# Background Characterization in Cryogenic Calorimeters for Rare Event Search Experiments

**Juliette Blé**

**LPSC PhD seminar – 13 April 2026**

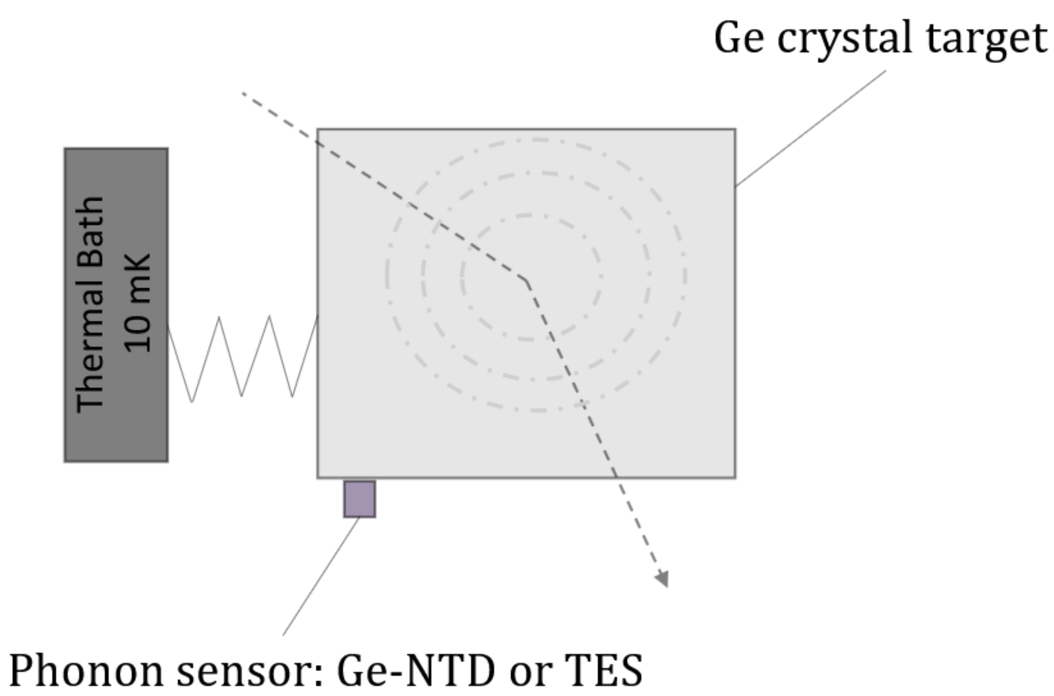
RICOCHET

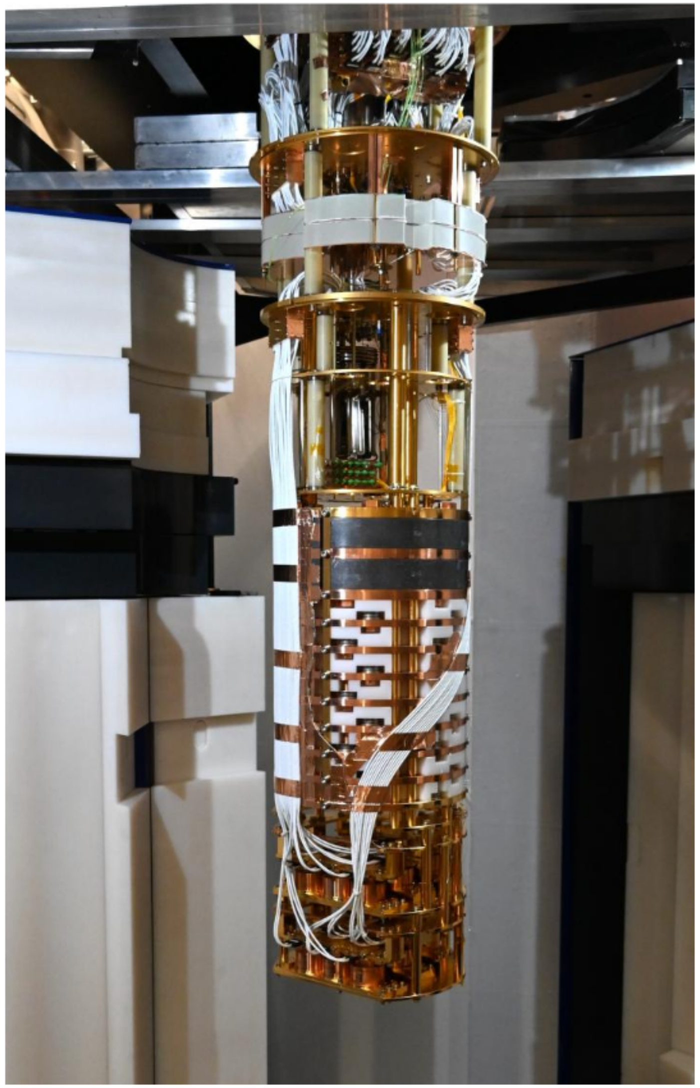
TESSERACT

GRENOBLE INP UGA

LPSC GRENOBLE | MODANE

# Cryogenic Calorimeter

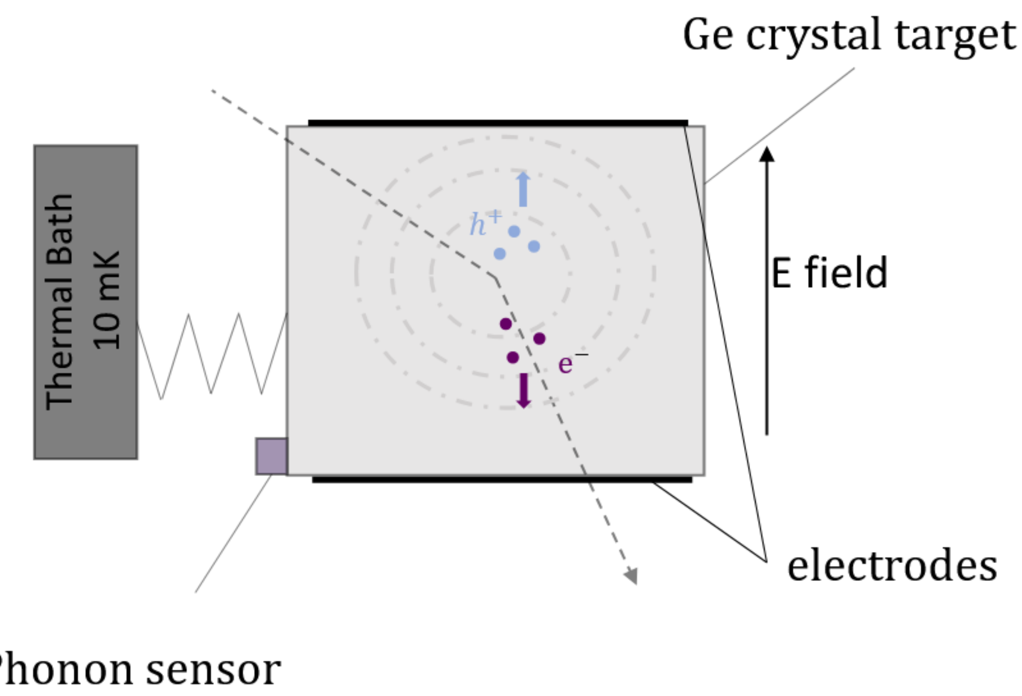


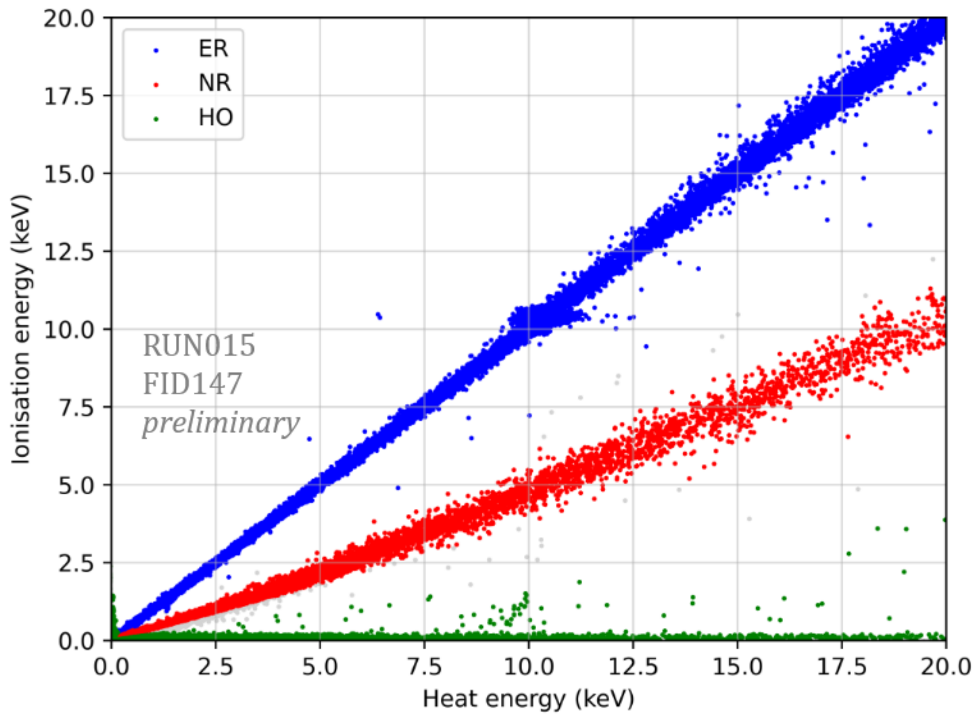



$$\Delta T \propto \frac{\Delta E}{T^3} \;\longrightarrow\;$$ Calorimeters cool down to ~ 10 mK

- **Exquisite energy resolutions**
- **Low energy threshold**

# Double Signal Readout




**Discrimination of Nuclear/Electronic Recoils**

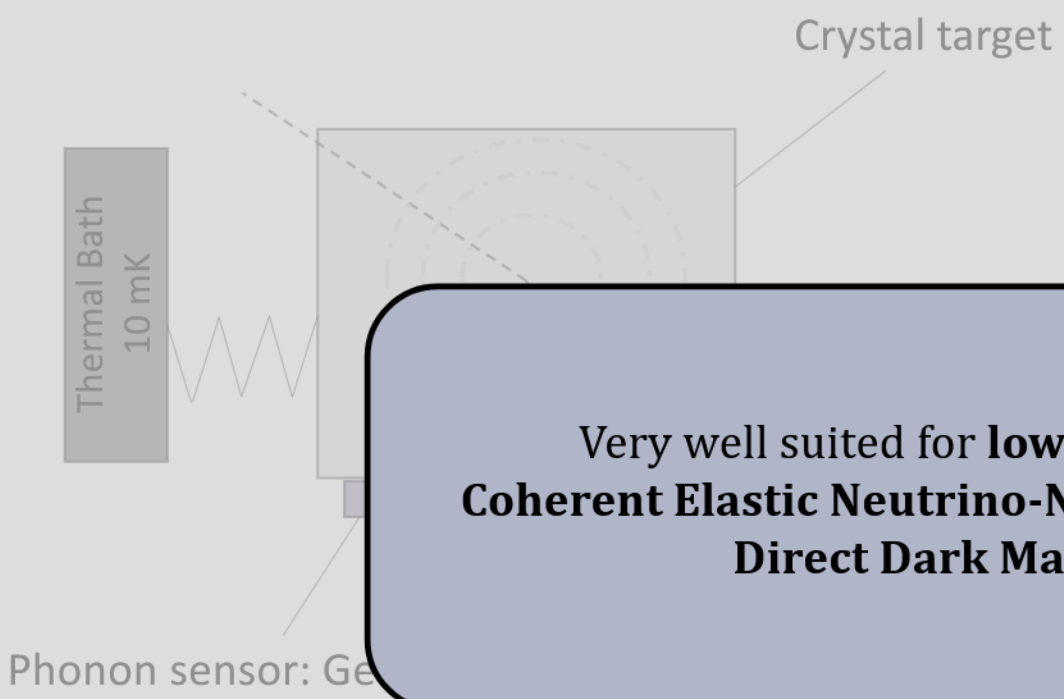
Quenching $\mathbf{Q} = \frac{E_{ion}}{E_r}$

ER $(\gamma/e^-)$ : Q = 1

NR (n/ν/DM) : Q ~ 0.2 – 0.3

- **Discrimination between Signal and Background**

# Cryogenic Calorimeter & Double Signal Readout

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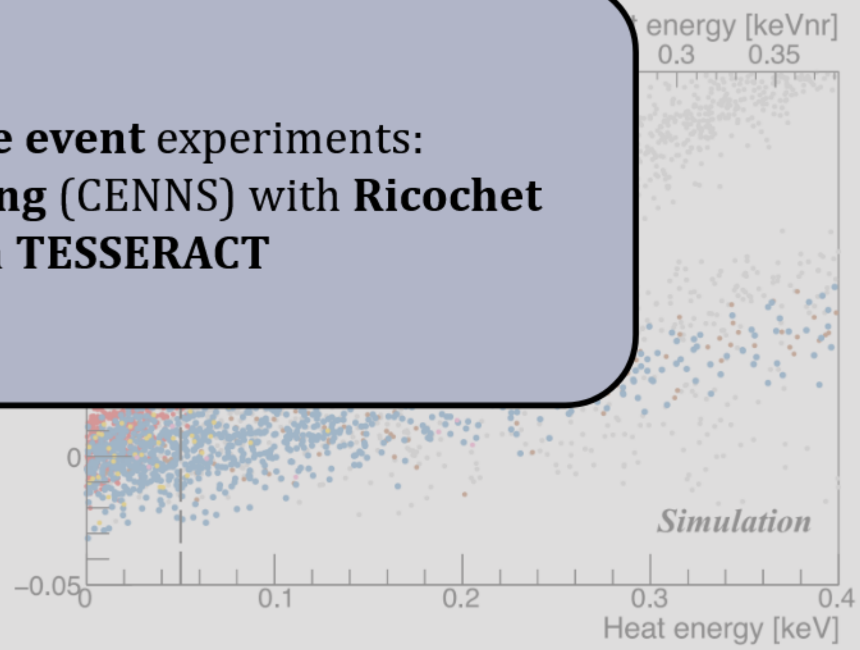
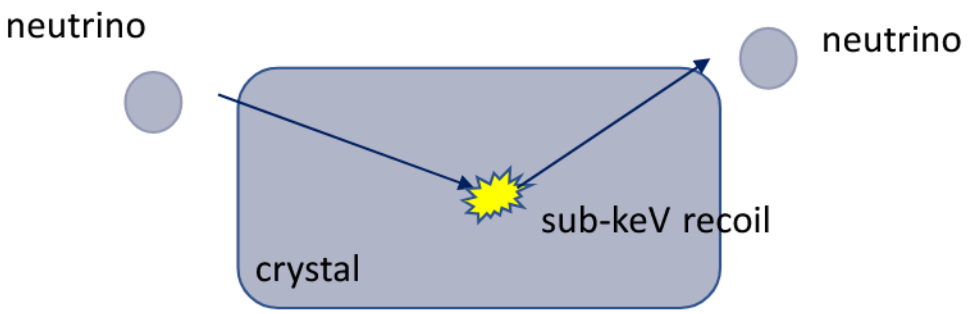


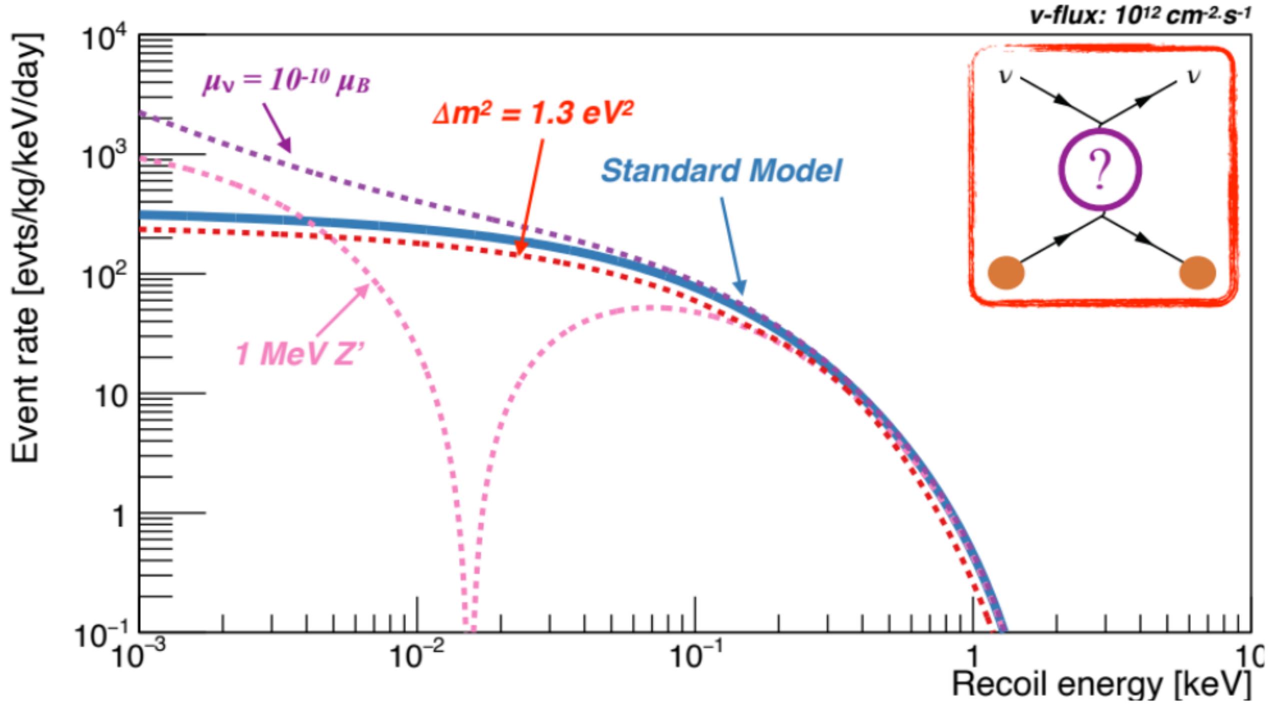

- **Discrimination between Signal and Background**

Very well suited for **low energy** and **rare event** experiments:
**Coherent Elastic Neutrino-Nucleus Scattering** (CENNS) with **Ricochet**
**Direct Dark Matter Search** with **TESSERACT**

# Coherent Elastic Neutrino-Nucleus Scattering




- Predicted since 1974 by Freedman
- Measured for the 1st time only in 2017 by the COHERENT Collaboration




- Cross-section measurement at low energy
- Test of new physics beyond the Standard Model
- Irreducible background for direct dark matter search (same signature)

