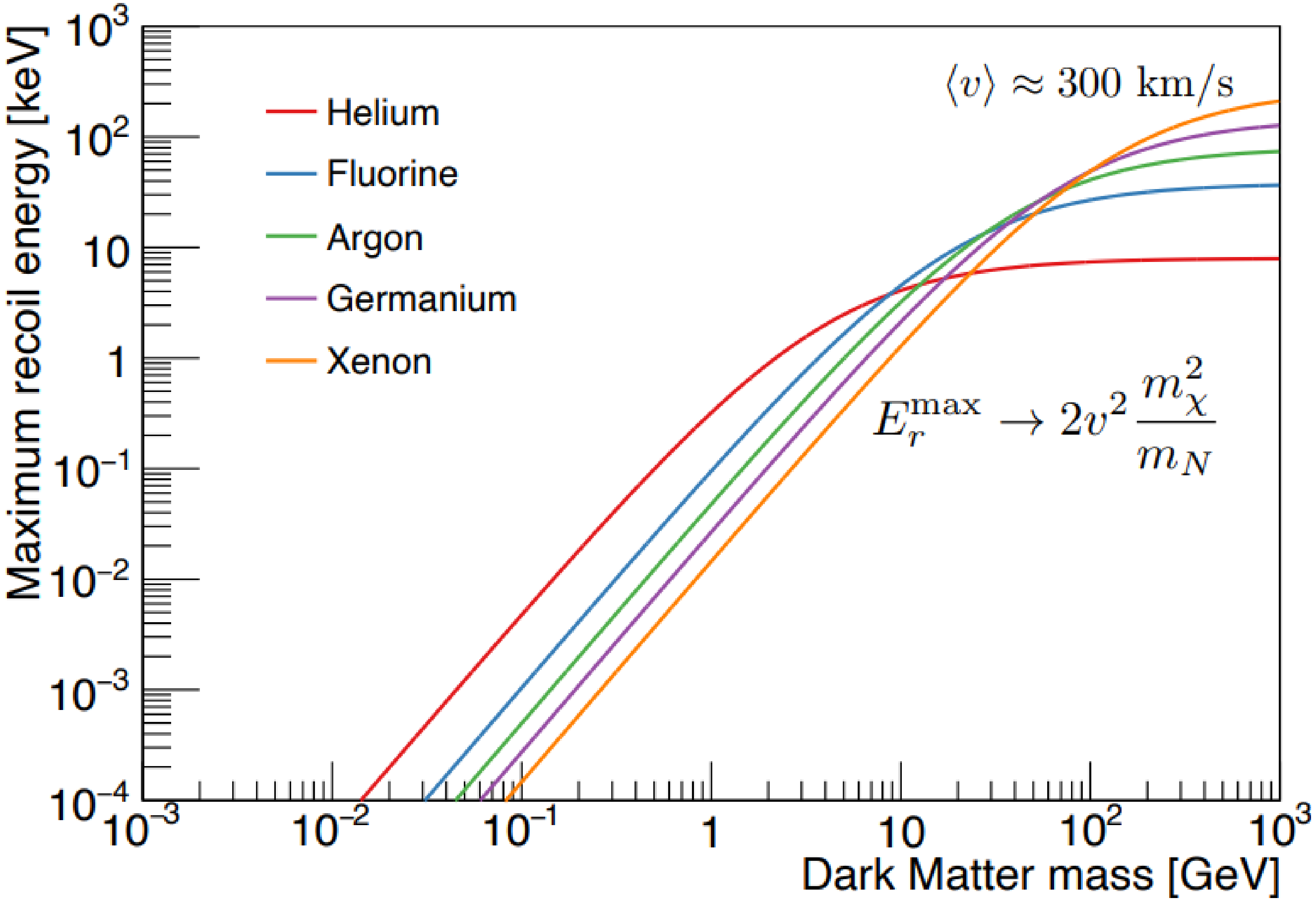
DM candidates



DM candidates

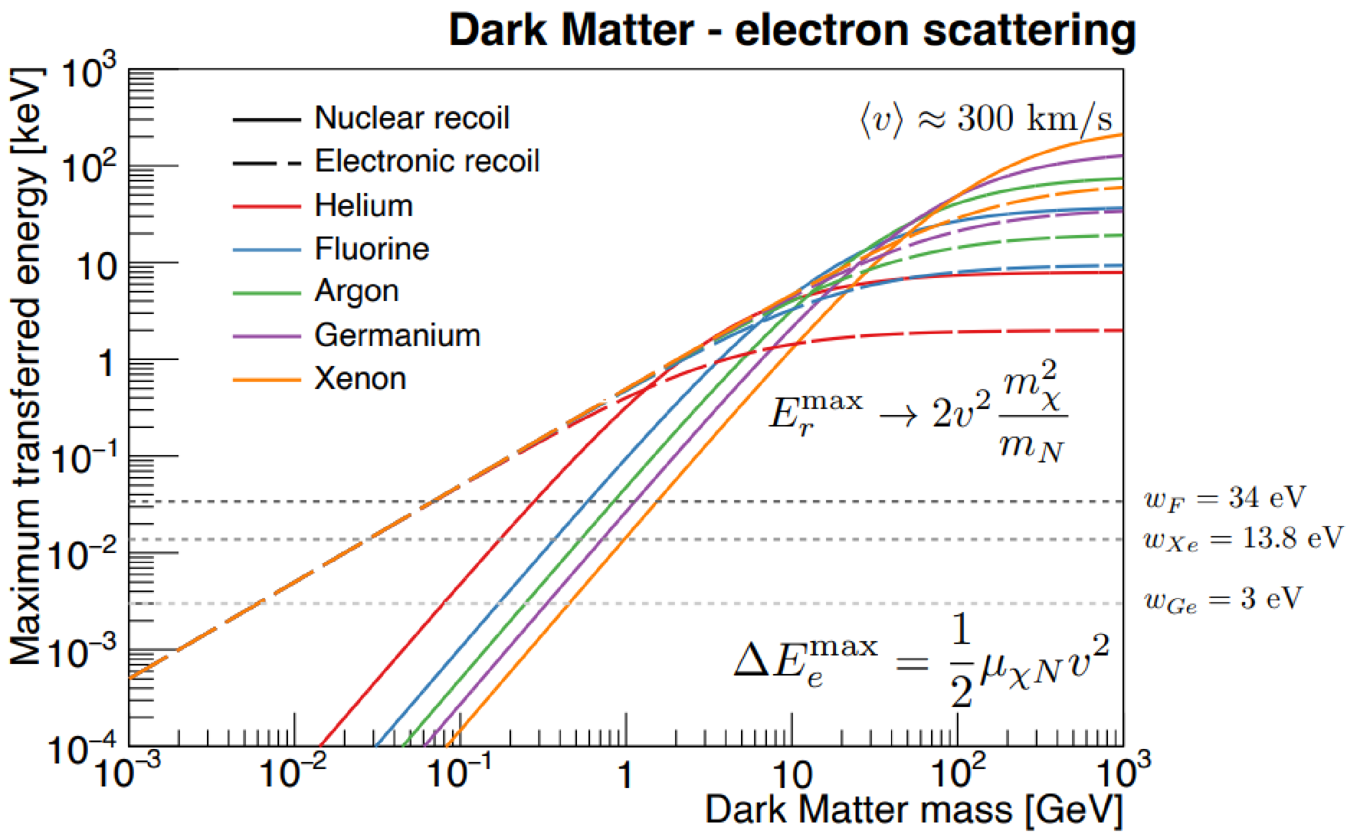


NR limits



For DM masses bellow ~100 MeV, switch to DM-electron scattering

DM-Electron scattering



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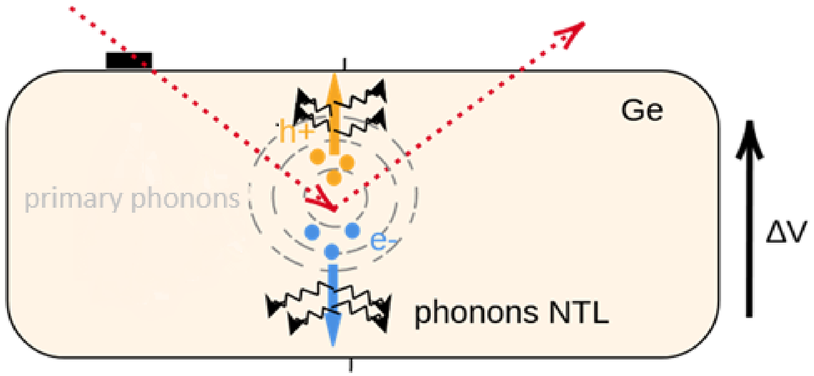
Germanium Semiconductor Technology



