TESSERACT

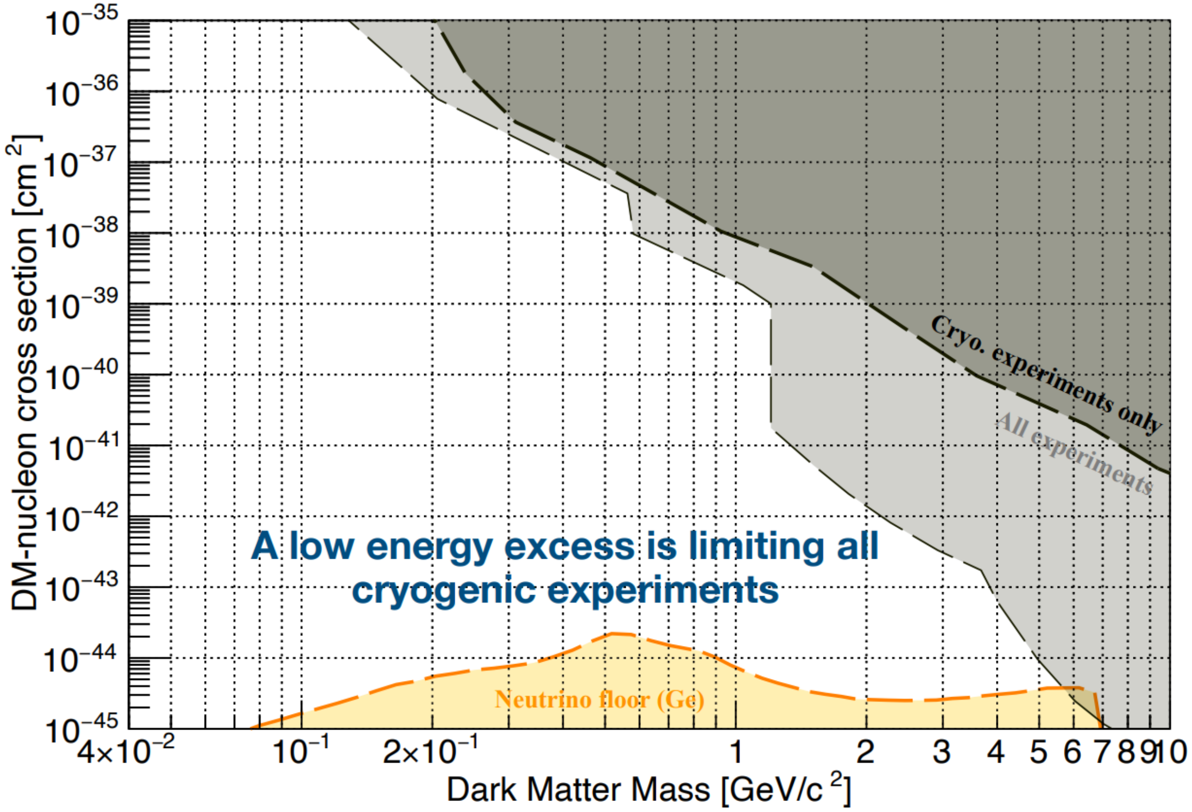
The TESSERACT Experiment at LSM: Ge Semiconductor Technology