# The Ricochet Experiment

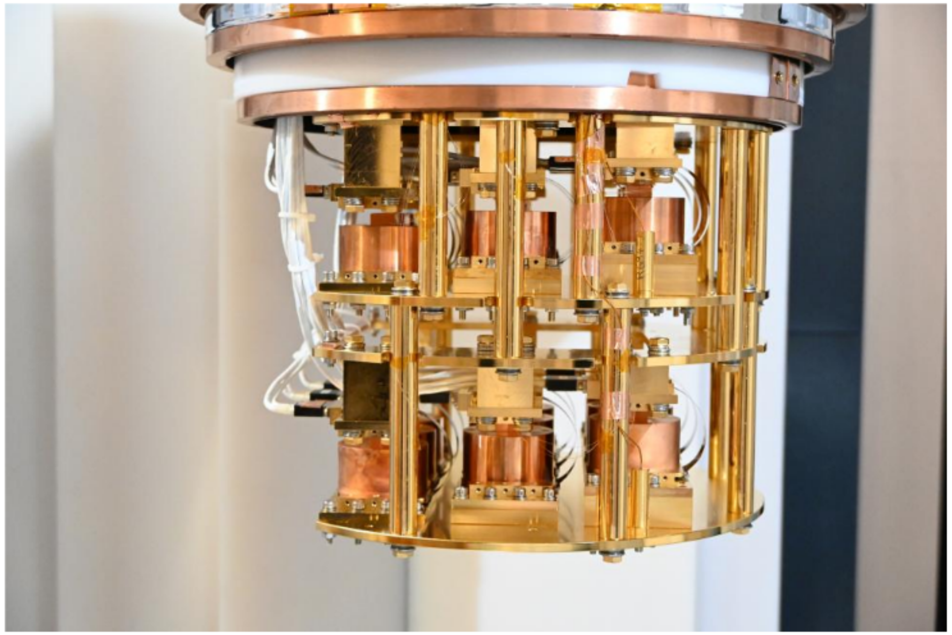
- **Ricochet** intalled at the **ILL** to measure CENNS with **reactor neutrinos**

- Use 18 x 42g Ge cryogenic calorimeter with double readout signal heat/ionisation

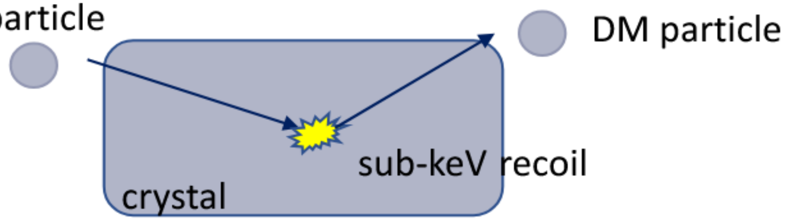
- **Characterization** of first detectors done during **commissioning runs** in 2024

  [Ricochet Collaboration, Phys. Rev. D **112** (2025), 112019]

- **Science runs began in July 2025**

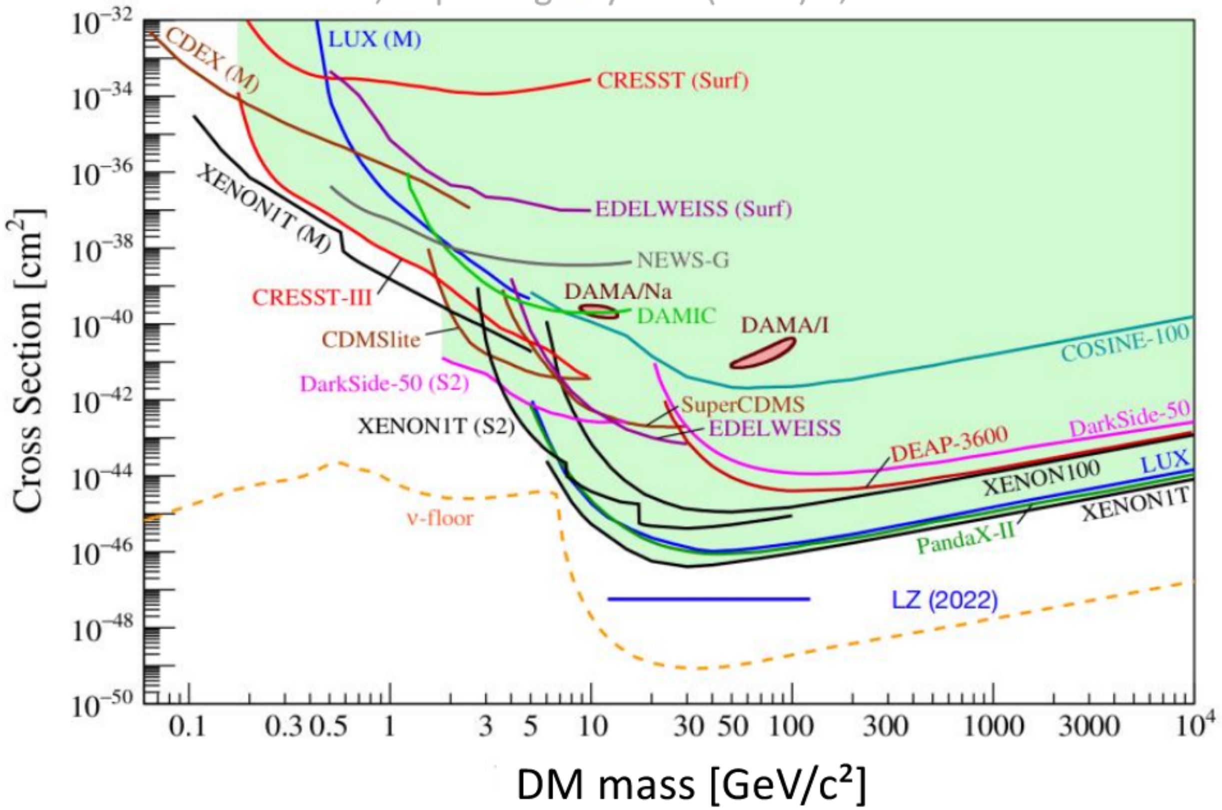


# Direct Dark Matter Search




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

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




Need to broaden DM searches including masses below the GeV

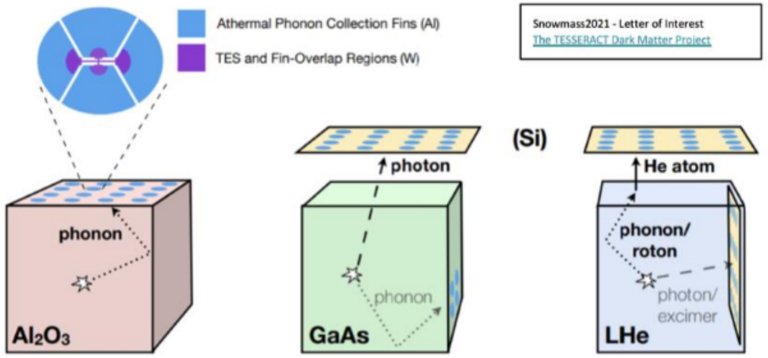
**Solid state and cryogenic detectors are best suited for low mass DM detection**

# The TESSERACT Experiment

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

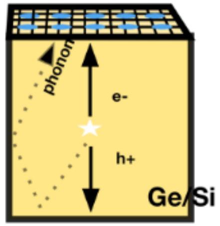
*<u>Goal:</u> extending the Dark Matter mass search window from meV-to-GeV with ultra low-threshold cryogenic detectors with multiple targets and particle identification capabilities*

## US + Swiss 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

Provide the experimental site in the deepest european laboratory **LSM**

**Commissioning** of cryostat + shielding at **LPSC** in 2027

Integration of the full setup at LSM in 2028

# The wishlist

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- **Ultra-sensitive detectors** (exquisite energy threshold and resolution)
    - Use cryogenic calorimeters

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  - Simultaneous readout of signals induced from energy deposition to distinguish Nuclear Recoils (NR) and Electronic Recoils (ER)
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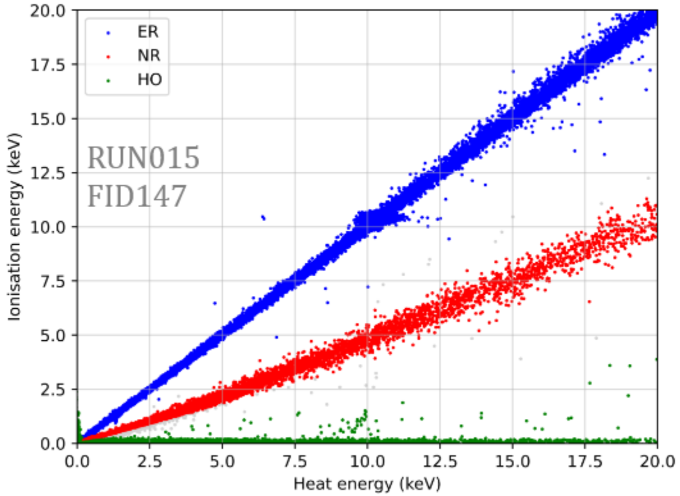

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- **Low and controlled background**

**My research**

Ricochet Data Analysis of FID detectors

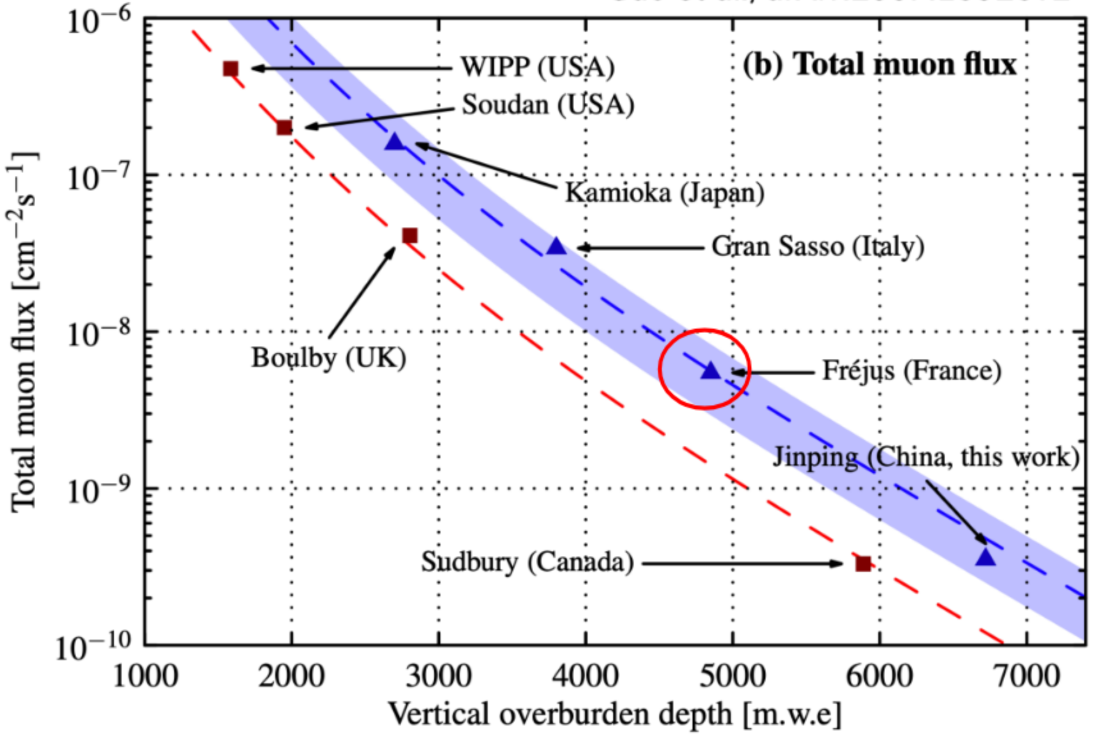
Final Assessment of Tesseract & Ricochet Radiogenic Background Budget

# Background Mitigation
# &
# Radiogenic Simulations for TESSERACT

# Background Mitigation

- **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 Mitigation

- **Cosmic rays + cosmogenic activation of detectors & shielding materials**
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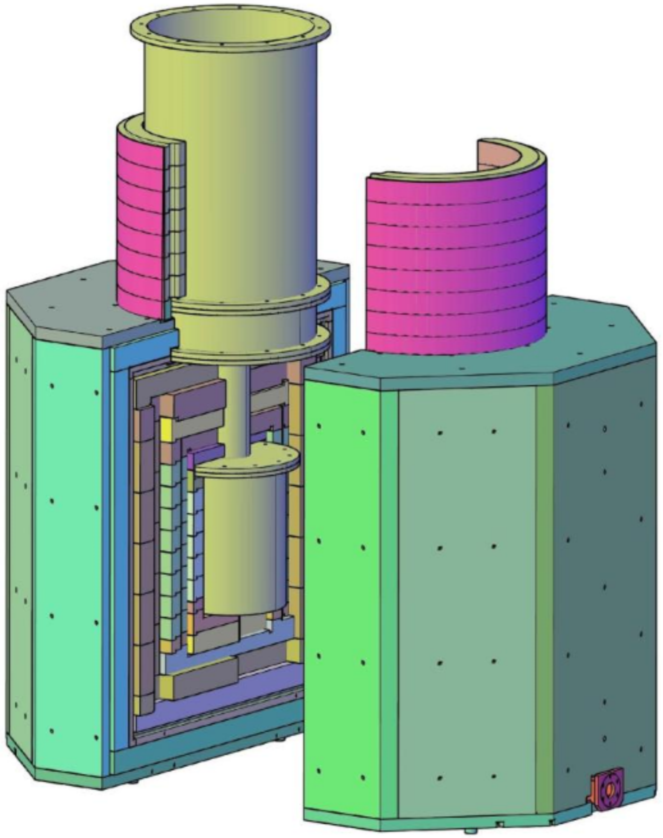
- **Natural radioactivity from Modane rock (U, Th, K)**
  - ✓ Passive/Active shielding

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

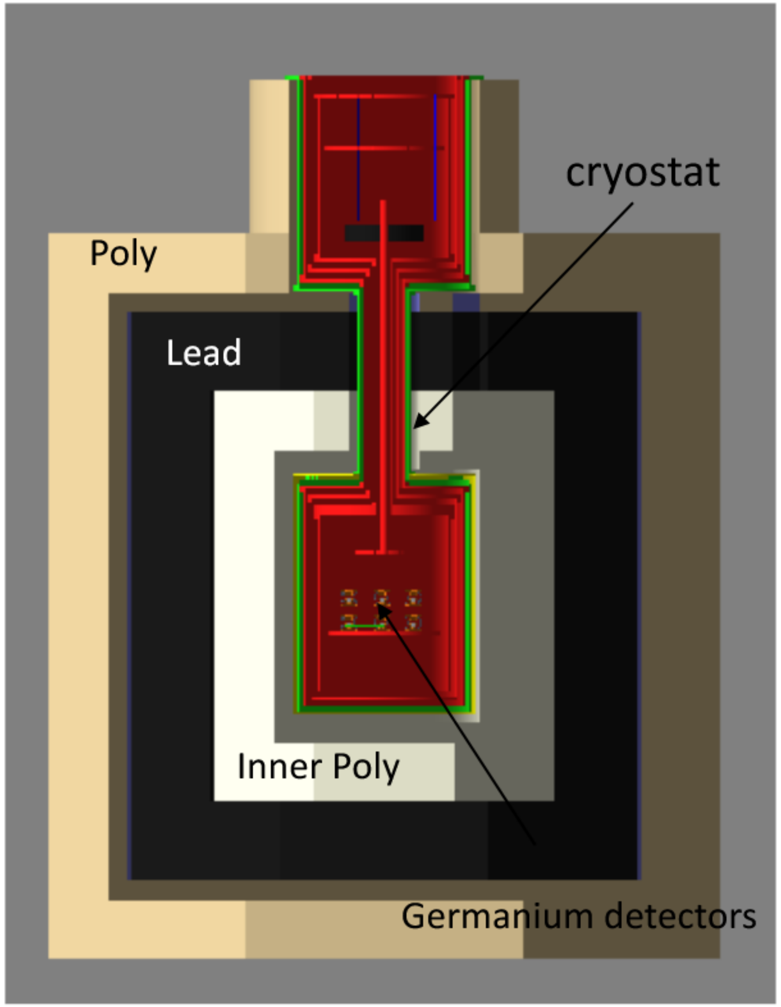


**My work:**
Geant4 simulations for

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

# Radiogenic Simulations

**Goal: have a complete estimation of radiogenic background budget**



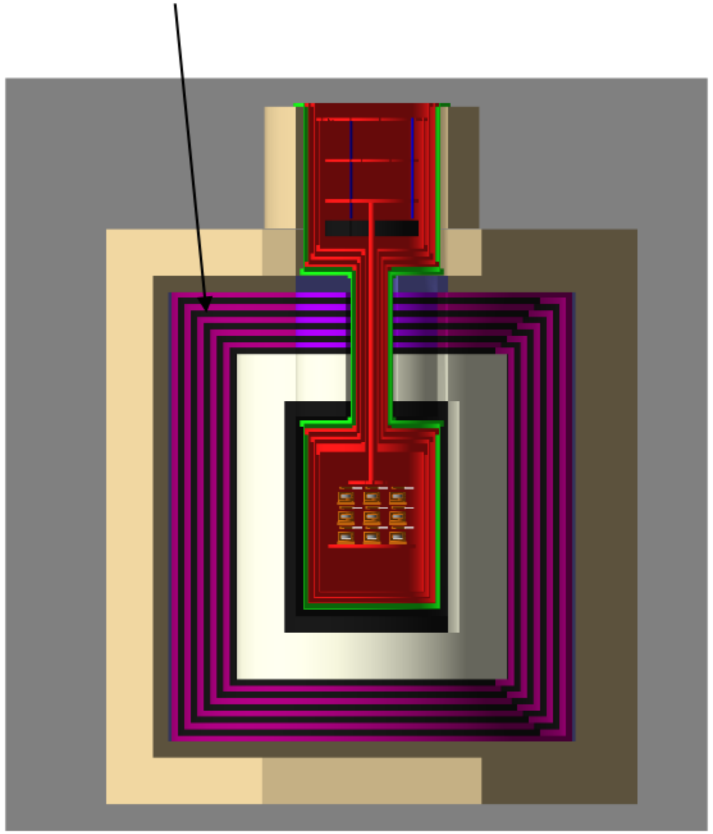

**Simulation of radiogenic background**

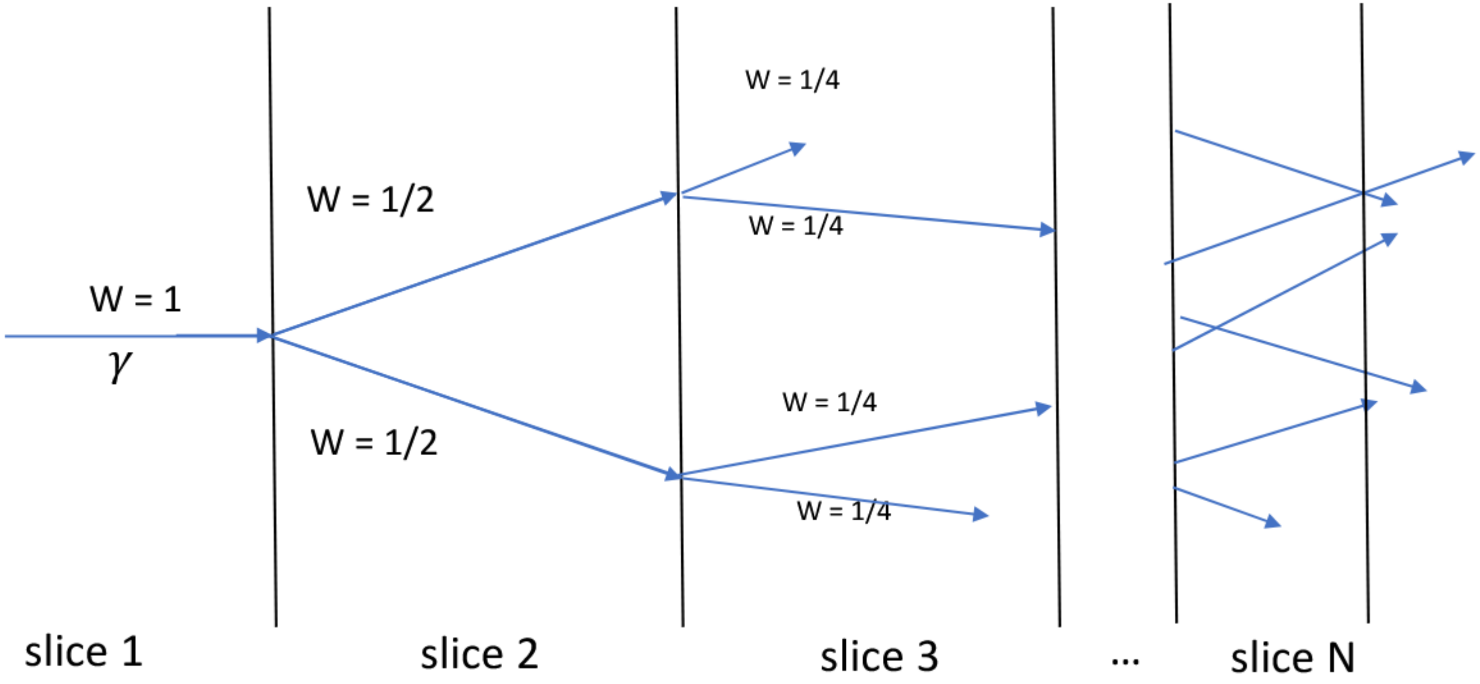
- Reproduction of shielding + cryostat + detectors geometry in Geant4
- Contamination of each different volume of the geometry
  **Consider decay chain** $^{238}$U, $^{235}$U, $^{232}$Th, $^{40}$K, $^{137}$Cs
  And **copper cosmogenic activation** ($^{60}$Co, $^{57}$Co,$^{58}$Co,$^{54}$Mn)
- Generate **gammas** and **neutrons** from **Modane rock + concrete**