Simultaneous readout of signals induced from energy deposition:

- **Ionization signal**: electron/hole pairs produced drift to the electrodes
- **Heat signal**: phonons

+ Neganov Luke Trofimov effect: phonons from e/h pairs drift

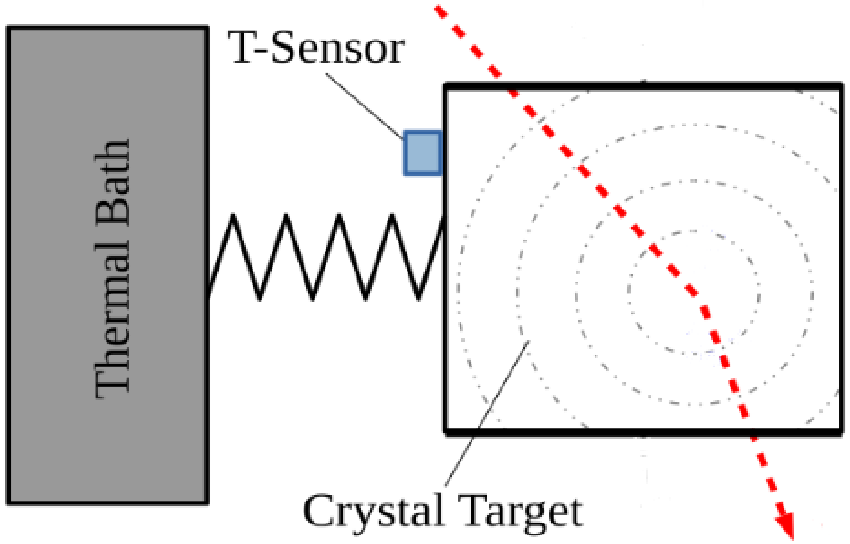
$$E_{tot} = E_{recoil} + E_{Luke} = E_{recoil} + \frac{1}{3eV} E_{ion} \Delta V$$

Two working modes:

- **High voltage**: amplification of signal → single e/h pair sensitivity : Optimal for **Electron Recoil DM** search

- **Low voltage**: Particle Identification capabilities : Optimal for **Nuclear Recoil DM** search

Calorimeter principle



Measure by Ge-NTD (Neutron Transmutation Doped) glued on the crystal:

$$R(T) = R_0 \, exp(\sqrt{\frac{T_0}{T}})$$

$$\Delta T \propto \frac{\Delta E}{T^3}$$

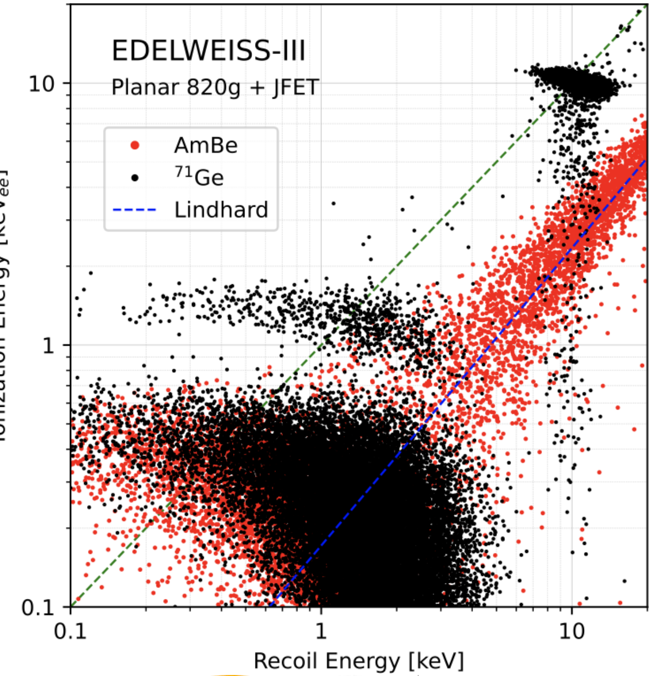
Low Voltage Mode

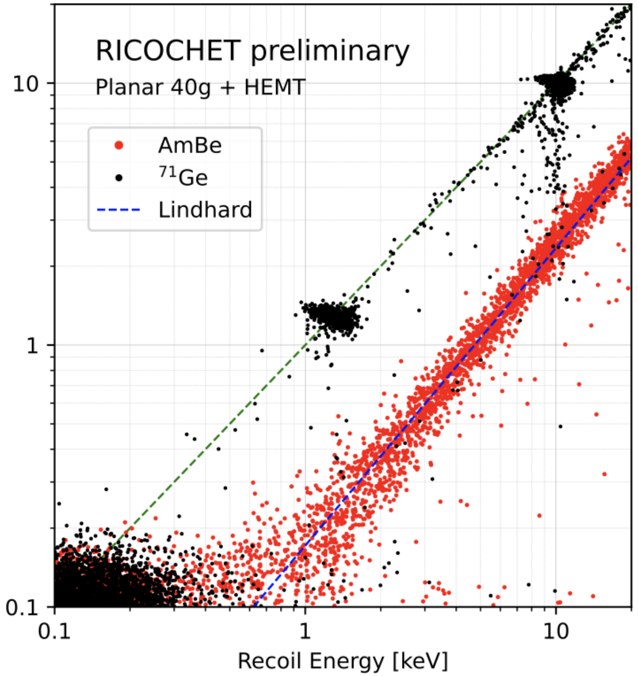
Quenching factor Q= E_{ion}/E_R

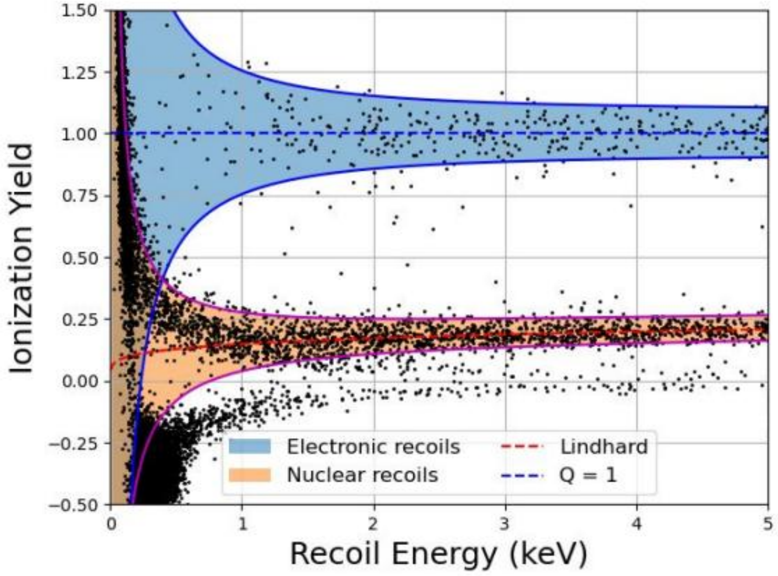
Q=1 for ER
Q<1 for NR
Q=0 for LEE

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

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



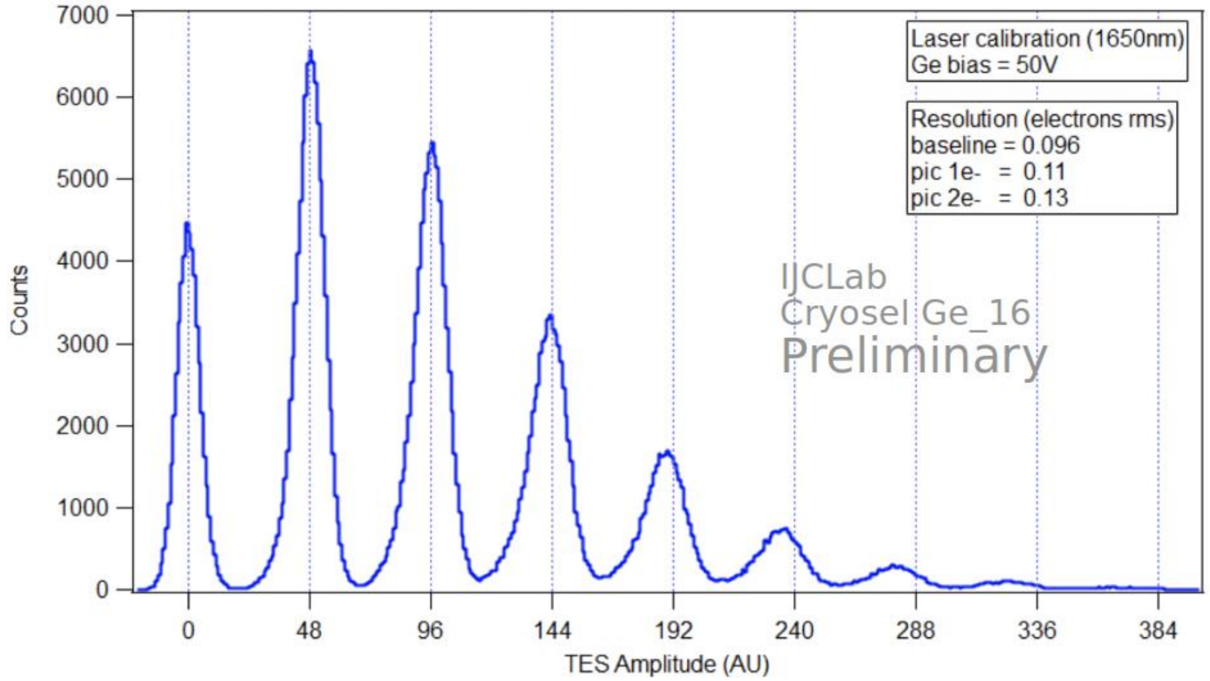




P.Vittaz