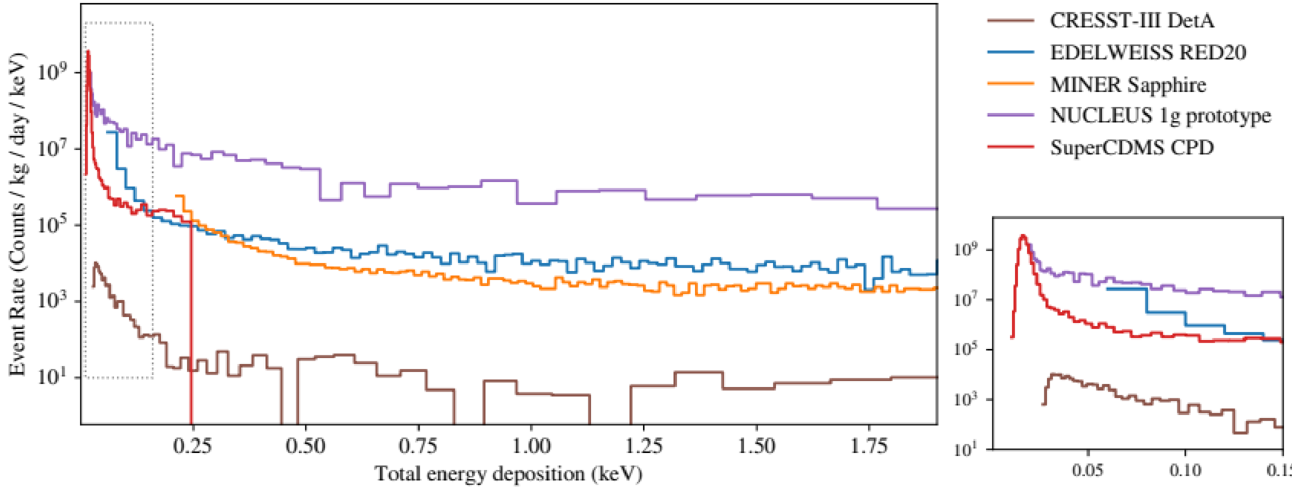
Juliette Blé, LPSC Grenoble

Identification of Dark matter 2026

Low Energy Excess (LEE)

LEE is the dominating background at low energy





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

LEE Characteristics:

- Non ionising
- Mostly independant of site
- Unknown origin

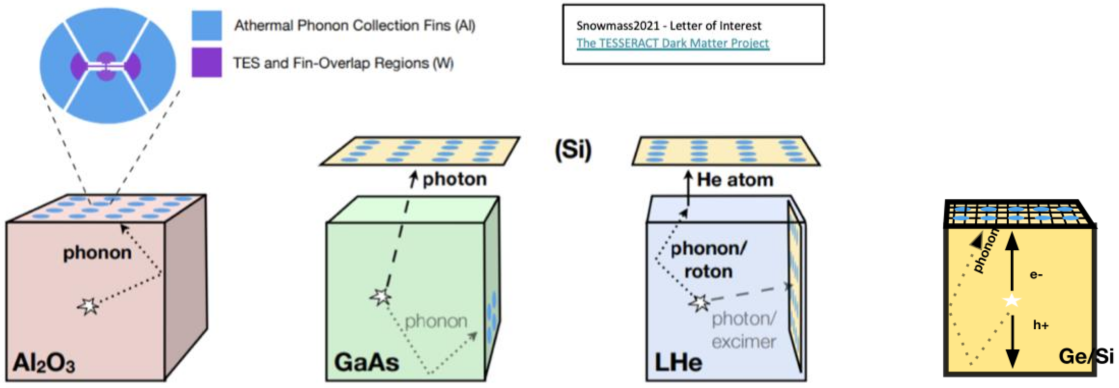
Design driver of TESSERACT:

1) Find the origin of LEE to mitigate it
2) Develop detector technologies with LEE rejection capabilities

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



- One design, several targets leading to **different DM sensitivities**

- French additions to the initial proposal:
  - add the Ge/Si semiconductors calorimeter technology and benefit from RICOCHET and EDELWEISS experiences
  - Provide the experimental site in the deepest european laboratory **LSM**

- Integration of the full setup at LSM in 2028

The TESSERACT experiment

D. McKinsey talk on 06/04

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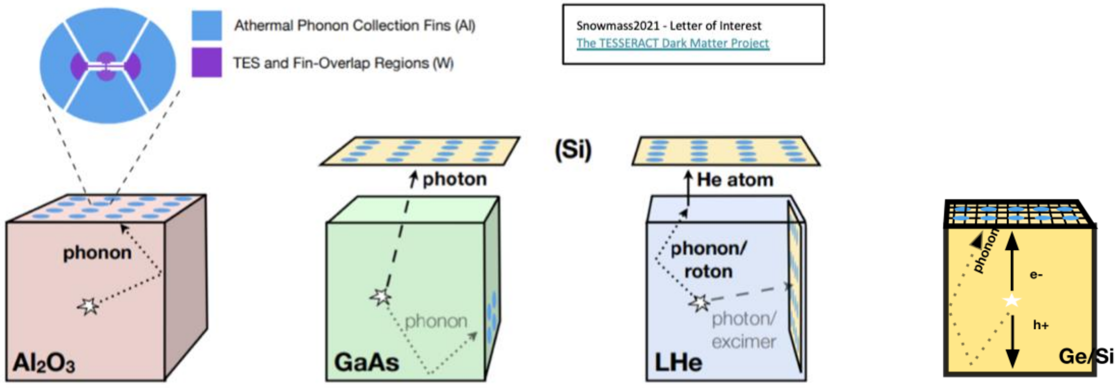