# Radiogenic Simulations – Biasing method

Event biasing = increase the sampling of rare but important events
Explore different interaction probabilities inside one event

Applied to $\gamma$ in lead shielding






- Use track weights to scale results → ensures correct normalization

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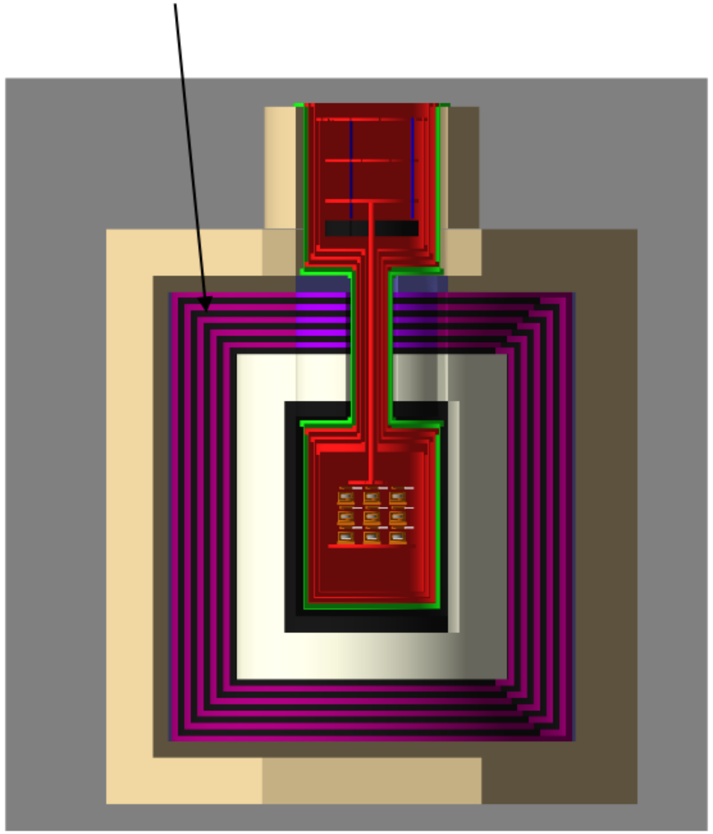
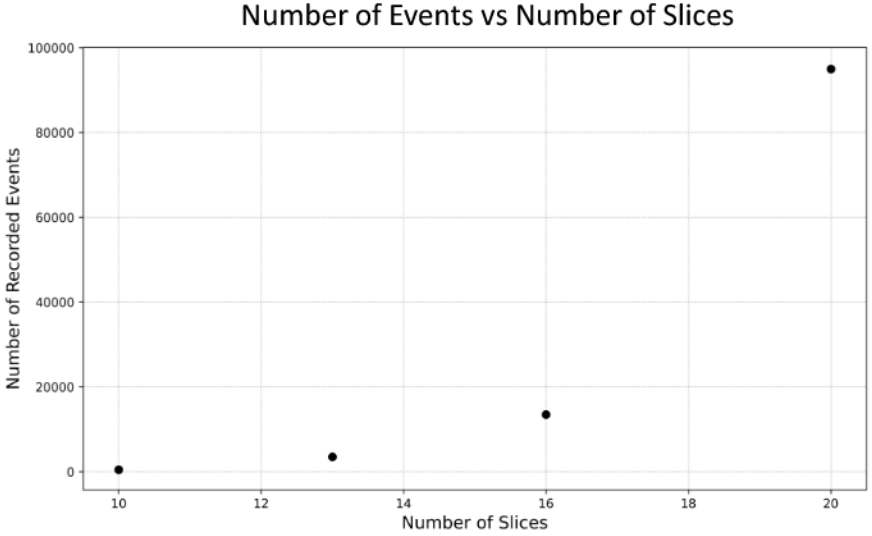
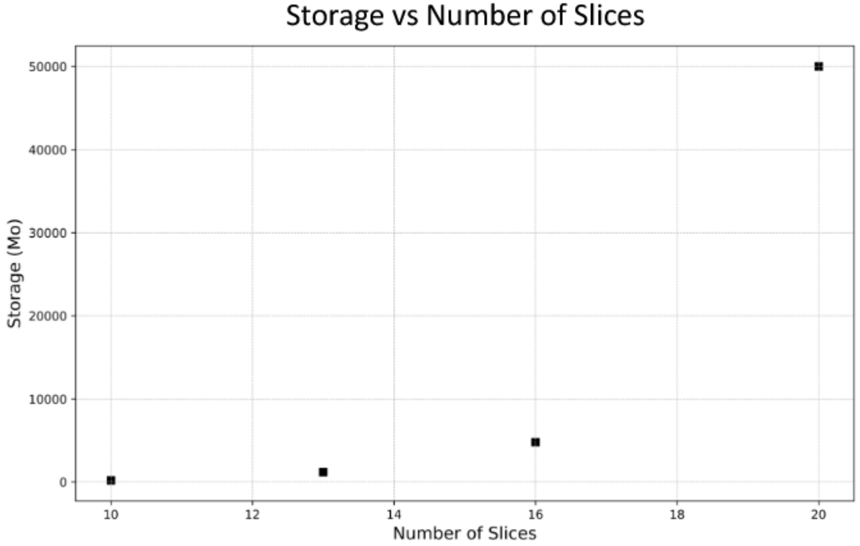




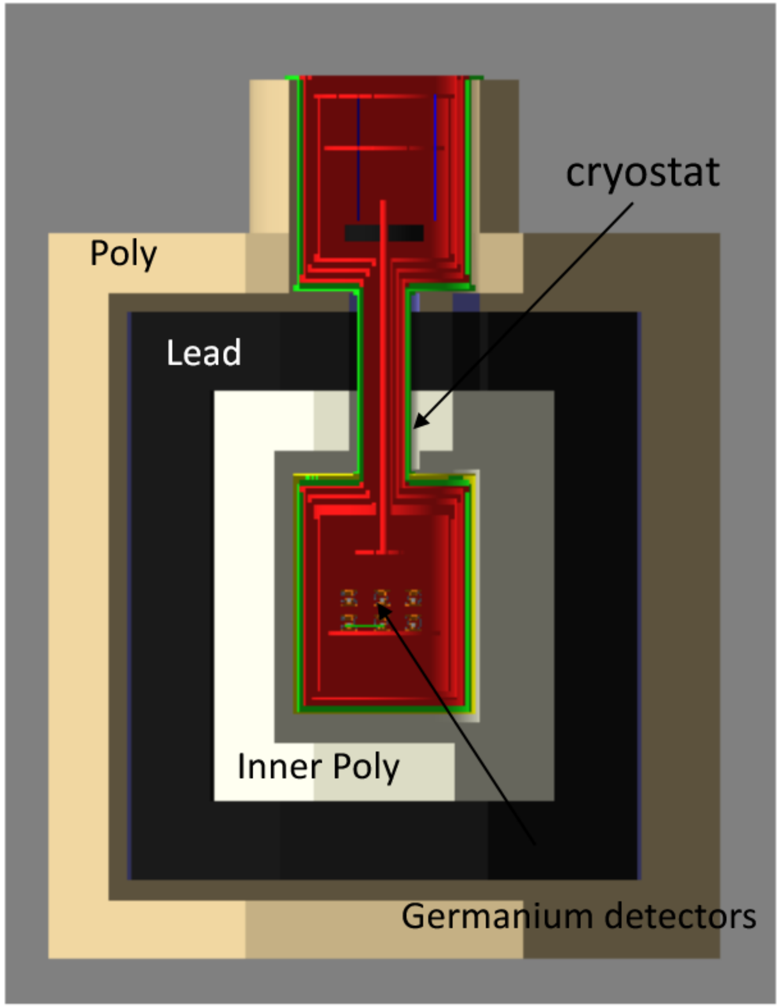




- Use track weights to scale results → ensures correct normalization
- Optimization of slices number by comparing computation time/memory/storage

  Using 16 Slices → **Boost** of a factor ~ 1E3 for external gammas

# Radiogenic Simulations

**Goal: have a complete estimation of radiogenic background budget**




**Simulation of radiogenic background**

↓

**Normalisation of Geant4 simulations output**

- Record number of events
  Obtain **energy**, **NR/ER** discrimination

- Normalisation:

External gammas/neutrons with **flux measurements in LSM**

$$\mathrm{DRU} = \frac{\#\,\mathrm{Counts}}{\#\,\mathrm{Primaries}} \times \varphi\,[\gamma/(cm^2 \cdot s^{-1})] \times \mathrm{Surface}[cm^2] \times 86400 \times \frac{1}{\mathrm{ROI\ [keV]}}$$

Internal contamination with activities **from material screening,** material activation with Activia simulations

$$\mathrm{DRU} = \frac{\#\,\mathrm{Counts}}{\#\,\mathrm{Primaries}} \times \mathrm{A}\left[\frac{Bq}{kg}\right] \times \frac{\mathrm{mass\ source\ [kg]}}{\mathrm{mass\ detector\ [kg]}} \times 86400 \times \frac{1}{\mathrm{ROI\ [keV]}}$$

1 DRU = 1 event/kg/keV/day

# Radiogenic Simulations

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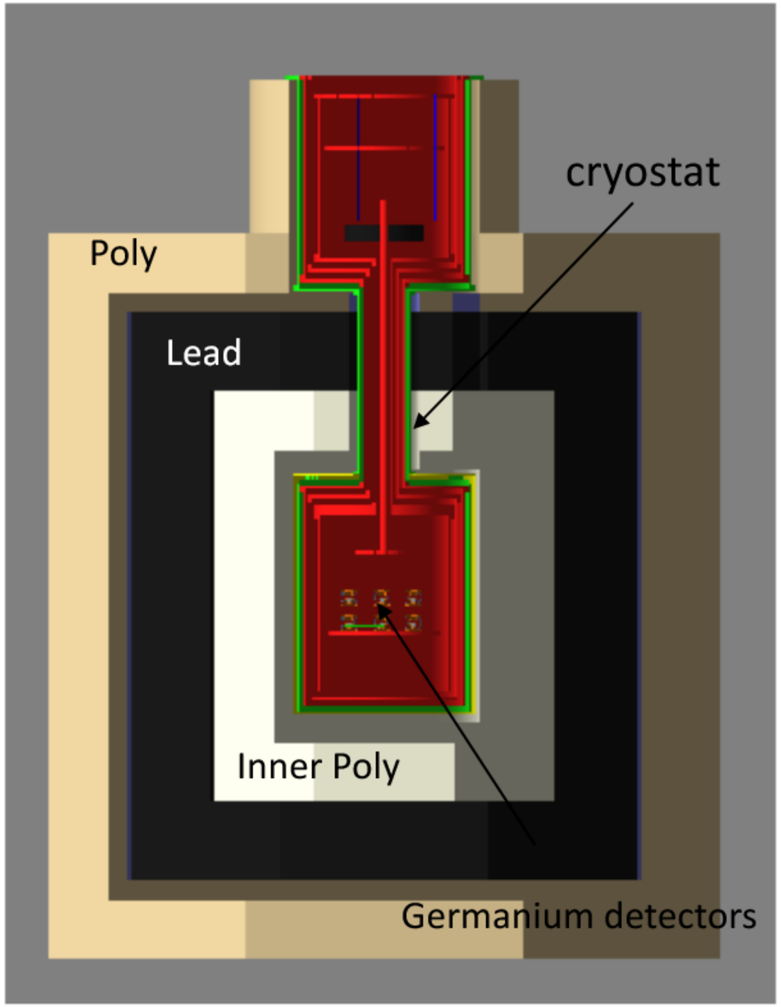
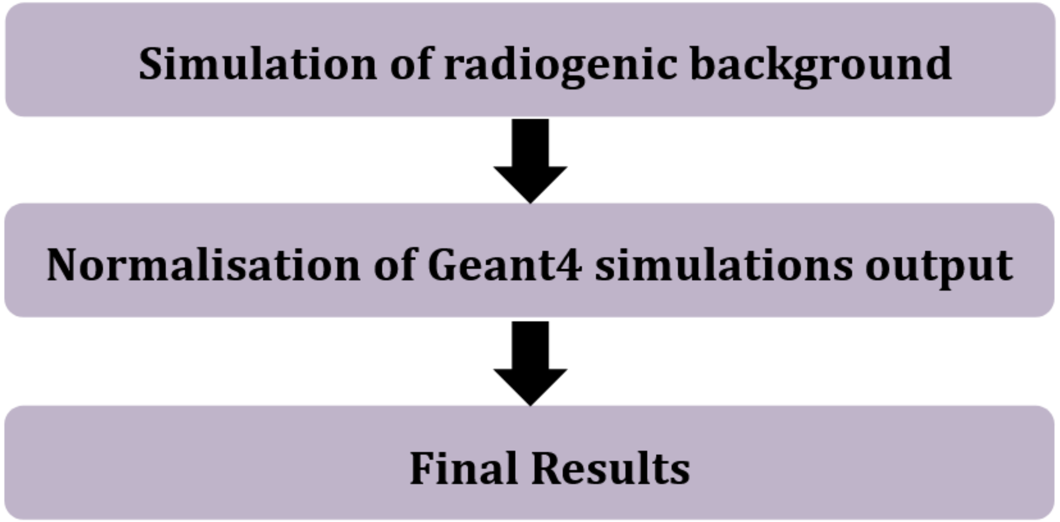
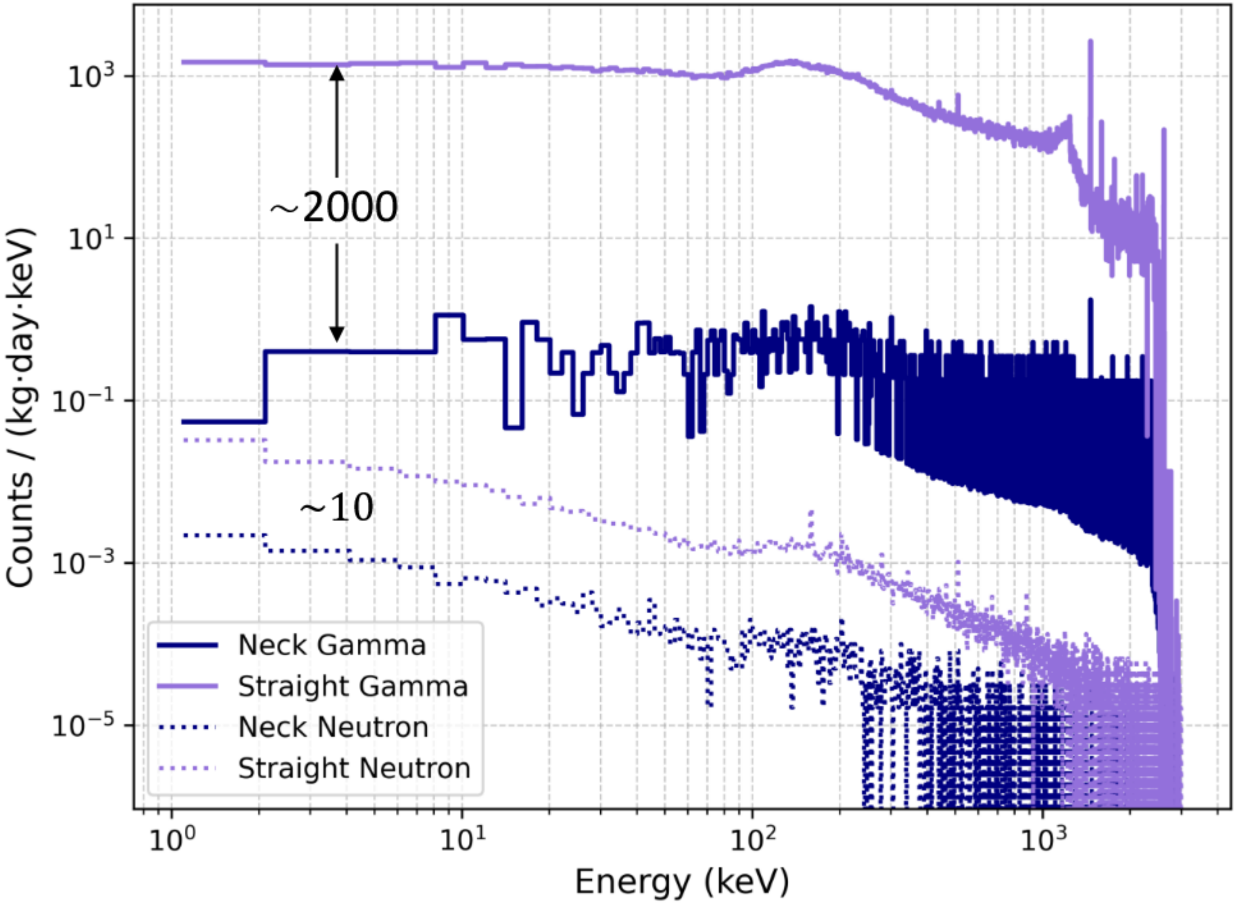


