Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

First measurement of GaAs as a scintillating calorimeter

DAREDEVIL project

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Laboratori Nazionali del Gran Sasso

DAREDEVIL

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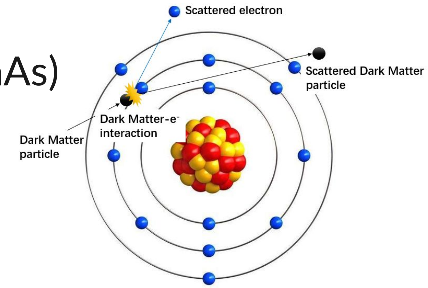
DARk-mattEr-DEVIces-for-Low-energy-detection

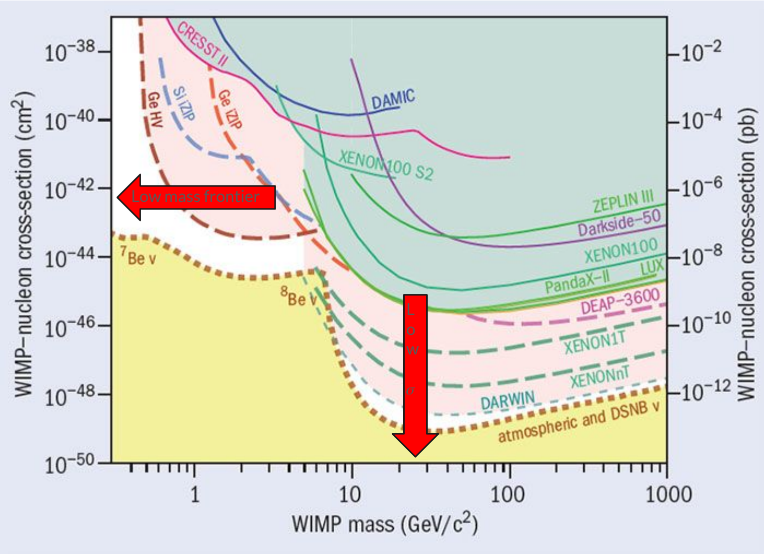
Develop a multi-target experiment to access DM candidates with mass in the sub-GeV range.

Detection channel: scattering on target electrons

Possible target materials:

- Dirac semimetals (ZrTe5)
- Weyl semimetals (CaAuAs)
- Superconductors (Al)
- Low gap semiconductor (GaAs)





DAREDEVIL COLLABORATION

Different expertise brought together for new class of detectors.

The team:

INFN LNGS – Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Gran Sasso

GSSI – Gran Sasso Science Institute

CNR SPIN

INRiM – Istituto Nazionale di Ricerca Metrologica

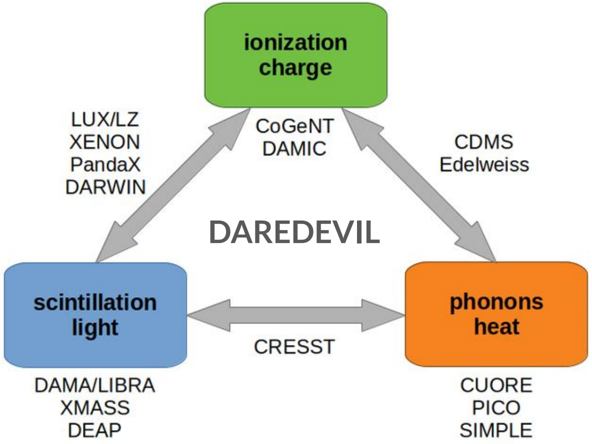
Detector production, testing and data analysis.