S. Scorza talk on 06/02

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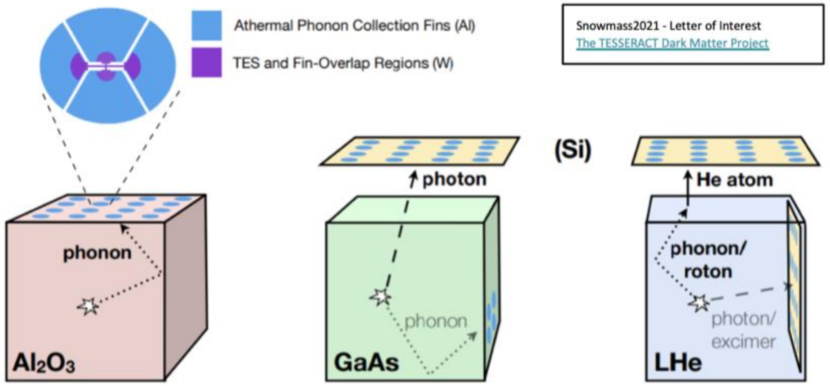
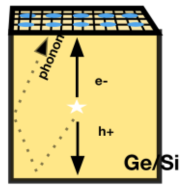


This talk



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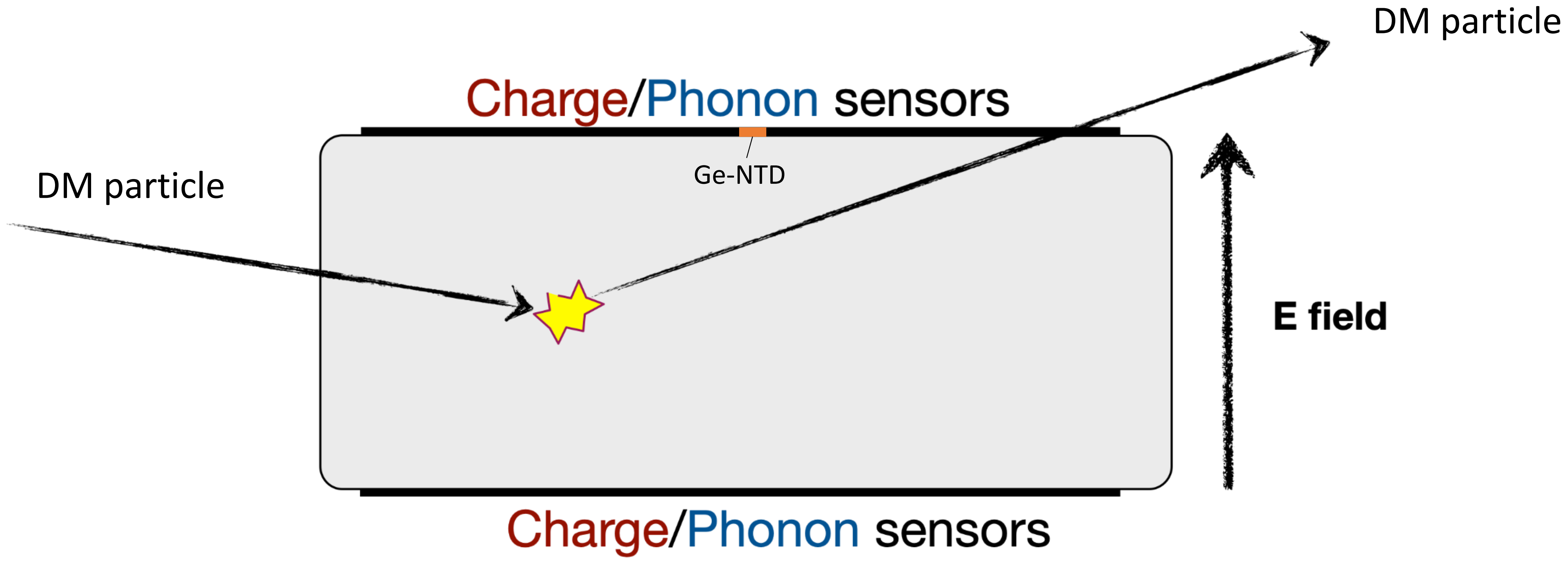
Dual phonon/charge detection