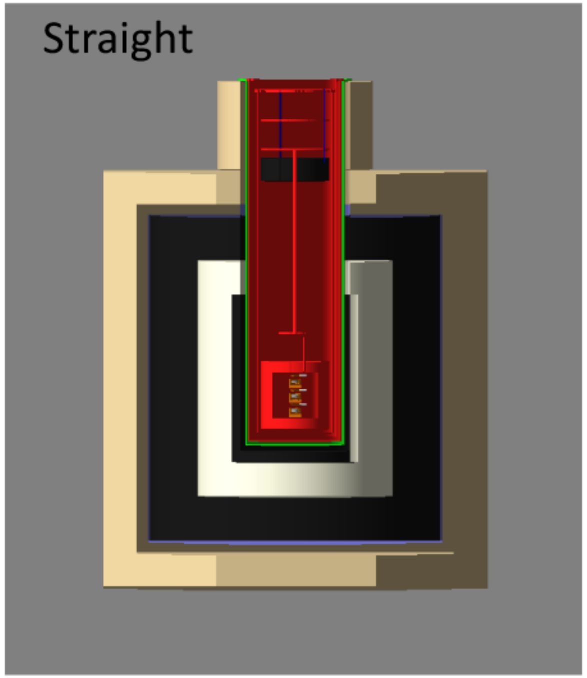



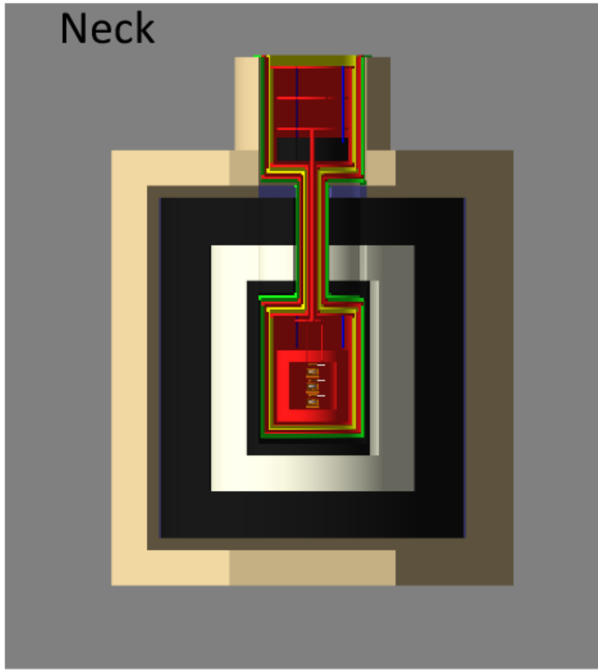

- **Optimisation** of the shielding design
- Specification on **material radiopurity**
- Estimate the **total radiogenic background budget** and **comparison with data**
- Use simulated background spectrum **for sensitivities projections**

# Radiogenic Simulations

**Shielding Optimization: Neck/Straight Cryostat Study**



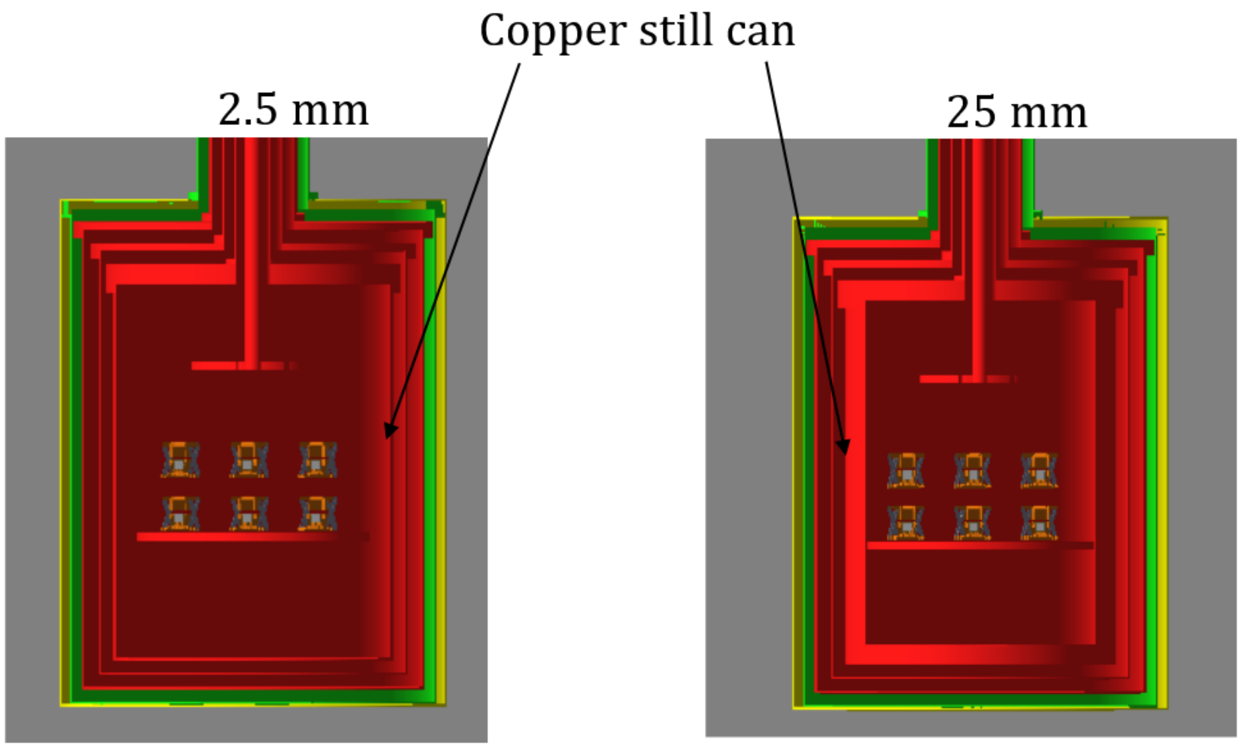



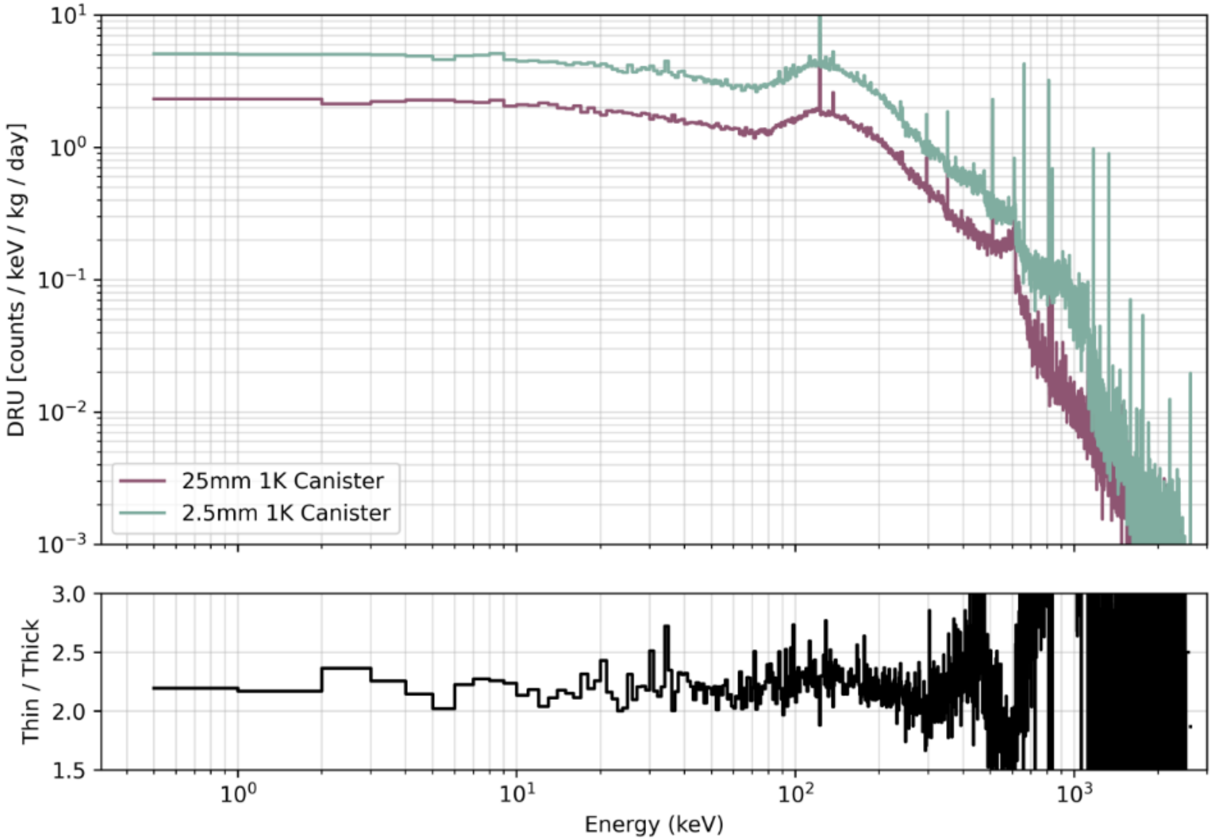




Assess the protection against LSM Neutrons & Gammas

# Radiogenic Simulations

**Shielding Optimization 1K Canister Thickness**



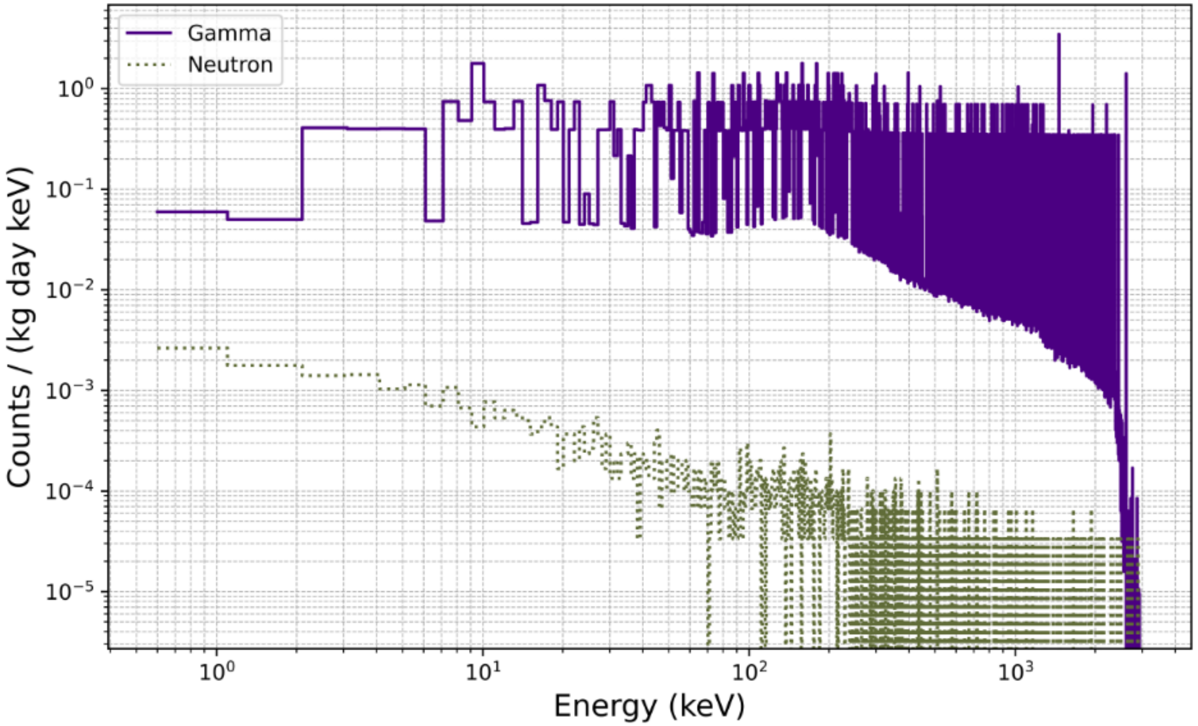




Assess the protection against internals + the increase due to greater mass

# Radiogenic Simulations

**Assessment of full radiogenic background budget**

Radiogenic background spectra for **external gammas + neutrons**




From Externals: 0.41 counts/(kg keV day)

# Radiogenic Simulation

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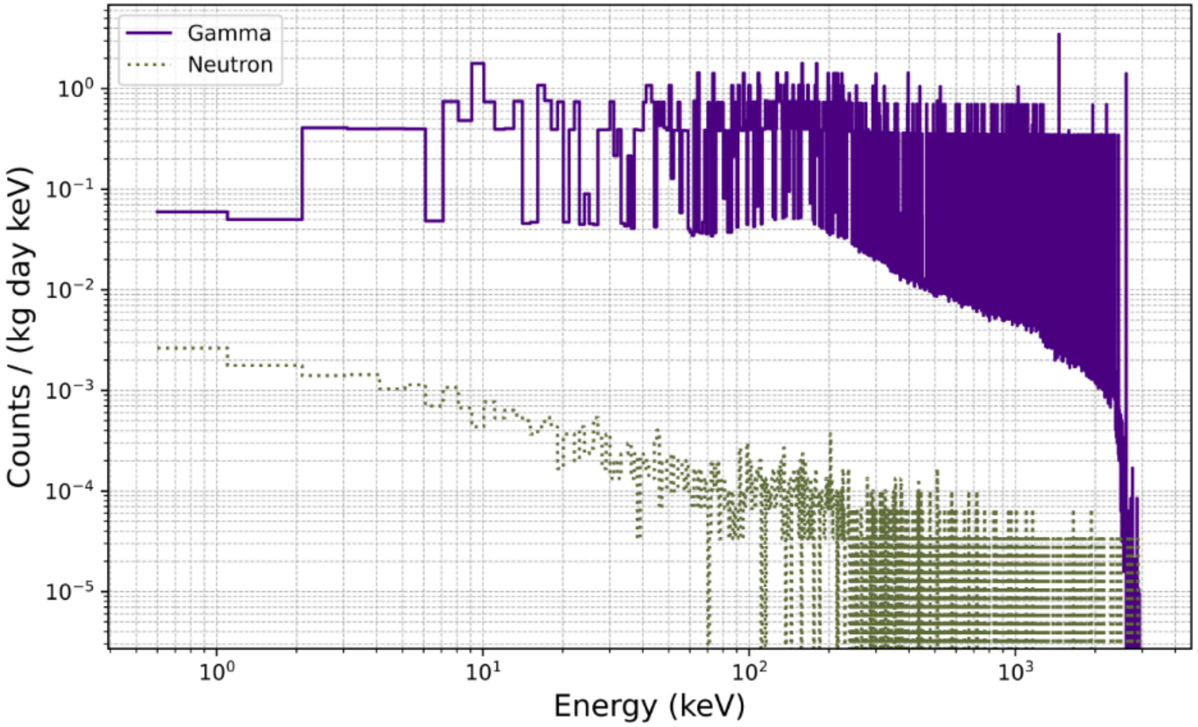
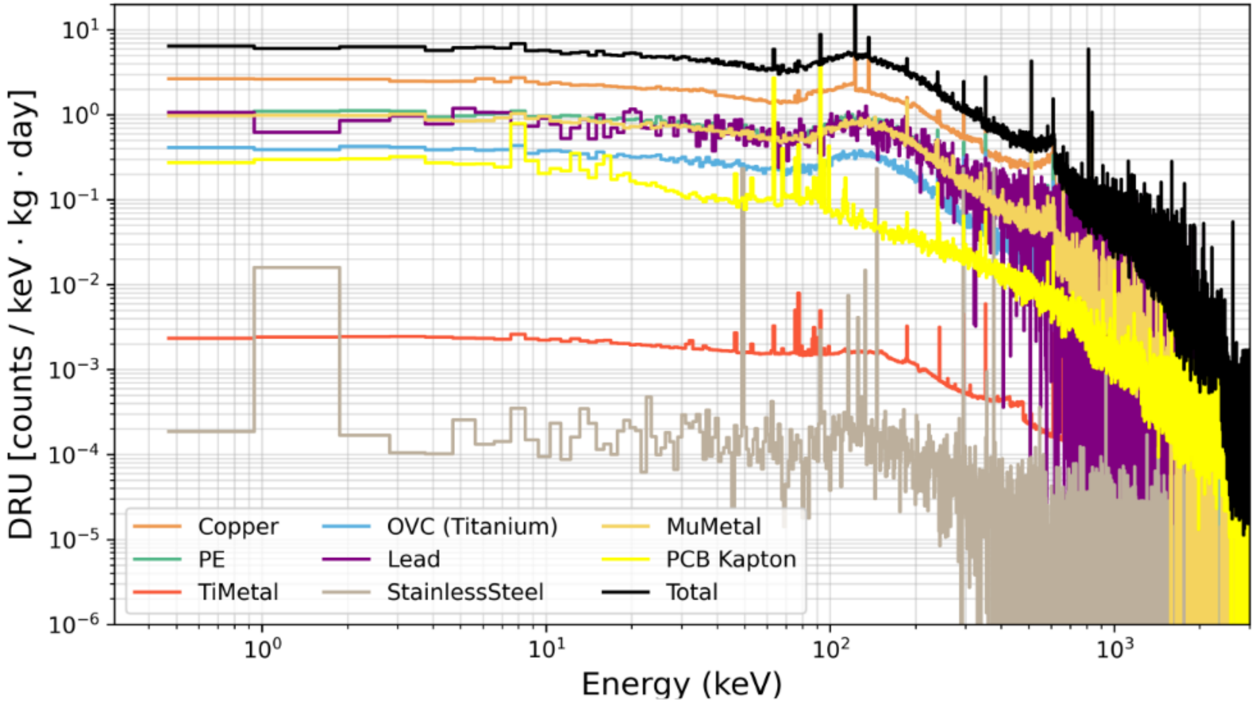
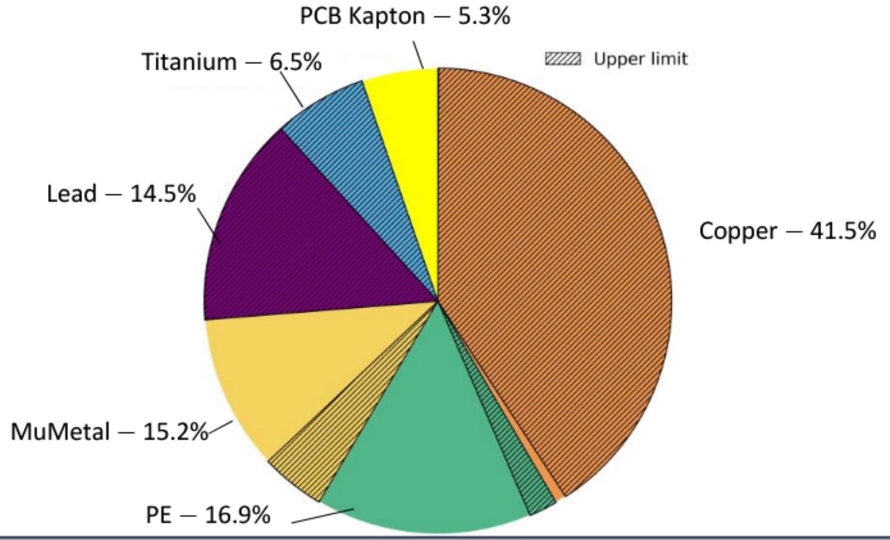