Materials and solid state modelling and simulation

TES fabrication

GOAL OF DETECTOR DEVELOPMENT

- Low threshold detection
- Linearity
- Particle identification
- 3 detection channels:
  - radiative - photons
  - not radiative - phonons
  - charge - electron/hole pairs

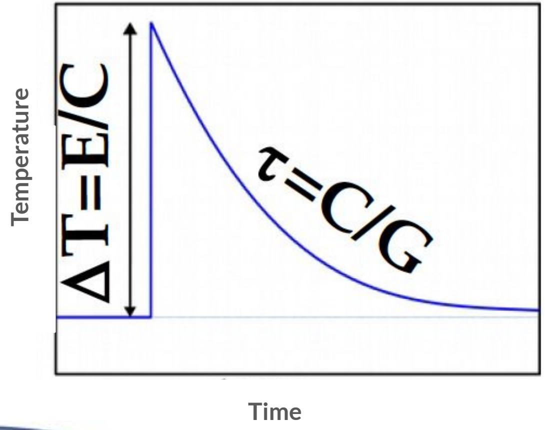


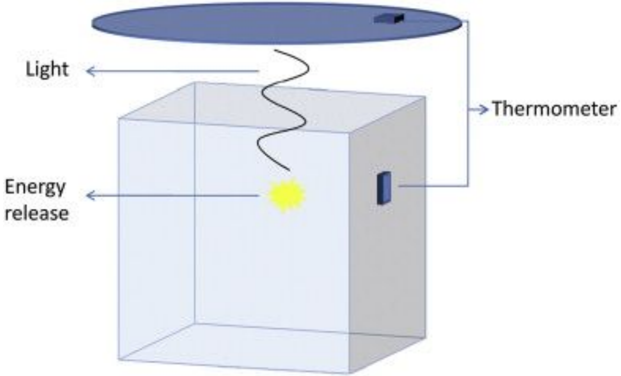
Low temperature calorimetry

LOW TEMPERATURE CALORIMETRY

Detection channels and sensors:

- **Phonon**: sensitive detectors (NTD, TES)
- **Light**: Cryogenic light detector based on photon absorber+phonon sensor
- **Charge**: Position reconstruction





GALLIUM ARSENIDE

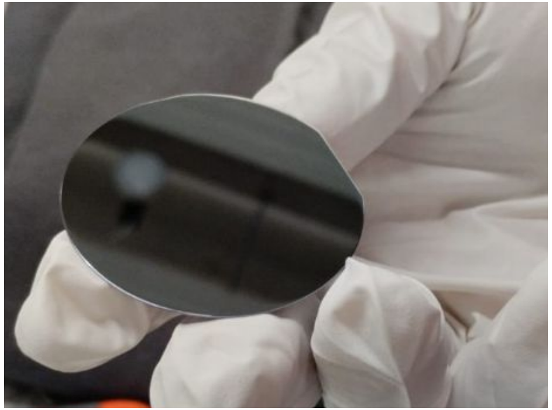
- scintillating material with direct band gap of 1.42 eV that will significantly improve the particle identification capability.

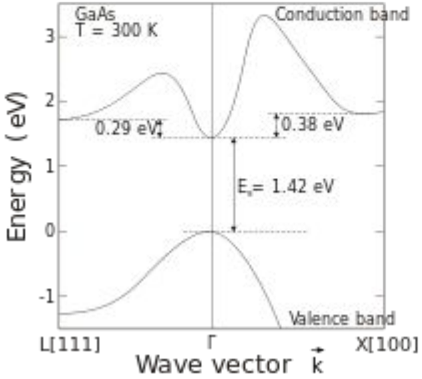
- It is a polar crystal, that would enhance sensitivity to dark photon absorption

- semiconductor material, allowing for controlled and effective charge collection

Thanks to these properties GaAs can be used as:

- Low temperature calorimeter
- Scintillator





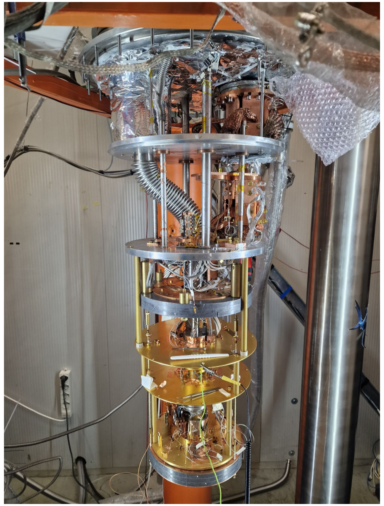
FIRST MEASUREMENT OF GaAs AS A LOW TEMPERATURE CALORIMETER