Energy threshold improved by one order of magnitude
TESSERACT will improve again this threshold for an ideal light NR interacting DM search

High Voltage Mode



First observation of a single-electron sensitivity in a 40g Ge cryogenic detector

High sensitivity for ERDM search

Discrimination of LEE:

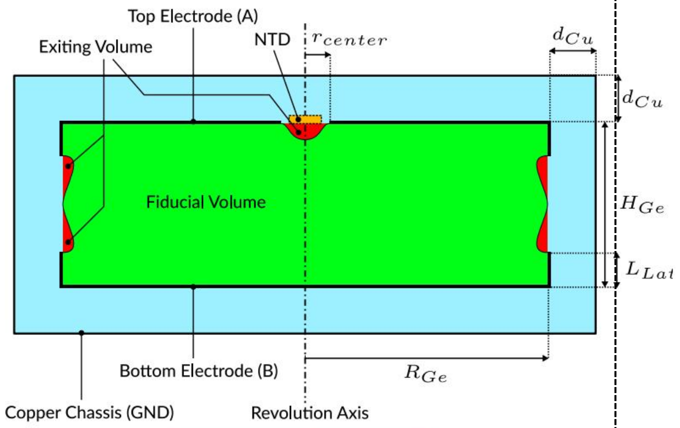
- total phonons (real) signal amplified by a factor $1 + \frac{V}{\varepsilon}$
- HO background not amplified