From Externals: 0.41 counts/(kg keV day)
From Internals: 6.45 counts/(kg keV day)

Total : 6.86 DRU

Radiogenic background spectra for **material contamination**



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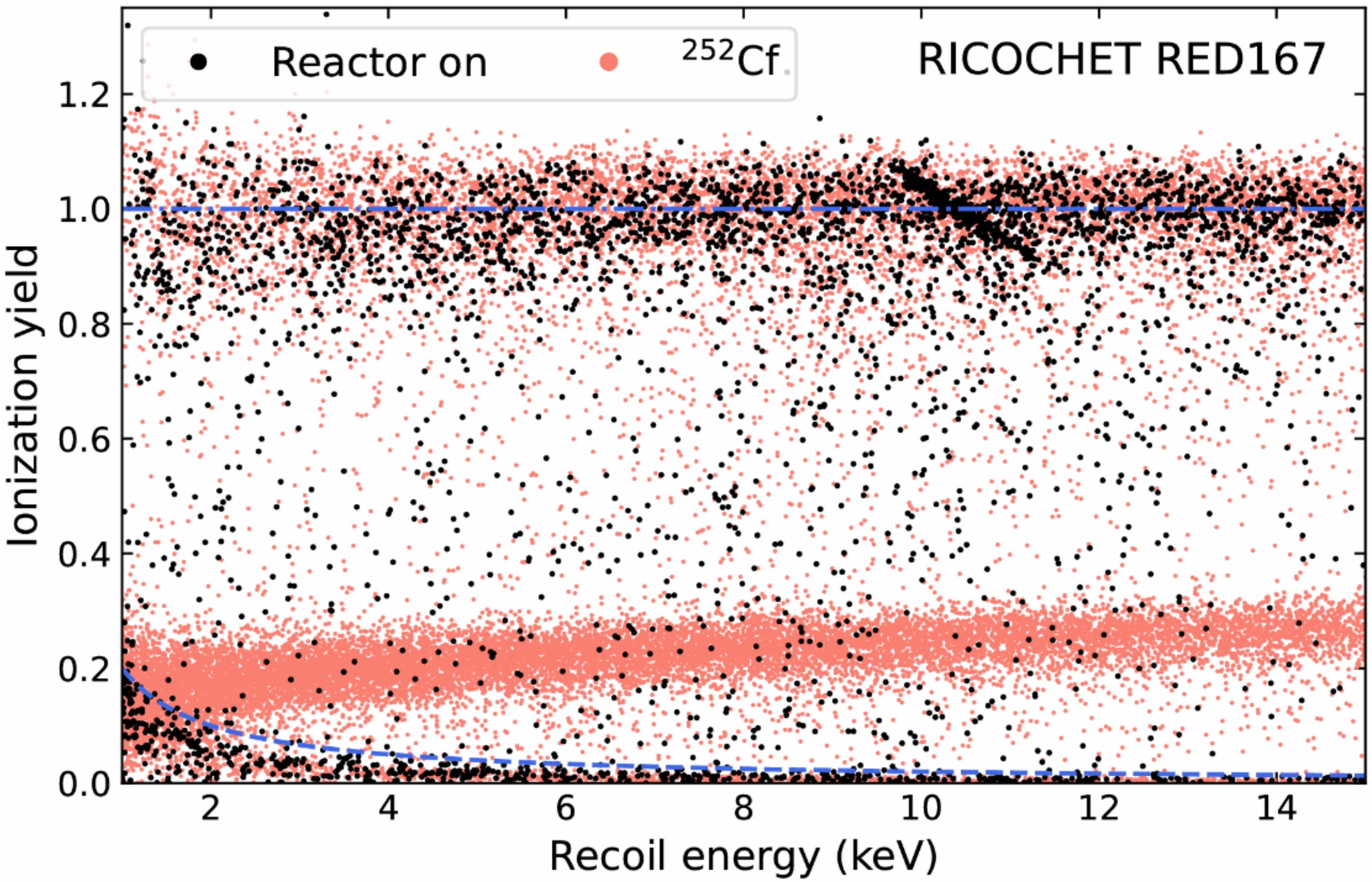
Ricochet Data Analysis of FID detectors

Final Assessment of Tesseract & Ricochet Radiogenic Background Budget

# Background Rejection
# Data Analysis with Ricochet detectors

# Background Rejection




Ricochet Collaboration, Phys. Rev. D **112 (2025)**, 112019

**Surface events:**

- Incomplete charge collection
- Coming from electrons interactions in copper holder / $\beta$ decay on detector surfaces or copper holder
- Prevent from a clear identification of NR

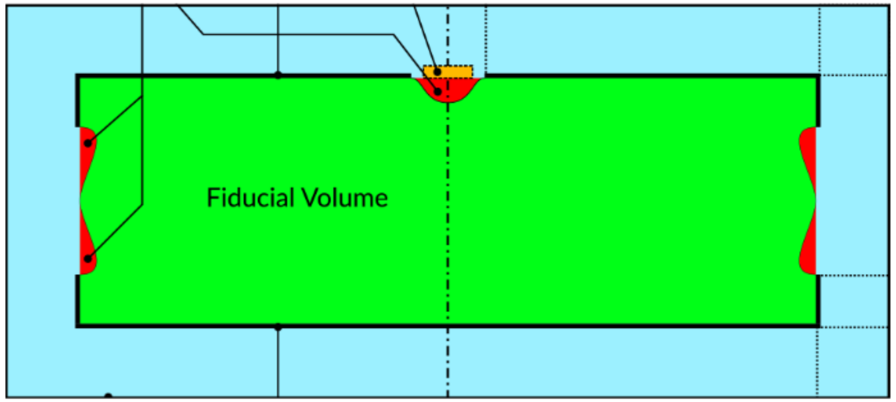
⇩

Use FID detectors for surface background rejection

# Background Rejection

## Two electrode geometries

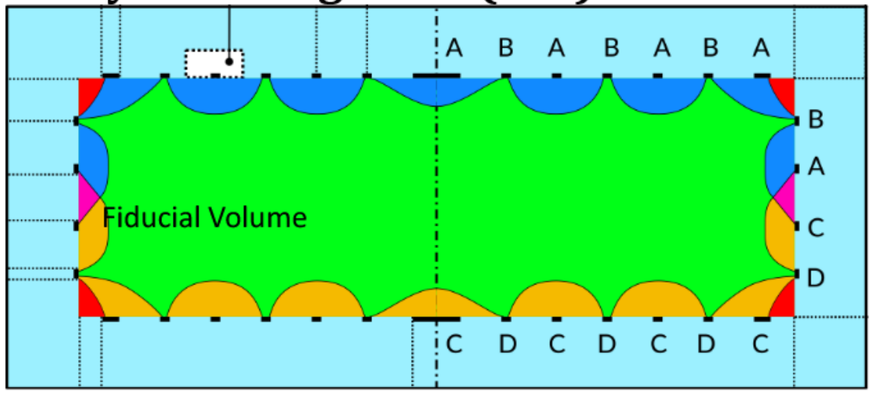
Planar



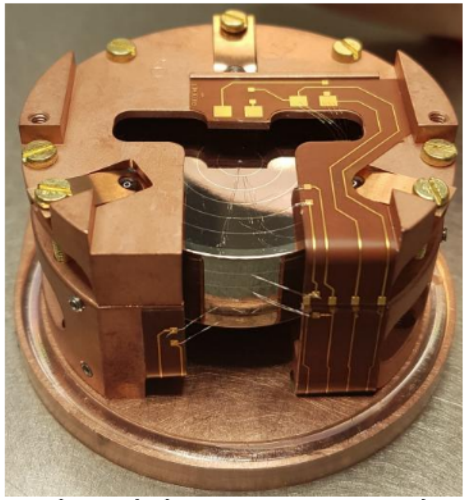

- **No surface** event **rejection**
- 2 fiducial electrodes
- Fiducial volume **100%**

*Planar detector in Ricochet*

Fully Inter-Digitized (FID)




- **Surface event rejection** possible
- 2 veto electrodes + 2 fiducial electrodes
- **Reduced** fiducial volume



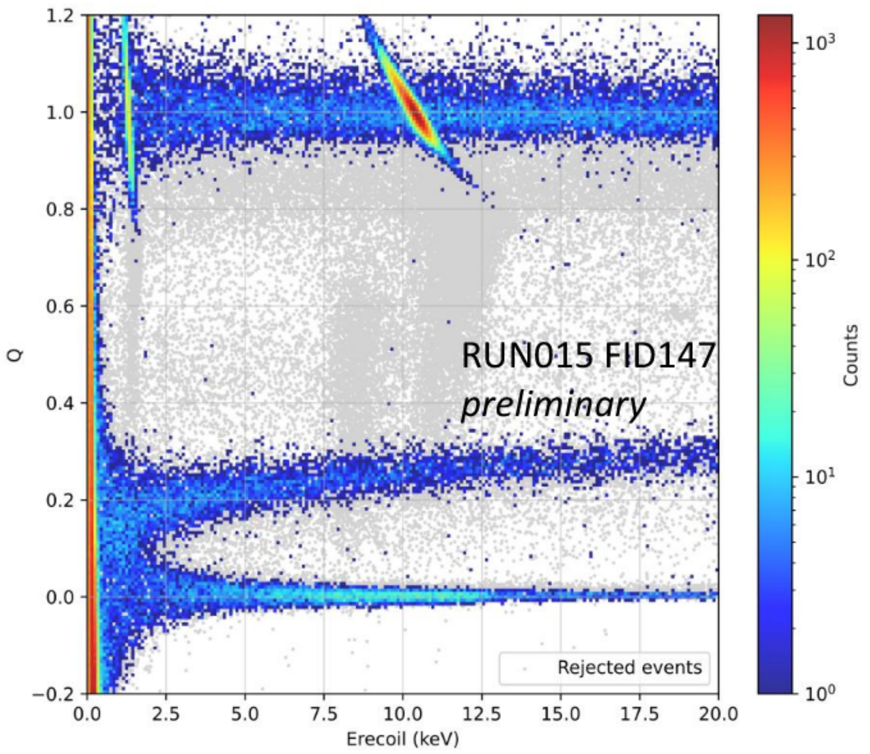
*Fiducial detector in Ricochet*

# Background Rejection

**Definition and study of energy dependant fiducial cut (in FID detectors)**

Require:

- No signal on veto1/veto2 electrodes
- Symmetric charge collection on fiducial electrodes




**Dedicated calibration campaign to determine discrimination power of detector to come**

Measurement of alphas rate in copper holder before exposition

↓

Exposition to Radon at SNOLAB underground laboratory
Implantation of Radon daughters (Pb210) on the holder surface

↓

Measurement of alphas rate in copper holder after exposition

↓

Dedicated run to study response of detectors to alphas

# Conclusion

- **Cryogenic calorimeter** well suited for **rare event search** (Dark Matter and CENNS)

- Contributions to **TESSERACT** and **Ricochet** collaboration:

**TESSERACT:**

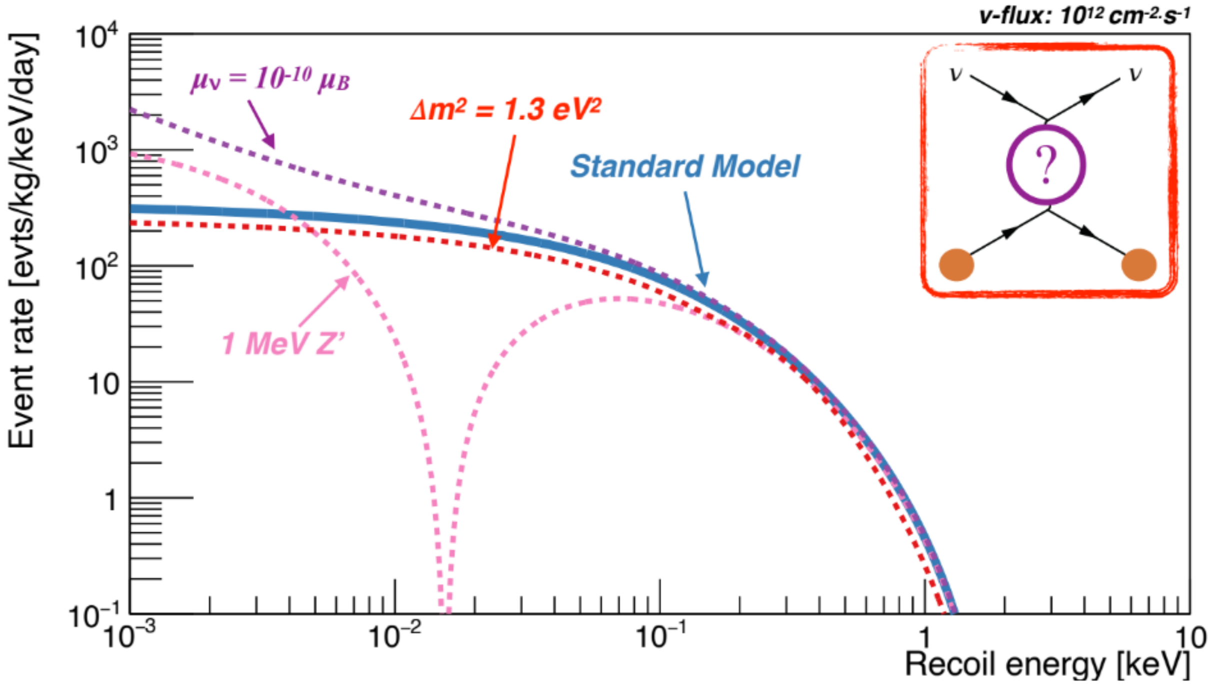
- Simulations Working Group coordinator
  - Finalization of shielding design
  - Assessment of radiogenic background budget with Geant4 simulations

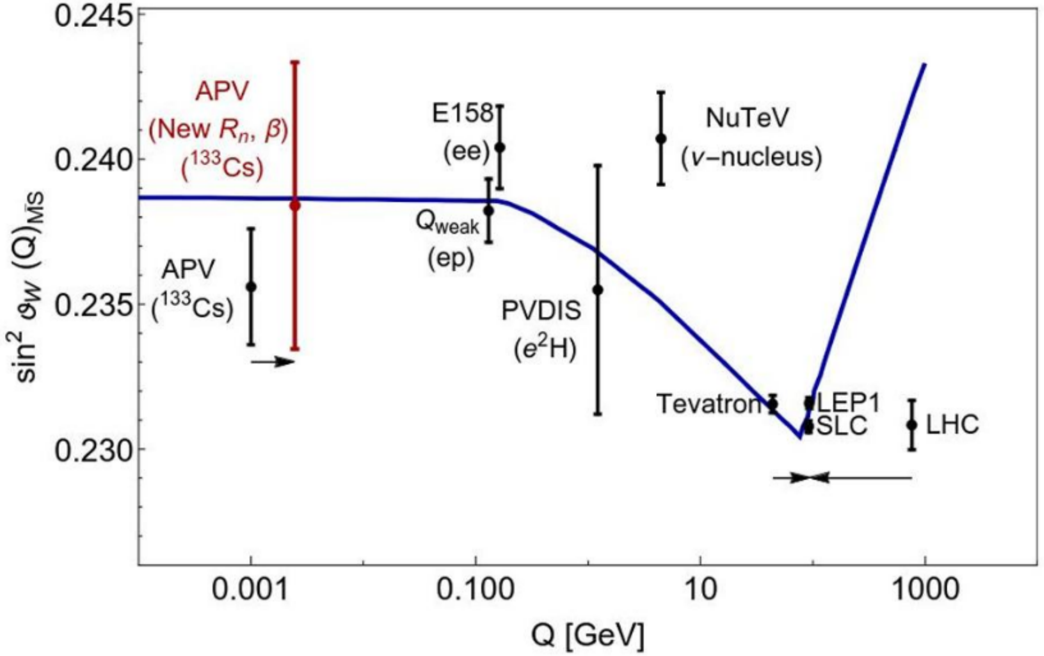
**Ricochet:**

- Surface event rejection study with FID detectors, dedicated data campaign to come
- Also simulated radiogenic background for Ricochet (paper in preparation)
- DAQ shifts + data monitoring