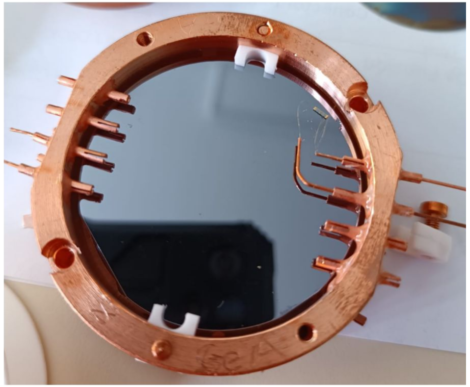
For this first measurement of GaAs as a cryogenic calorimeter, we used:

- 2-inch diameter and 0.5 mm thick wafer (5.35 g).
- The wafer was equipped with a 3 × 0.6 × 0.4 mm NTD (Neutron Transmutation Doped Ge thermistor) - phonon sensor

We conduct the measurement in PT assisted dilution refrigerator in HALL-C @LNGS

For the calibration we used an 55Fe and 238U/234U sources





 published on EPJ-C https://doi.org/10.1140/epjc/s10052-024-13123-8

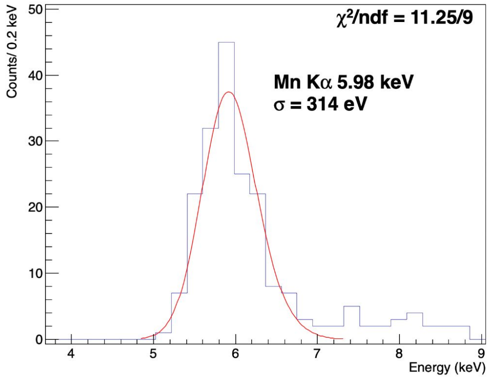
RESULTS

We conducted a 12-hour long calibration. From the datastream we identify relevant signal events and several basic parameters are computed:

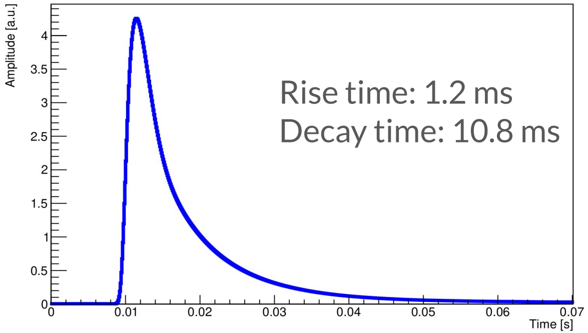
- Baseline level, slope, RMS
- Rise time
- Decay time
- Average pulse

Energy estimator: Optimum Filter - maximises signal to noise ratio

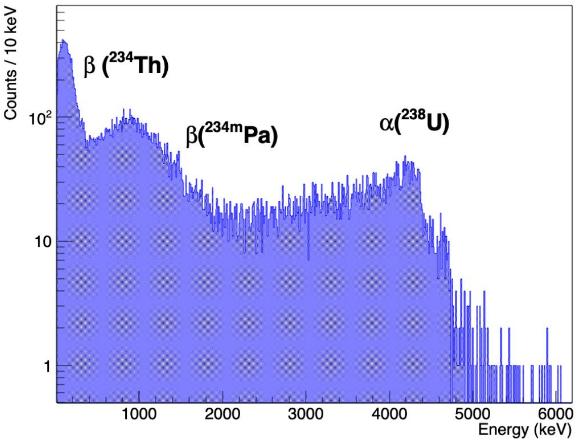
Baseline resolution (RMS) PT off	283 ± 48	eV
Peak σ at 5.9 keV PT off	314 ± 22	eV
Baseline resolution (RMS) PT on	542 ± 6	eV
Peak σ at 5.9 keV PT on	546 ± 21	eV