FID detectors

Developed by EDELWEISS collaboration and used by RICOCHET

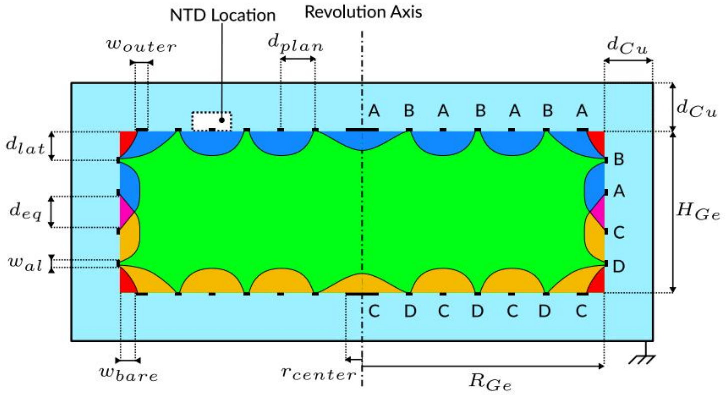
Salagnac & al: arXiv:2111.12438

Planar



2 electrodes
No surface event rejection
96% fiducial volume

Fully Inter Digitized

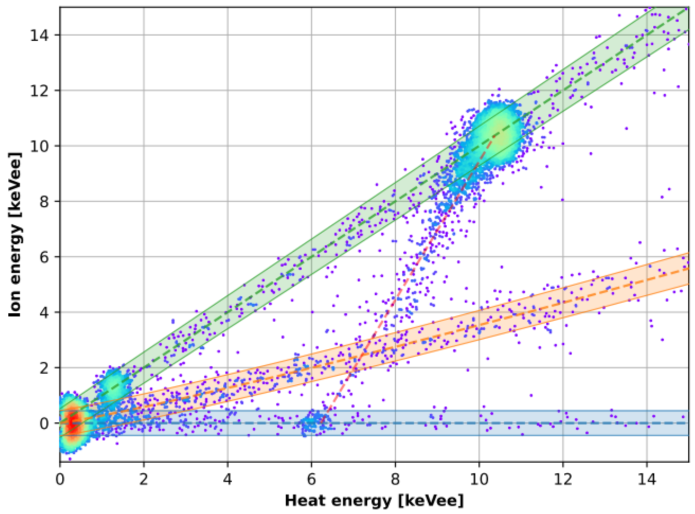


4 electrodes
Surface event rejection
62% fiducial volume

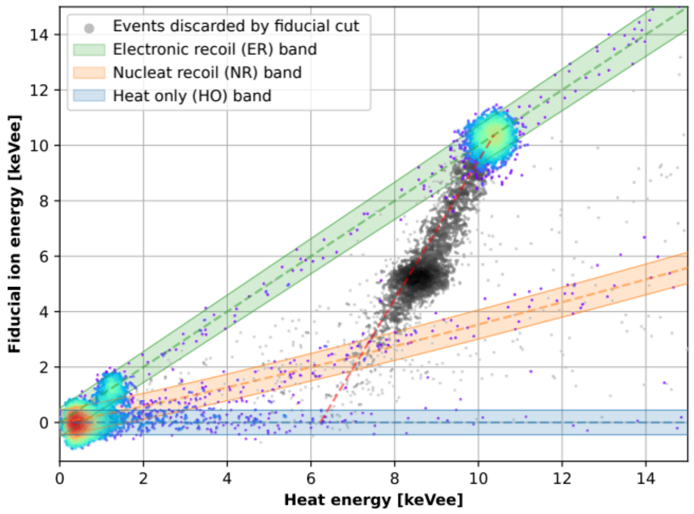
FID detectors

Salagnac & al:
arXiv:2111.12438

Without surface events rejection



With surface events rejection



US Contributions

SPICE: 2 targets
Al2O3: ERDM, use of 2 TES to discriminate pulse shapes, 100 meV-MeV
GaAs: ERDM and NRDM, dual photon/phonon readout, MeV-GeV and eV-MeV

Herald:
Liquid Helium: NRDM, particle identification with pulse shape + multiple He4/photon detectors, MeV-GeV