# BACKUP

# CENNS



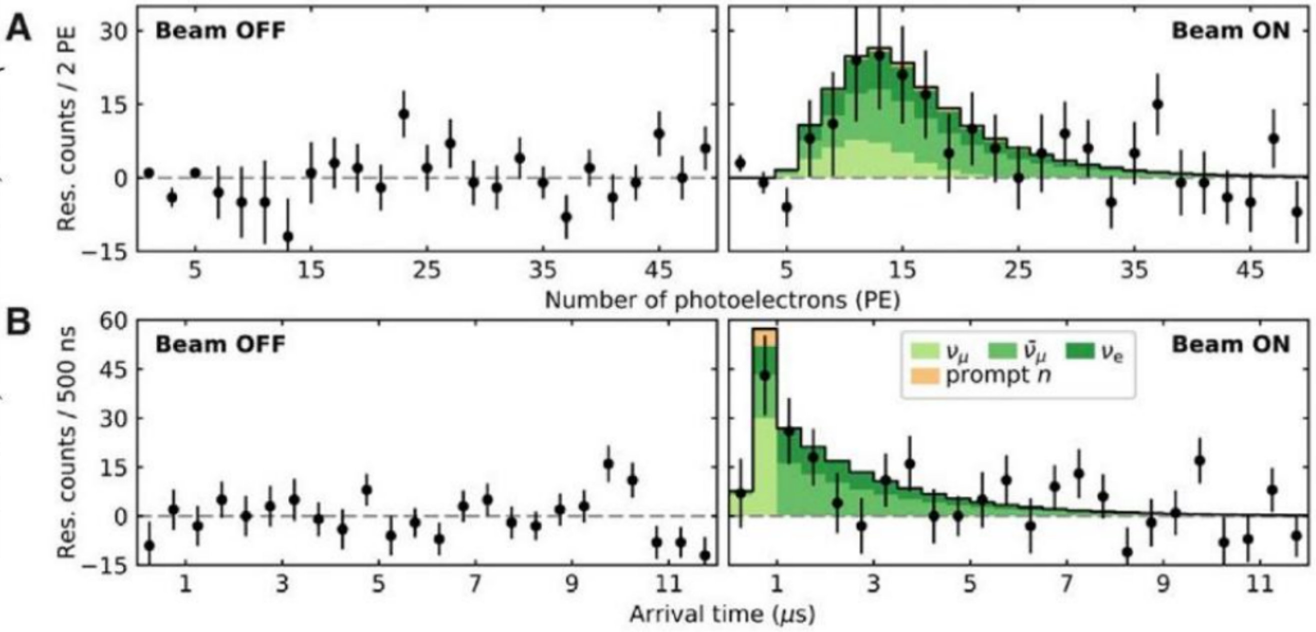



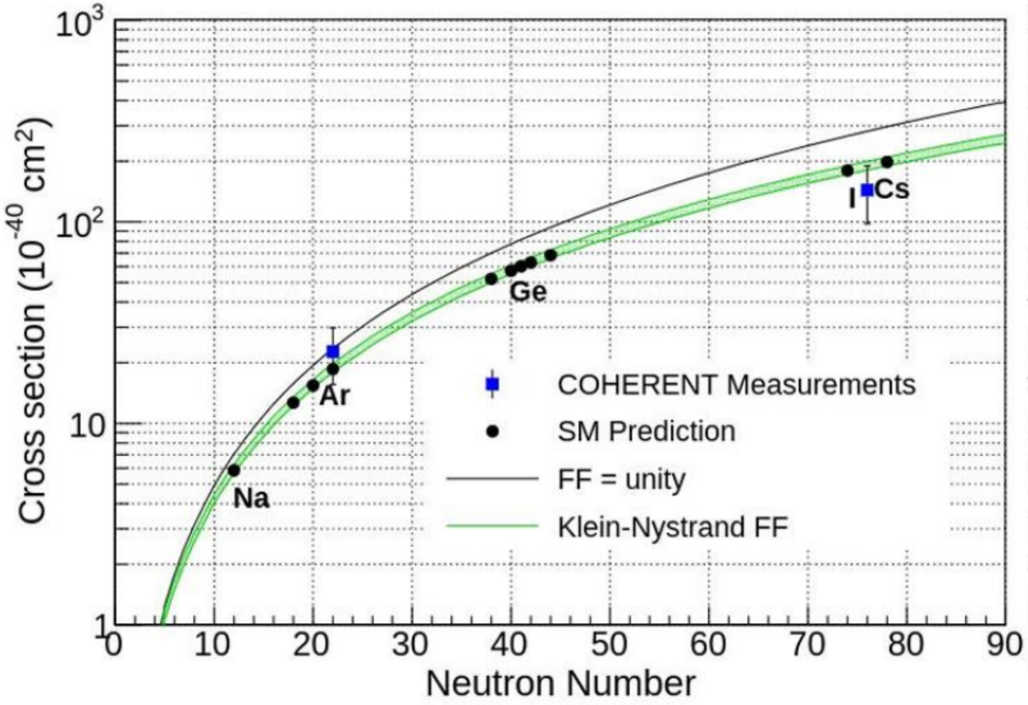

M. Cadeddu and F. Dordei Phys. Rev. D 99, 033010, 2019

# First CENNS measurement by COHERENT

First measurement by the COHERENT collaboration in 2017 with accelerator neutrinos
Using different targets to measure the CENNS cross-section dependency with $N^2$

D. Akimov, Science 357, 1123 (2017)



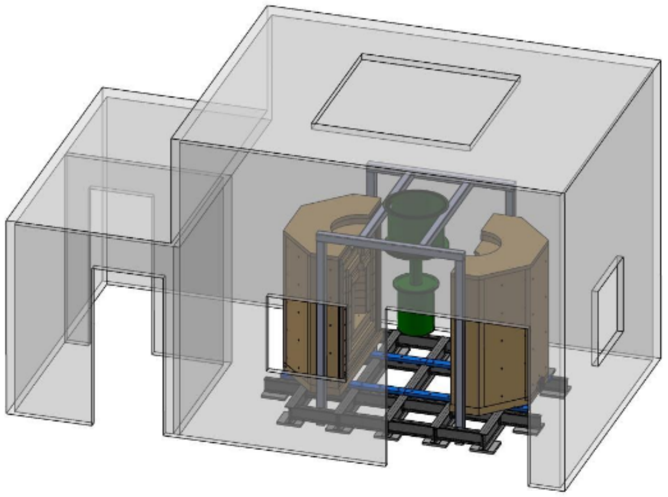



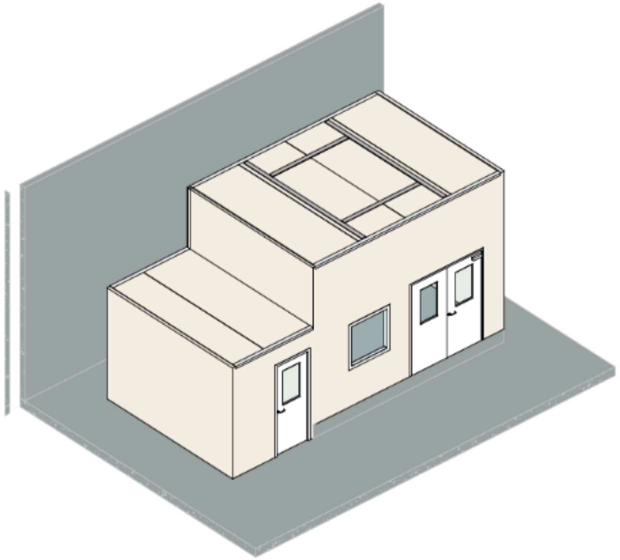

D.Akimov et al., PRL (2021), arXiv:2003.10630

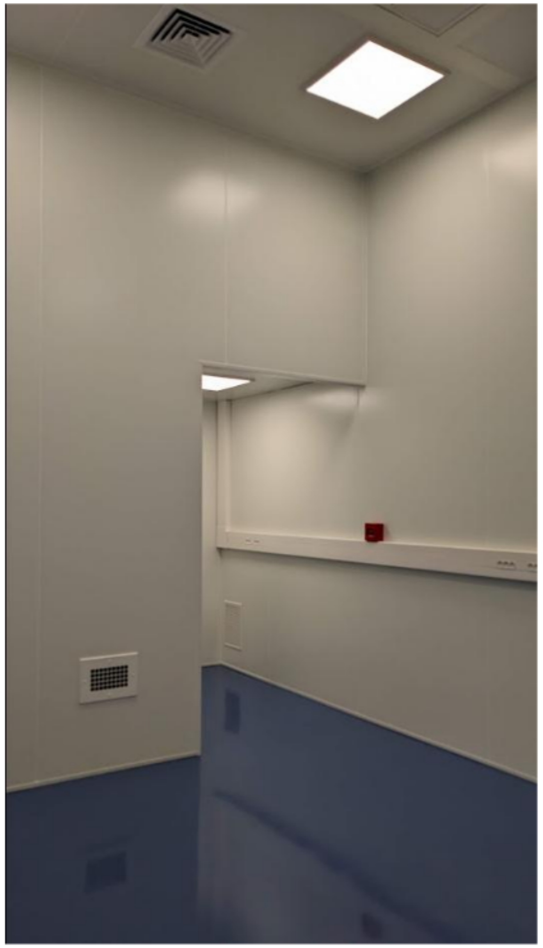
# Commissioning @ LPSC

Clean room for the cryostat and shielding ready at LPSC

- Platform under construction
- Cryostat design under finalization and shielding tender to be published soon

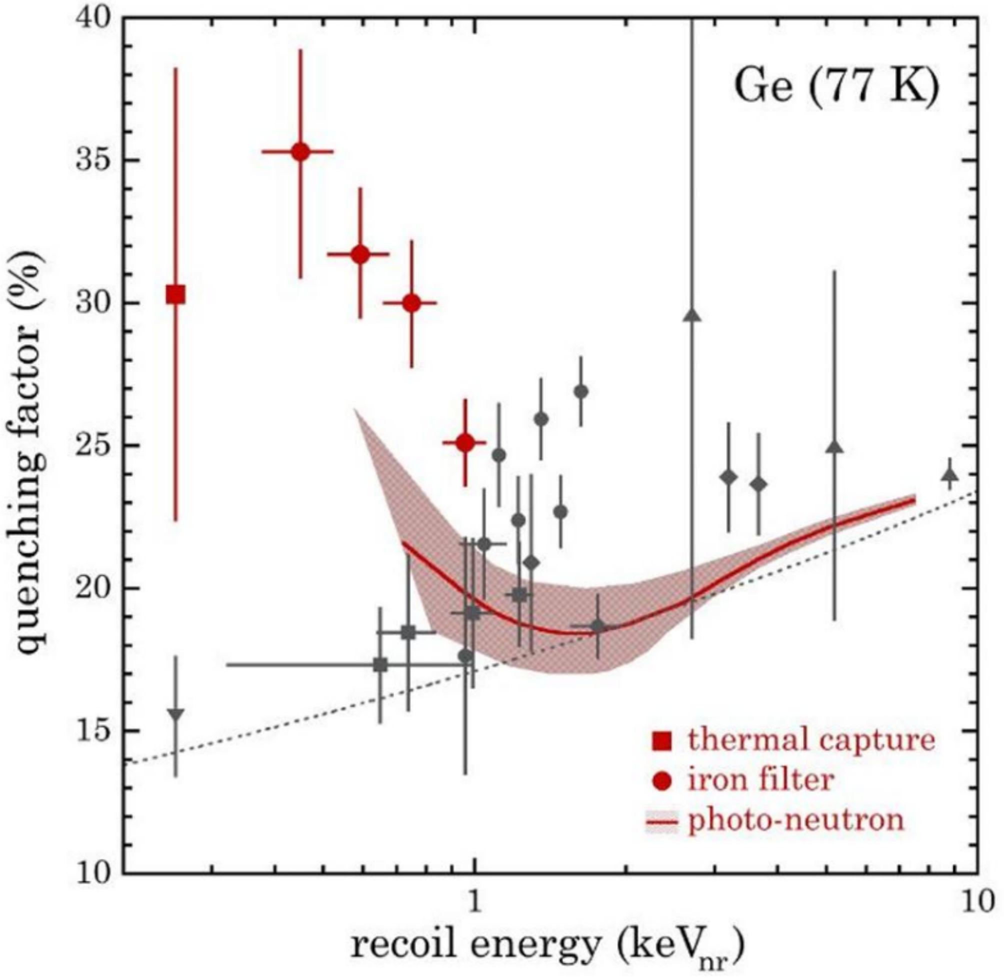






# Quenching

Collar, Kavner, Lewis, Phys. Rev. D 103, 122003 (2021)




Recent measurement of quenching factor at low energy seem to be incompatible with Lindhard model

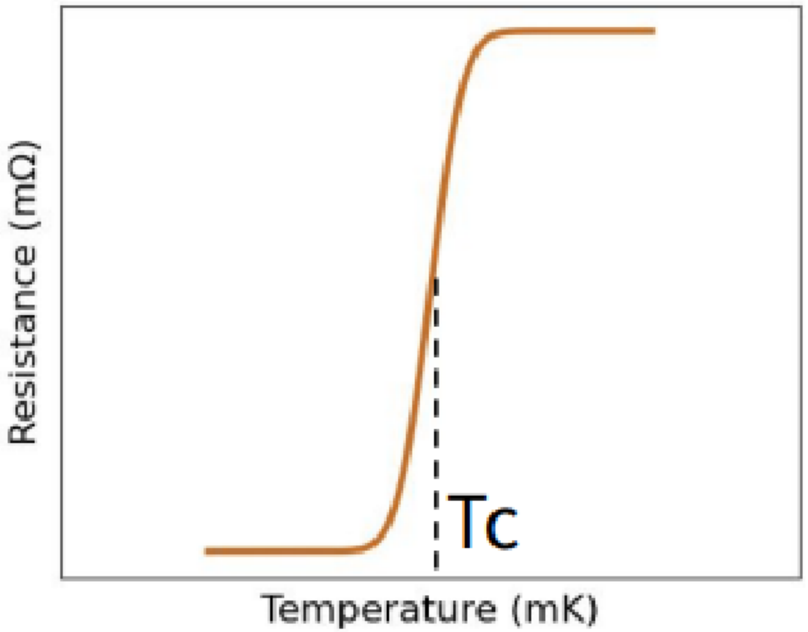
→ Necessity of our own quenching measurement onsite

→ Use a Californium source to have nuclear recoils

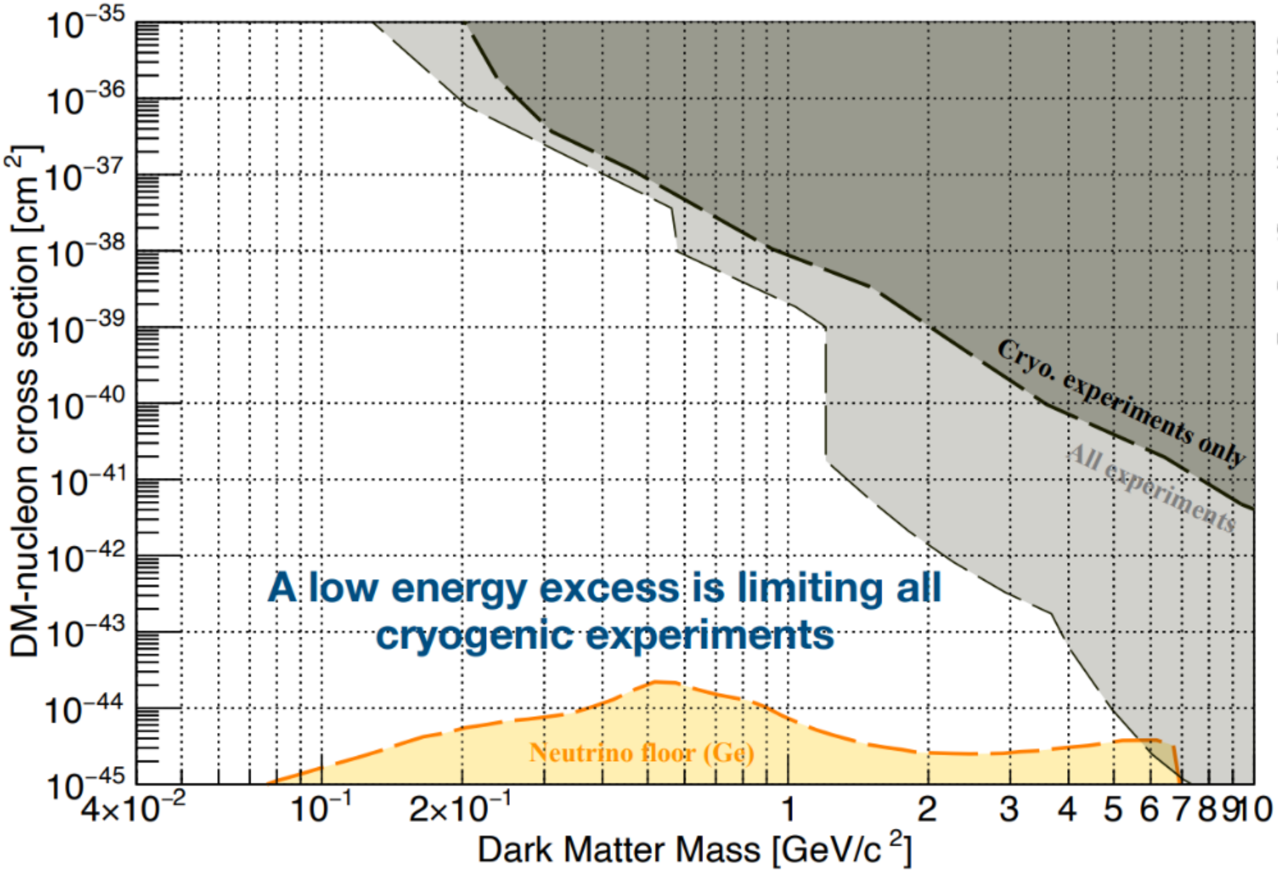
→ Data analysis of RUN014 Cf data ongoing

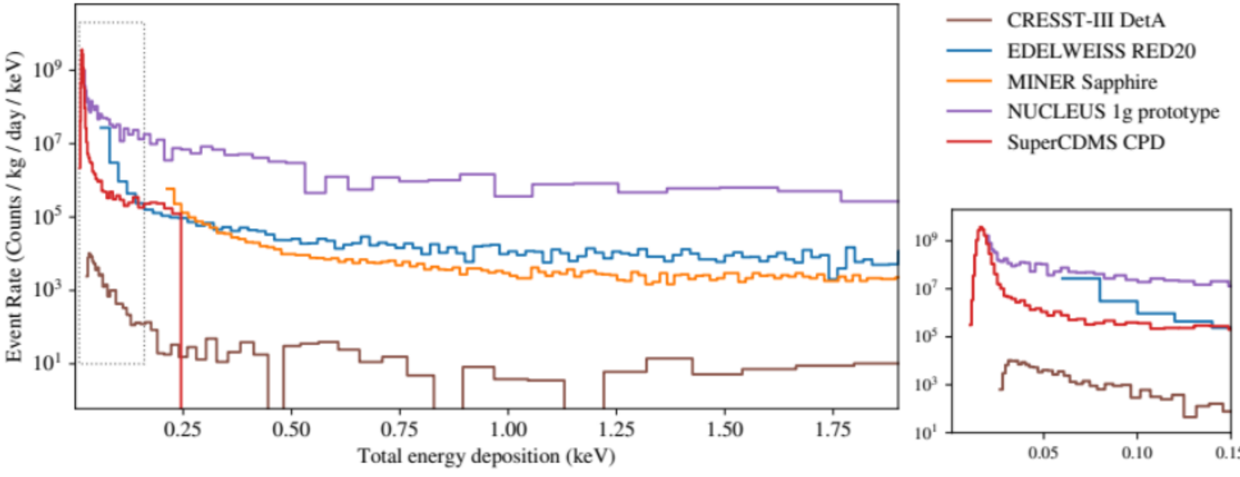
# Transition Edge Sensor (TES)

- Superconducting thin film operated at constant and critical temperature
- Particle interaction → small temperature elevation leads to big elevation of the resistance