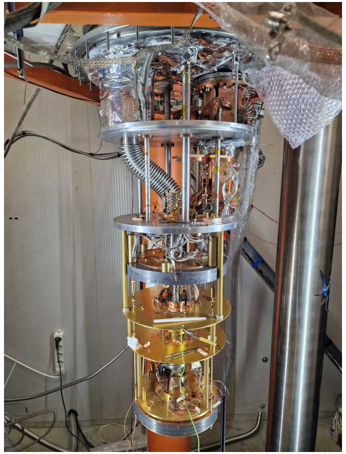
Average pulse



Total energy spectrum



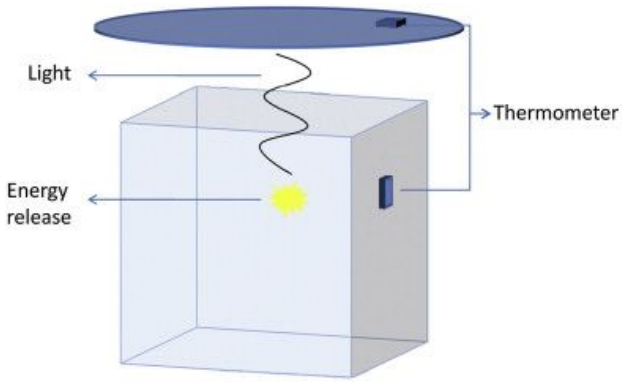
CRYOGENIC FACILITY UPGRADES



Another decoupling spring

Pulse tube mounted on independent support

LIGHT AND HEAT READOUT



Particle interaction in GaAs crystal

↳ Deposits energy in the main absorber

Phonon signal

A portion of the energy is converted into phonons

↳ Detected by an **NTD** attached to the GaAs crystal

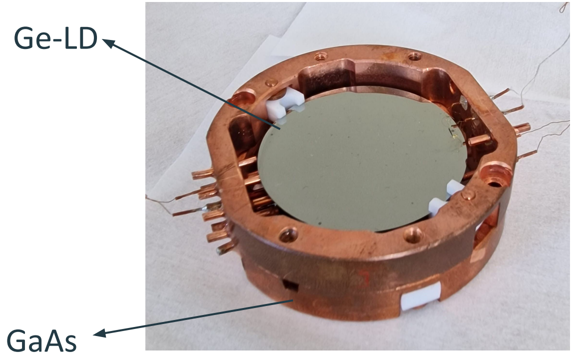
Light signal

The remaining energy is emitted as **light (scintillation)**

↳ Collected by a **secondary calorimeter**: a **Germanium crystal**

↳ Light absorbed in Ge produces a thermal signal

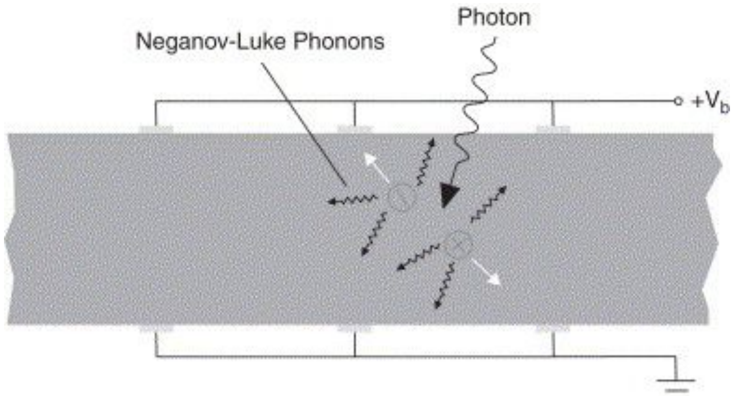
↳ Read out by a second **NTD** on the Ge crystal

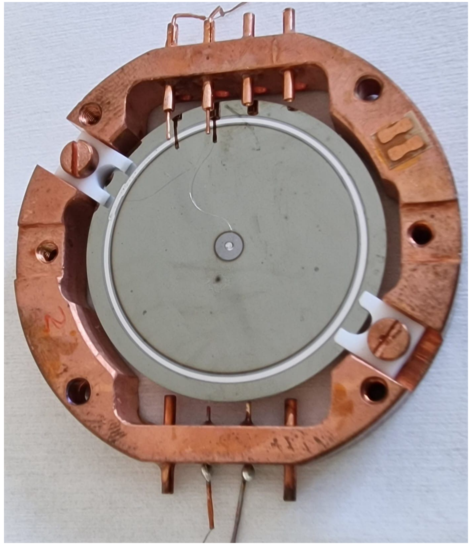


NEGANOV-TROFIMOV-LUKE EFFECT

Amplification of phonon signal with static electric field:

- electron-hole pairs created by interacting photons are accelerated
- during the acceleration they scatter along crystal lattice
- phonon signal will be increased by a factor of 10





EXPERIMENTAL SET-UP

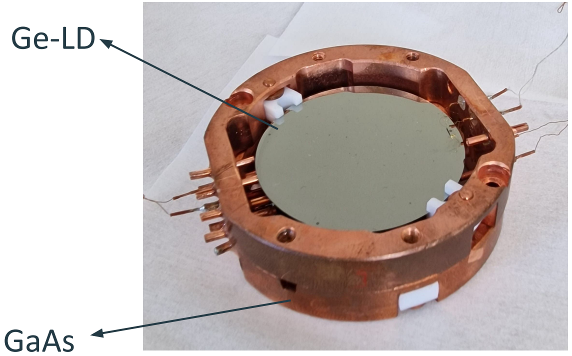
GaAs crystal:

- 2-inch diameter and 0.5 mm thick wafer
- 3 × 0.6 × 0.4 mm NTD
- γ-ray source : Thorium tungstate (74W and 90Th) wire and 55Fe
- α source 238U/234U

Ge-LD

- 2-inch diameter and 0.5 mm thick wafer
- 3 × 0.6 × 0.4 mm NTD
- 55Fe source for the calibration

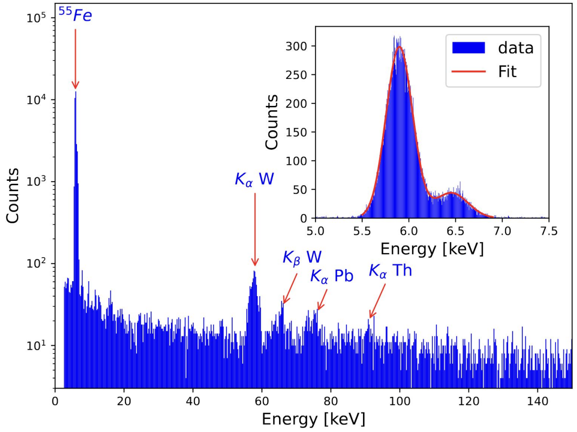
The distance between the two crystals is 10 mm.



DATA ANALYSIS AND RESULTS - GaAs

After upgrades

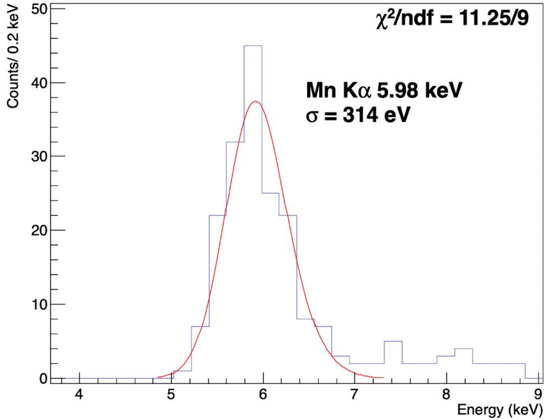
Low energy spectrum



Baseline resolution (RMS)	121 ± 2	eV
Peak σ at 5.9 keV	140 ± 8	eV

Before upgrades

Low energy spectrum



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Peak σ at 5.9 keV PT off	314 ± 22	eV
Baseline resolution (RMS) PT on	542 ± 6	eV
Peak σ at 5.9 keV PT on	546 ± 21	eV