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



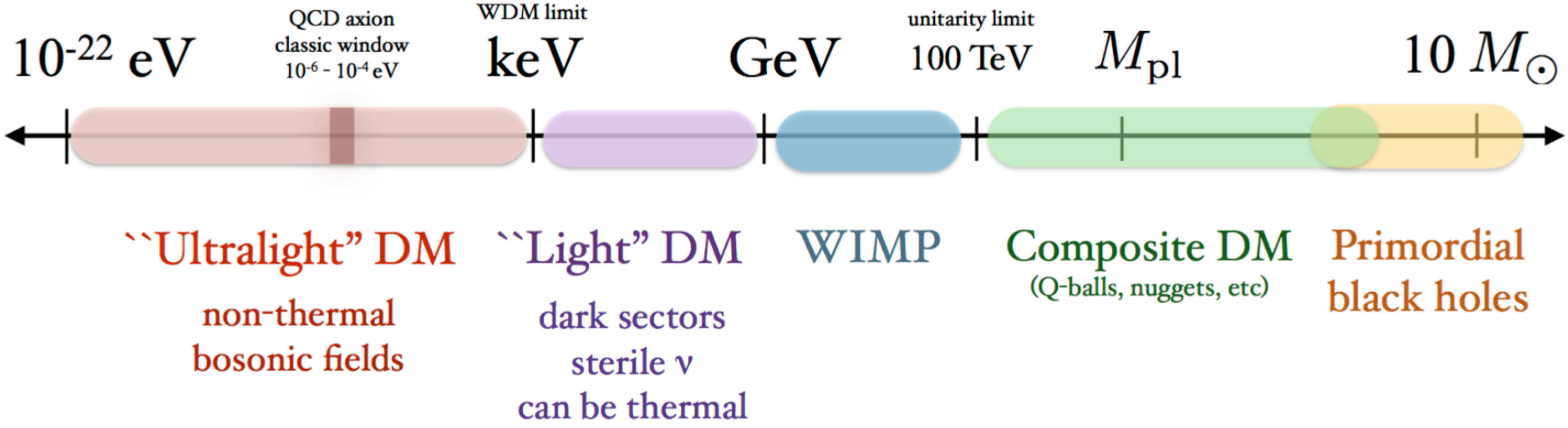

P. Adari, SciPost Phys. Proc. 9, 001 (2022)

LEE Characteristics:

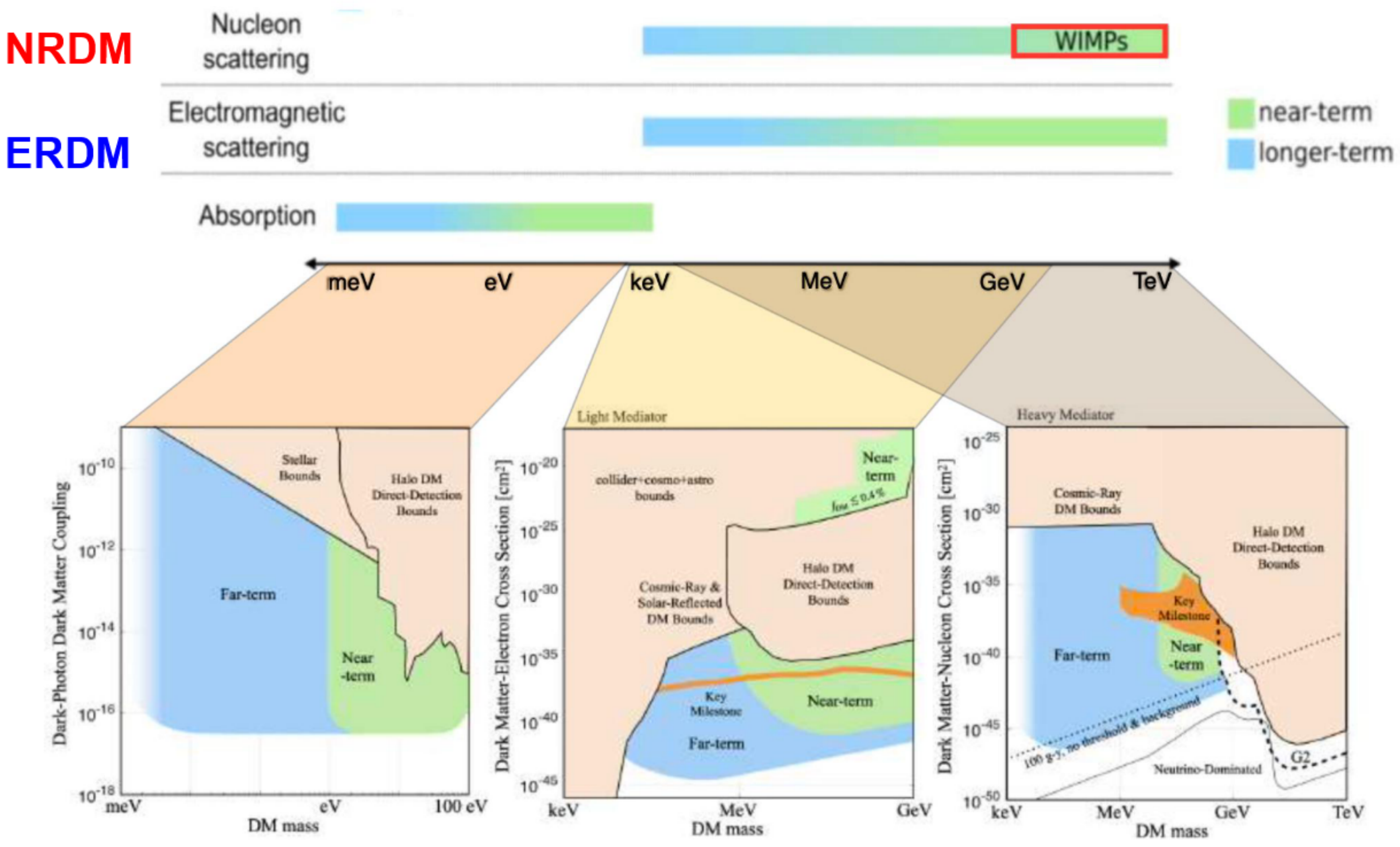
- Non ionising (« Heat Only »)
- Mostly independant of site
- Unknown origin

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

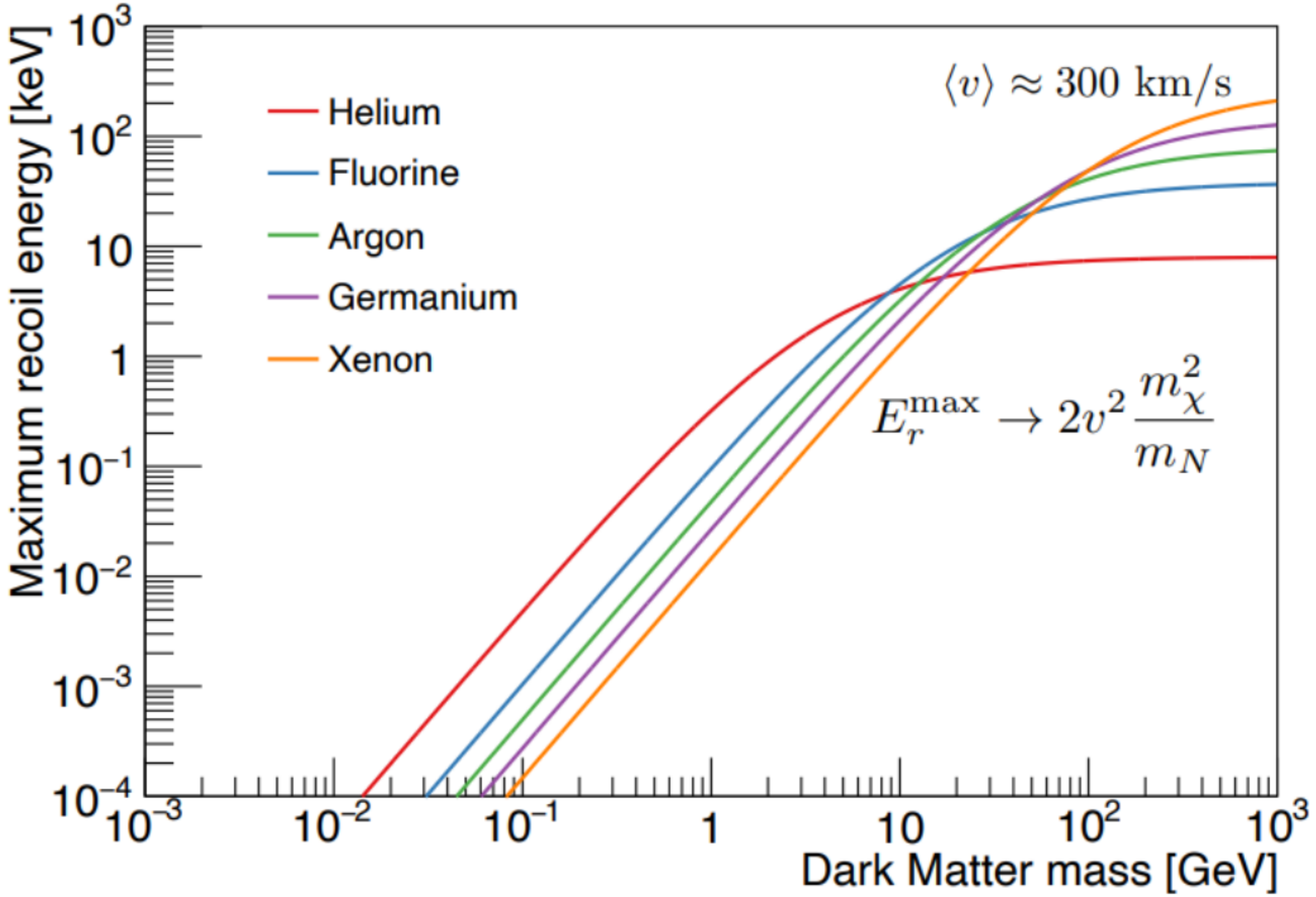
# DM candidates



# DM candidates

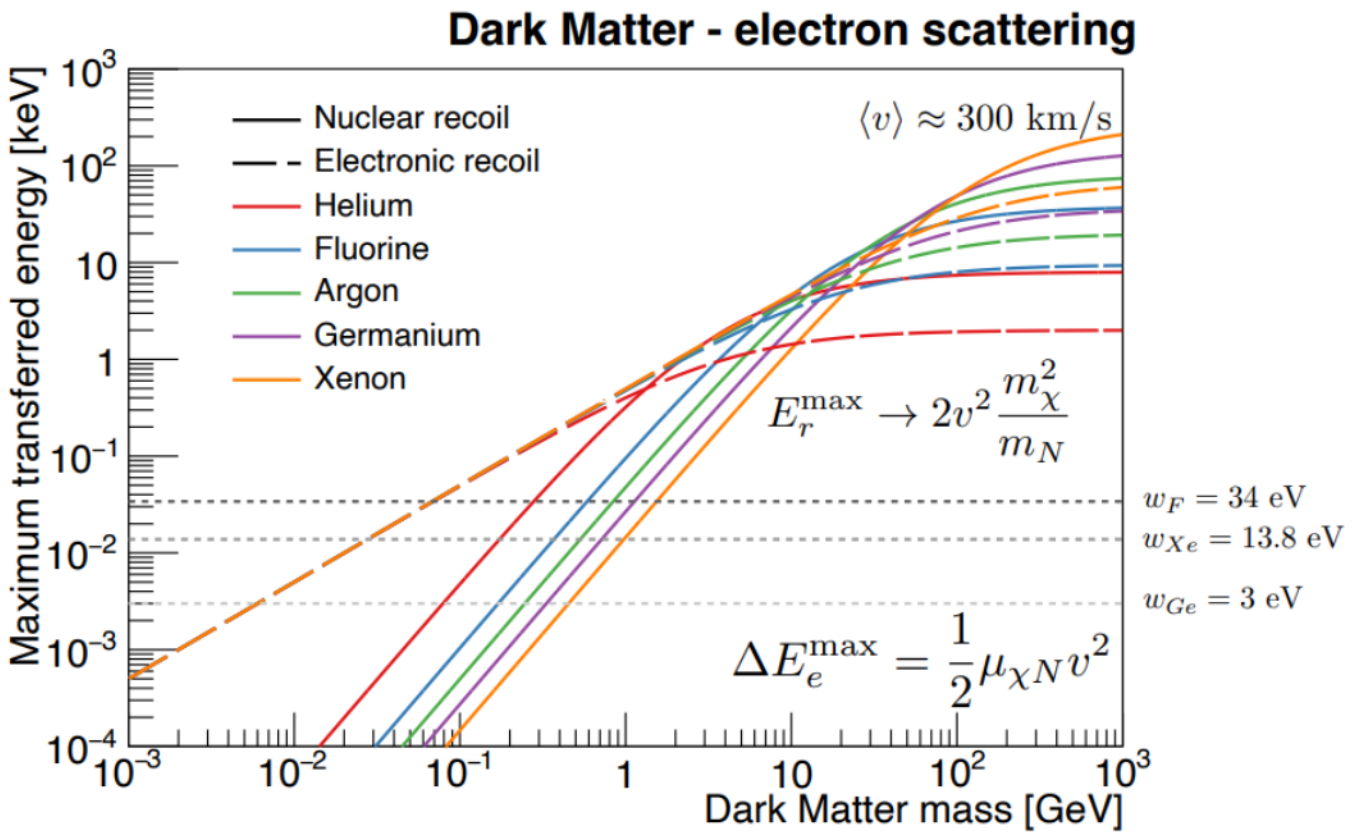


# NR limit




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

# ER scattering



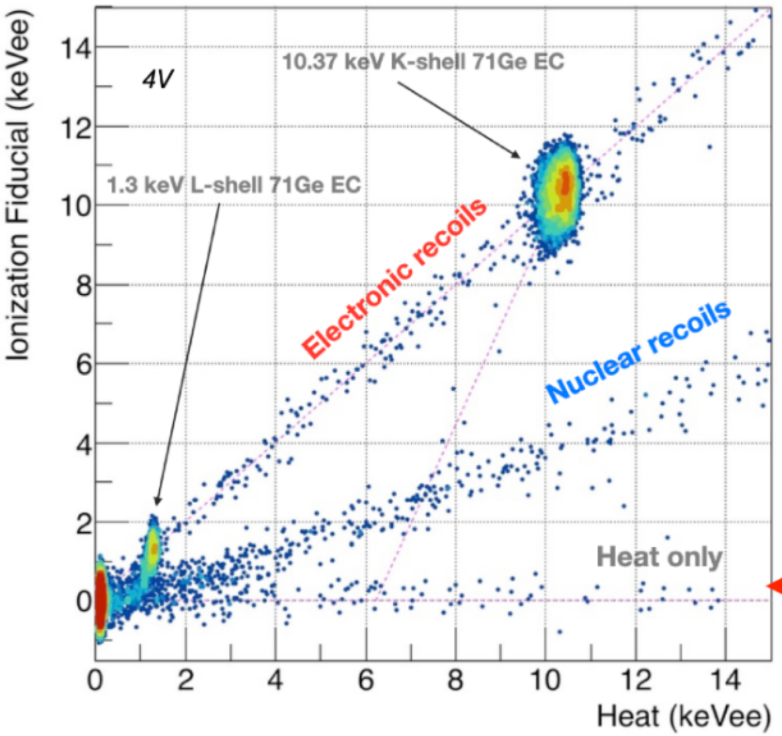

For DM masses bellow ~100 MeV, switch to DM-electron scattering

# Ge/Si semiconductors

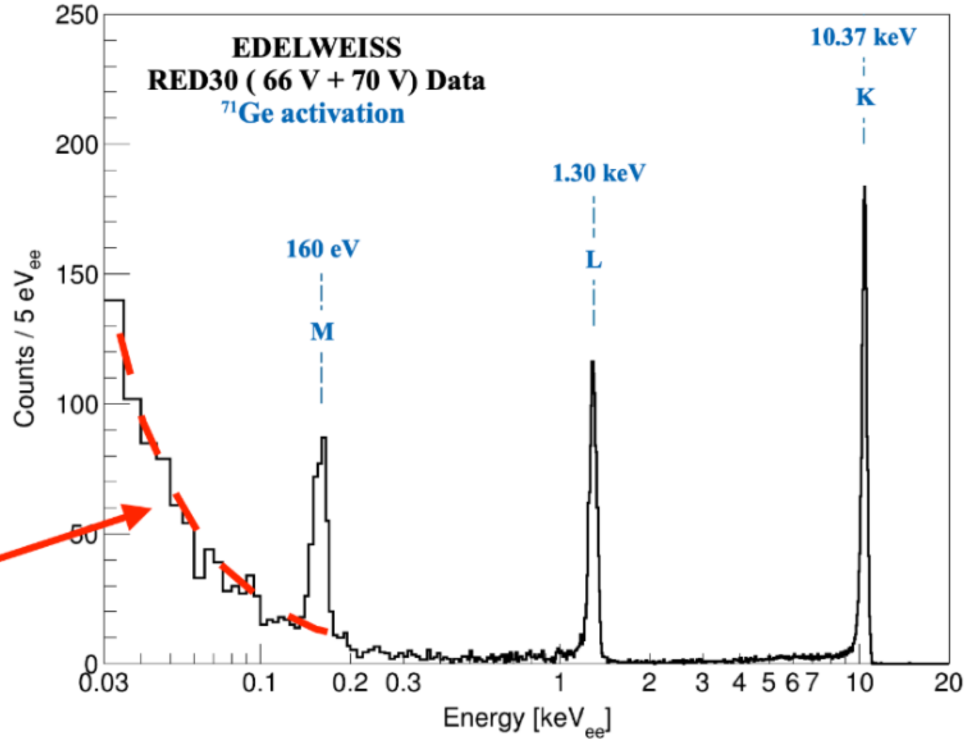
Two working modes:

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

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




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



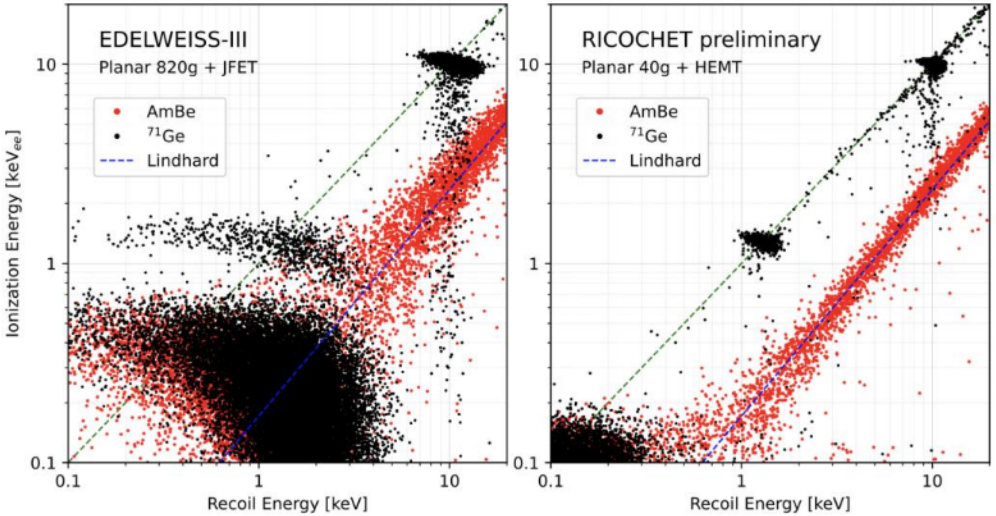

LEE

# Ge/Si semiconductors: Low Voltage Mode

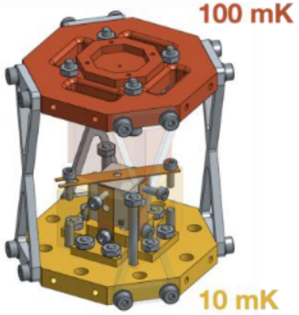
Optimal for **NRDM** sensitivity

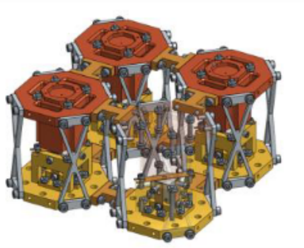
Energy thresh.: 4.5 keVnr
Ion. thresh.: 700 eVee

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




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



Total payload: 4 x 5.35 g

- 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

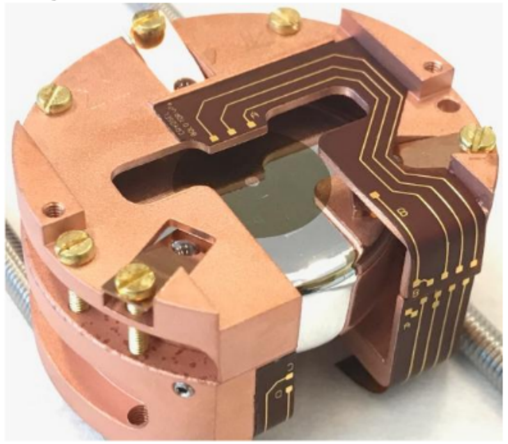
**Ricochet resolution goals:** 20 eV (heat) + 20 eVee (ionisation) - almost achieved (by a factor of ~2)

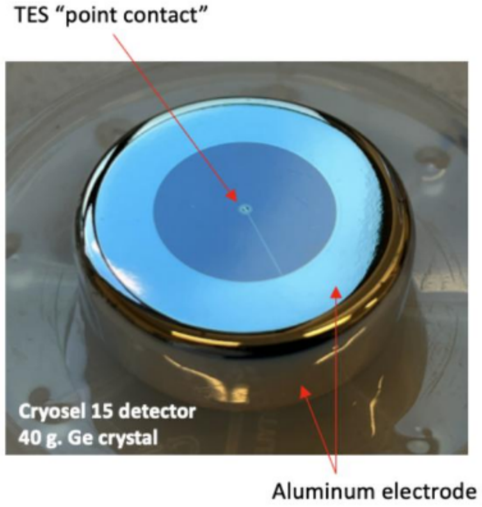
**For TESSERACT:**

- 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

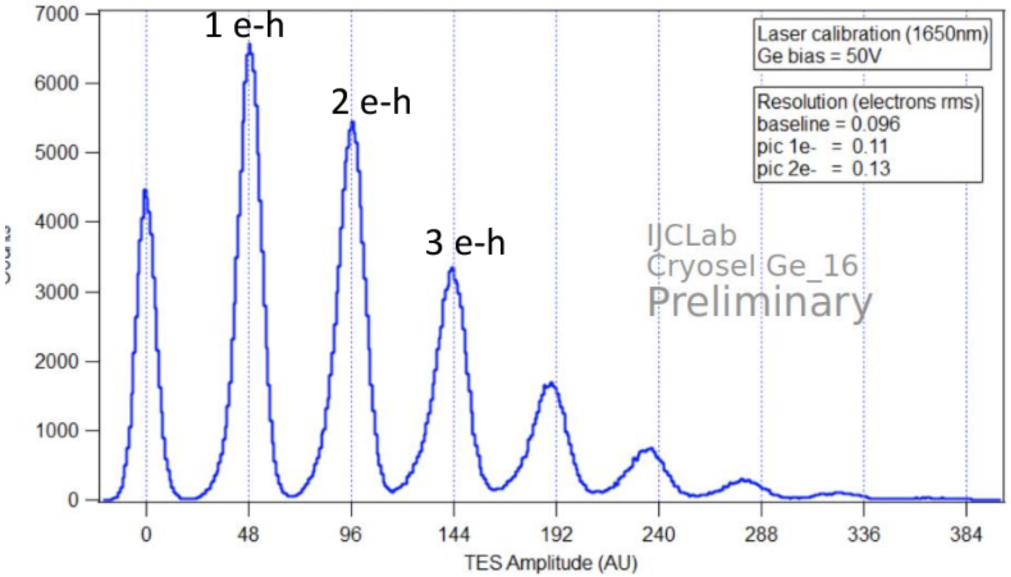
# Ge/Si semiconductors: High Voltage Mode

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

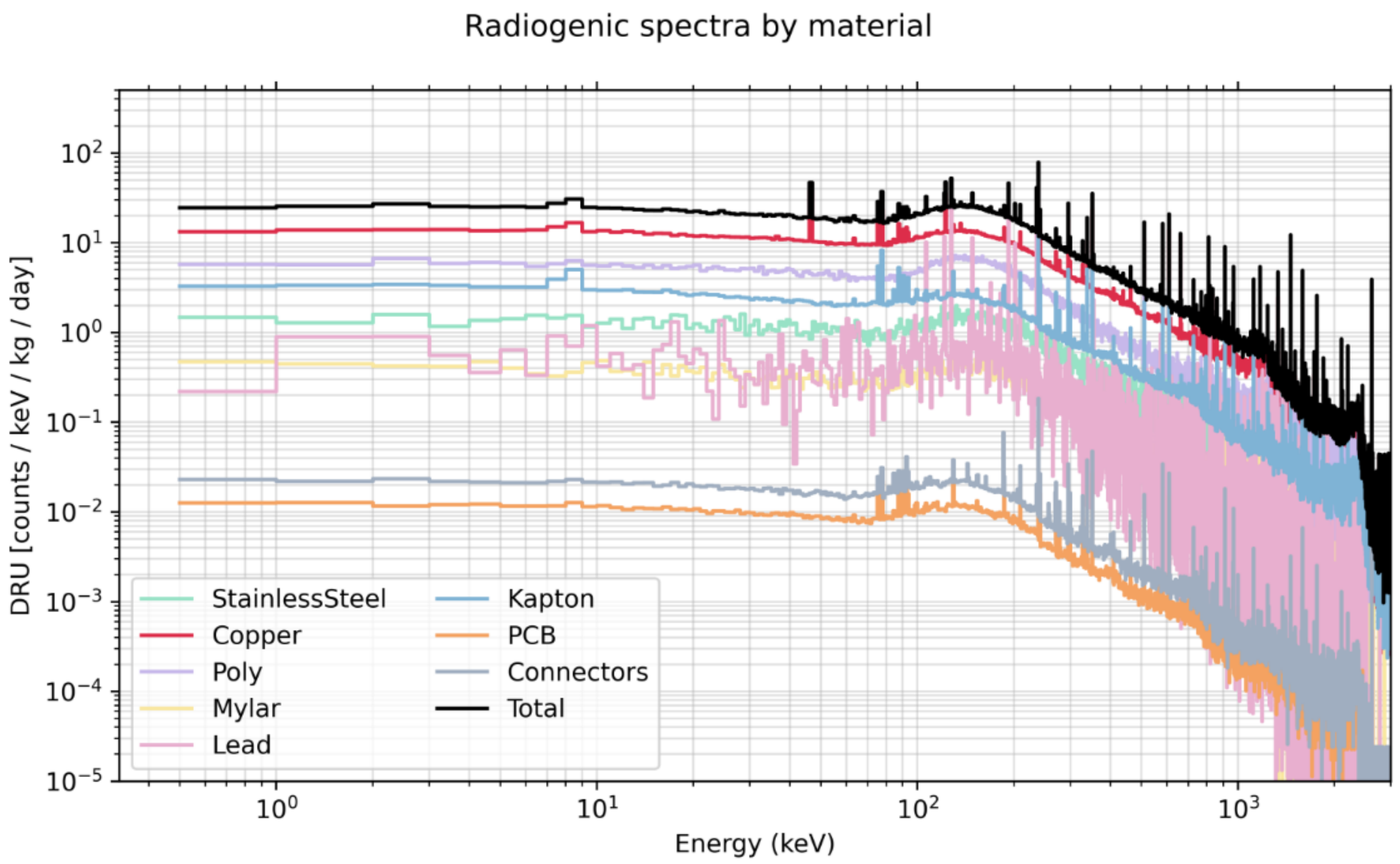
## First R&D results shown at TAUP2023:

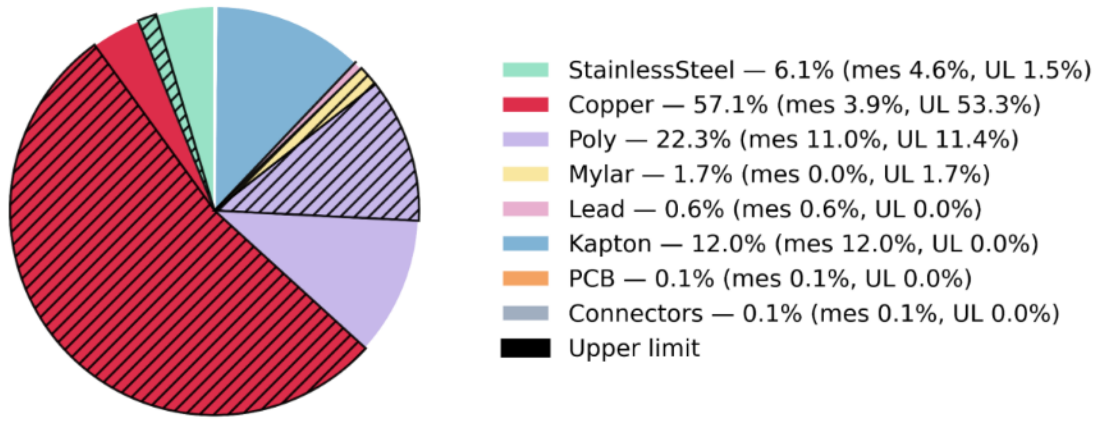
- Stable operation up to 60 V
- Confirmation that first NbSi SSED acts as efficient LEE veto
- New prototype currently being tested with significantly improved performance

## For TESSERACT:

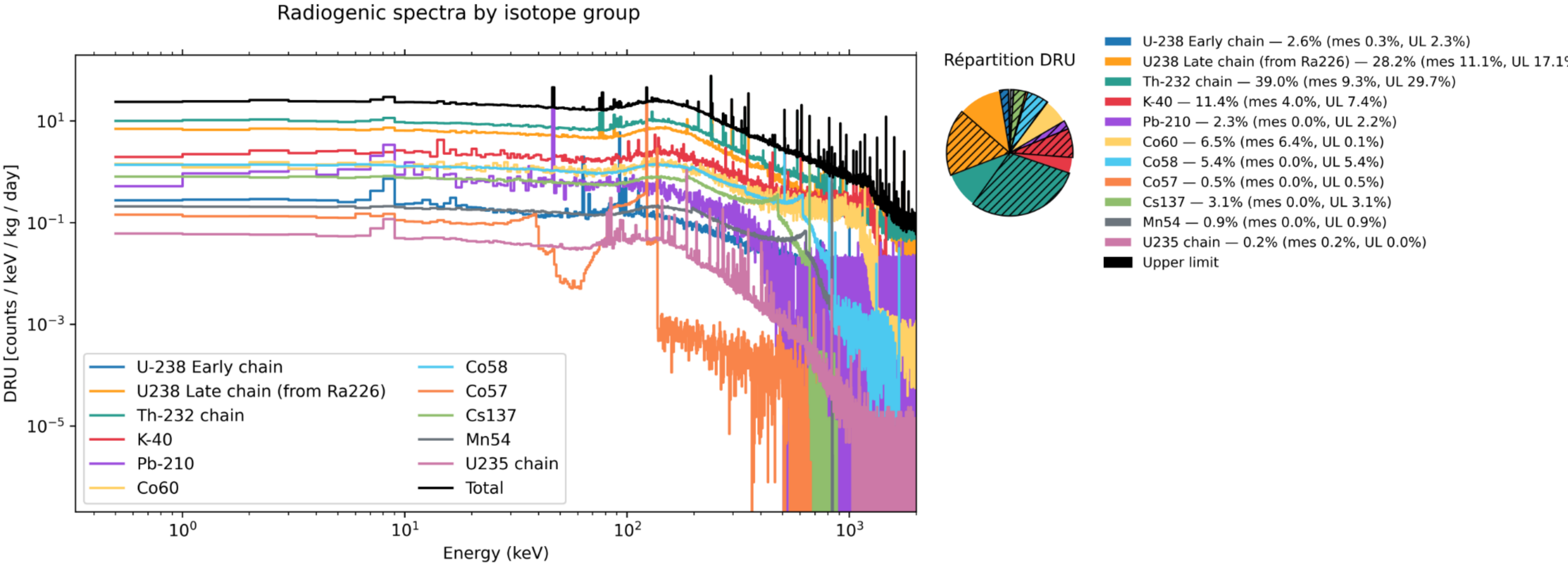
- Switch to low-imp. TES for sub-eV SSED energy threshold
- LEE discrimination down single e-h pair
- Exquisite sensitivities to ERDM with LEE discrimination

# Ricochet radiogenic simulations – per material

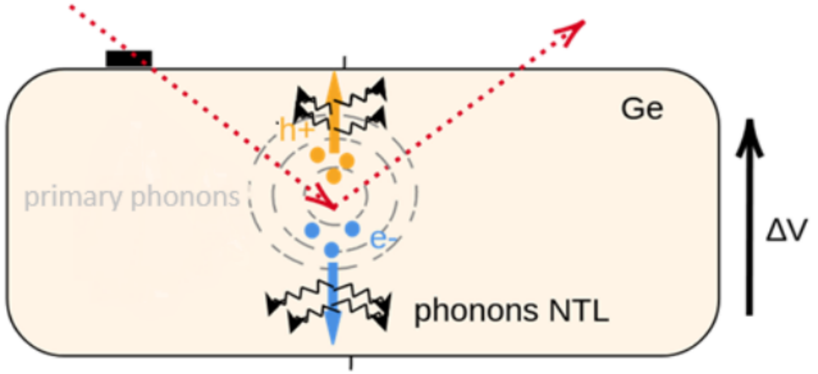


# Ricochet radiogenic simulations – per isotope



# 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

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

Two working modes:

- **High voltage**: amplification of signal single e/h pair sensitivity :

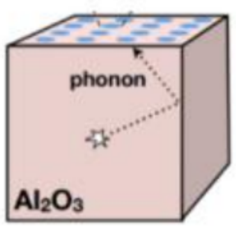
Optimal for **Electron Recoil DM** search

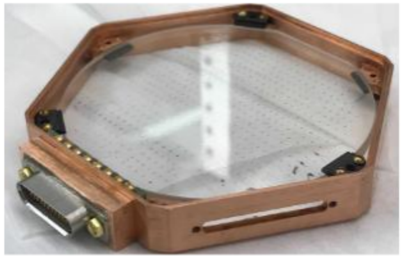
- **Low voltage**: Particle Identification capabilities :

Optimal for **Nuclear Recoil DM** search

# SPICE: Sub-eV Polar Interaction Cryogenic Experiment

## $Al_2O_3$ :



Look for ERDM

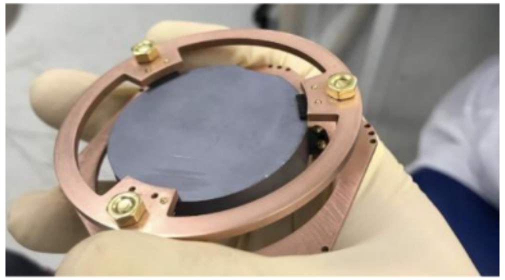
•mass range : 100 meV - MeV

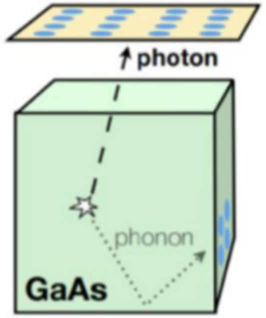
•**LEE mitigation method : use of two TES (pulse shape discrimination)**

•No particle identification

•Single Phonon sensitivity

## GaAs :






ERDM and NRDM

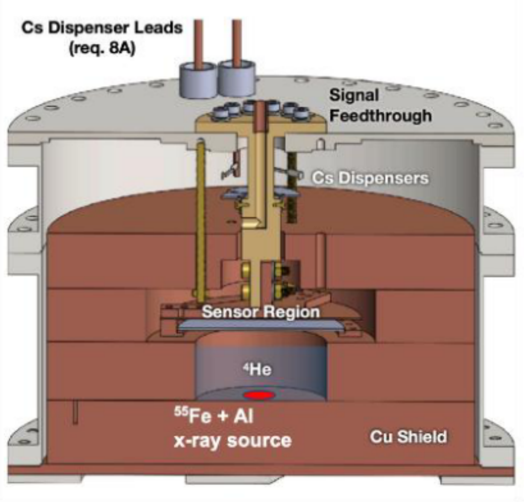
•mass range : eV - MeV and MeV - GeV

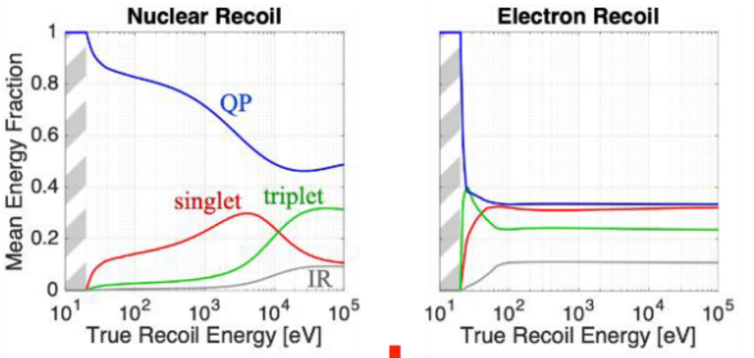
•**LEE mitigation method : photon / phonon coïncidence in two separate sensors** (~ eV scale)

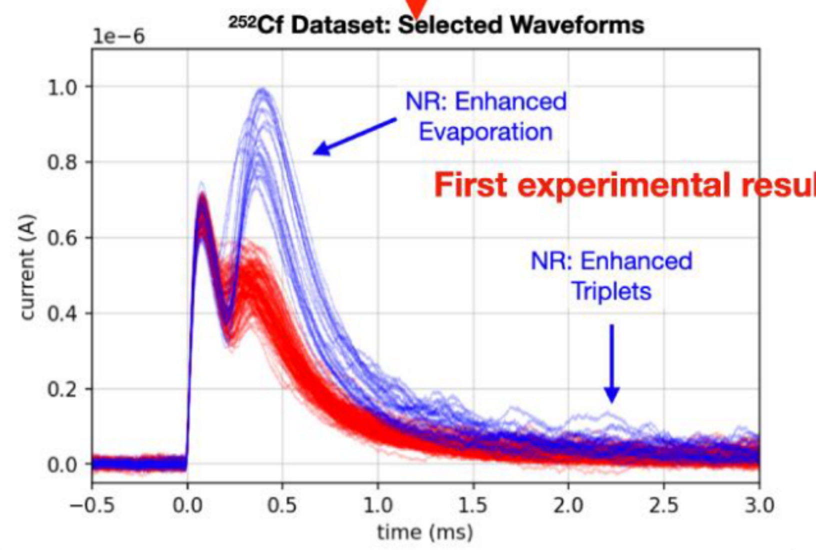
•Particle identification with dual Photon –

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)**