DATA ANALYSIS AND RESULTS - Ge-LD

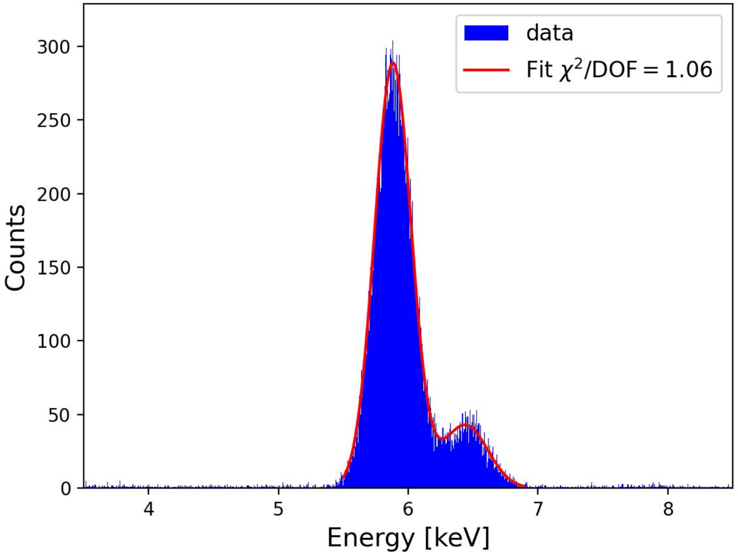
55Fe source used for the calibration of the LD.
After the calibration :

- A voltage of **130 V** was applied to the electrodes
- Gain of ~12

Improved baseline resolution

From **σ = 60 eV** (w/o NTL effect) → To **σ = 5 eV** (with NTL effect)

W/O NTL-Effect



Baseline resolution (RMS)	60.4 ± 0.5	eV
Peak σ at 5.9 keV	102 ± 8	eV

DATA ANALYSIS AND RESULTS

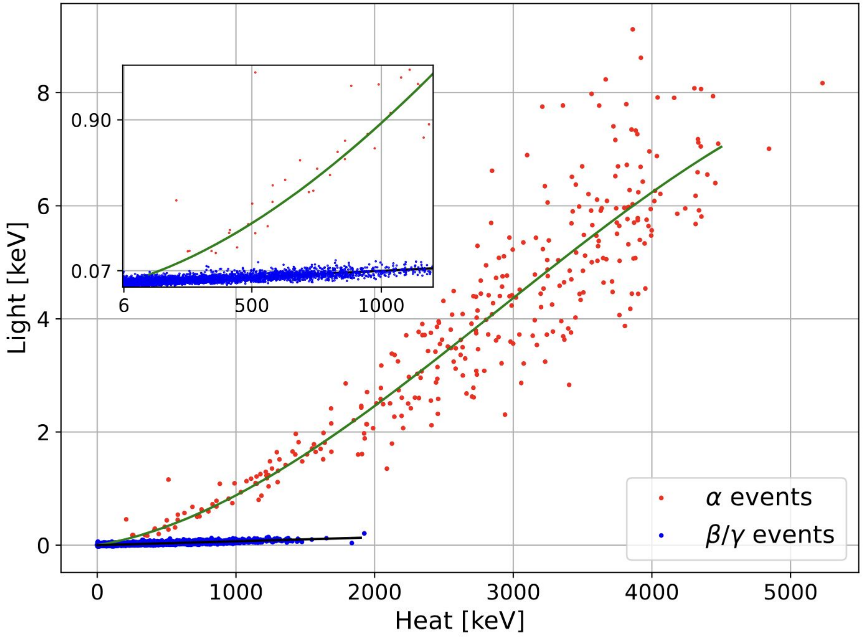
After the calibration of GaAs and Ge-LD:

- For each heat event, the corresponding **light window** was analyzed
- Built the **light vs heat scatter plot**

2 “Anomalies”:

- **Alpha events** show **higher scintillation light** than beta/gamma events (see ZnSe and ZnO)
- **Non-linear** response is observed in **alpha events.**

	Light yield (keV/MeV) @ 1 MeV
β/γ	0.07 ± 0.01
α	0.9 ± 0.2

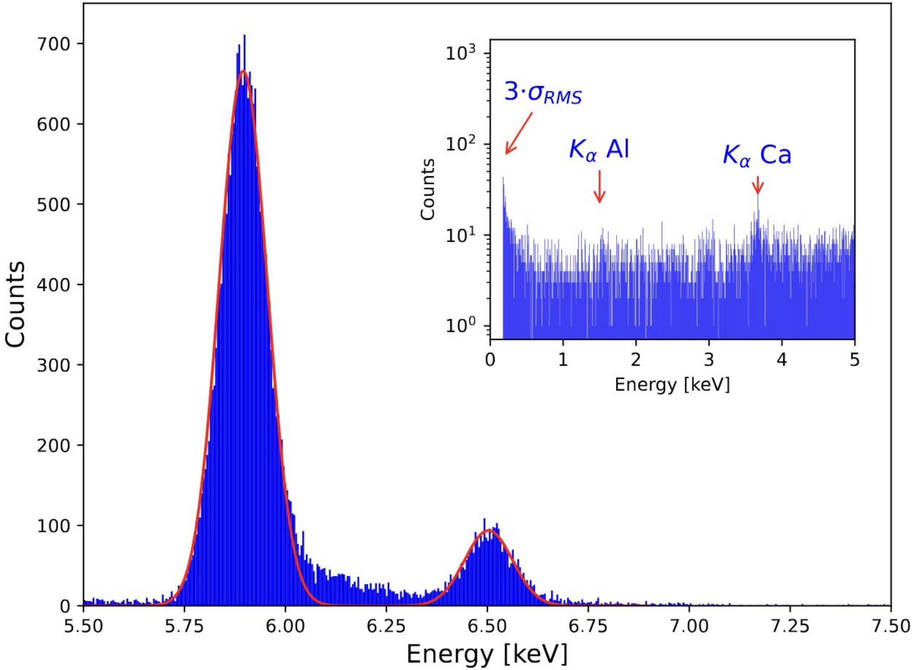


NEW GaAs CRYSTAL

The new crystal was measured under identical conditions to the previous sample.

- 2-inch diameter and 0.325 mm thick wafer (3.5 g).
- The wafer was equipped with a 3 × 0.6 × 0.4 mm NTD .
- For the calibration we used an 55Fe.

Baseline resolution (RMS)	44.5 ± 0.8	eV
Peak σ at 5.9 keV	59 ± 1	eV



CONCLUSION AND PERSPECTIVES

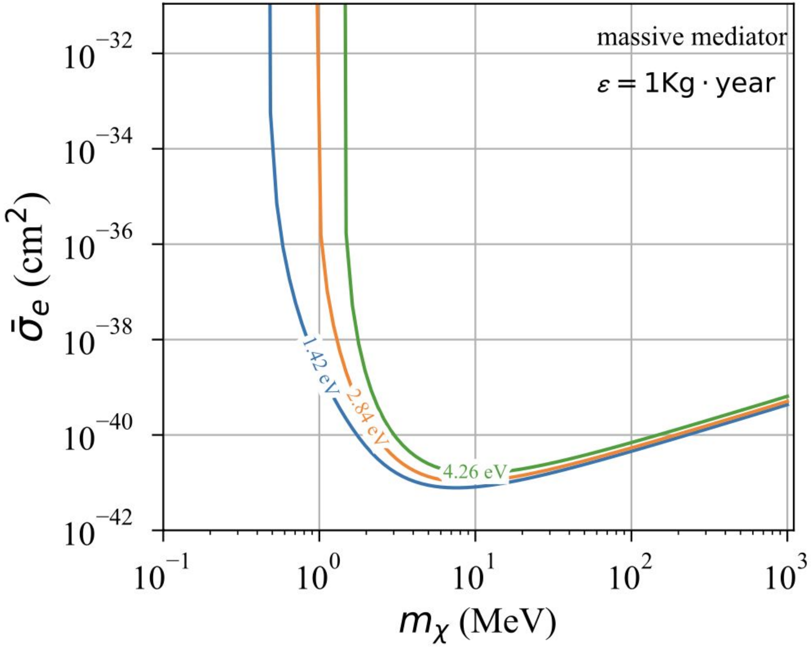
- **Cryostat upgrades successful**
  ↳ GaAs detector threshold improved from **1.5 keV** to **360 eV**

- **First demonstration** of **particle discrimination** in GaAs via **light yield**

- **New GaAs crystal** further improved threshold:
  ↳ from **360 eV** to **133.3 eV**

Next goal: reach **few-eV threshold**

- Use **Transition Edge Sensors (TES)** as thermal sensors



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THANK YOU FOR YOUR ATTENTION

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