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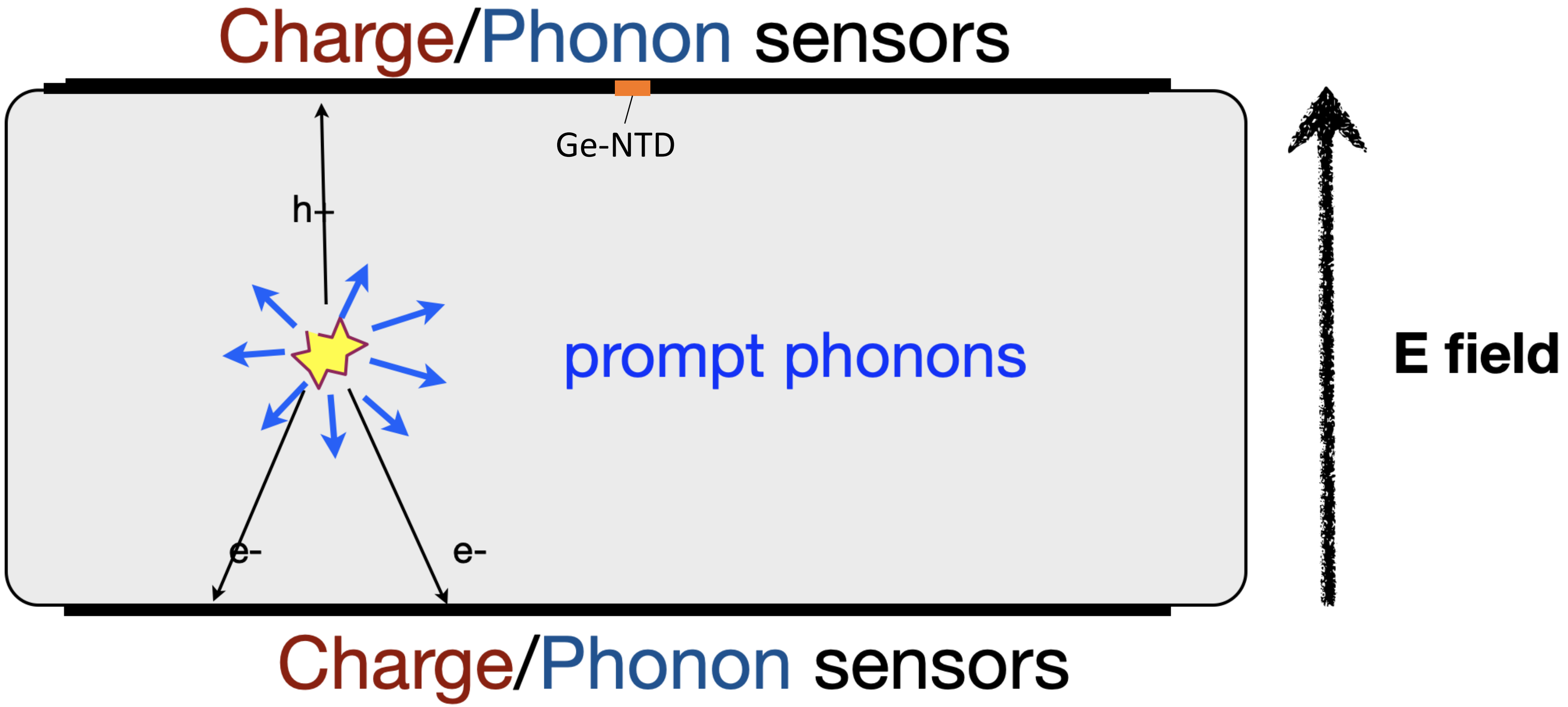

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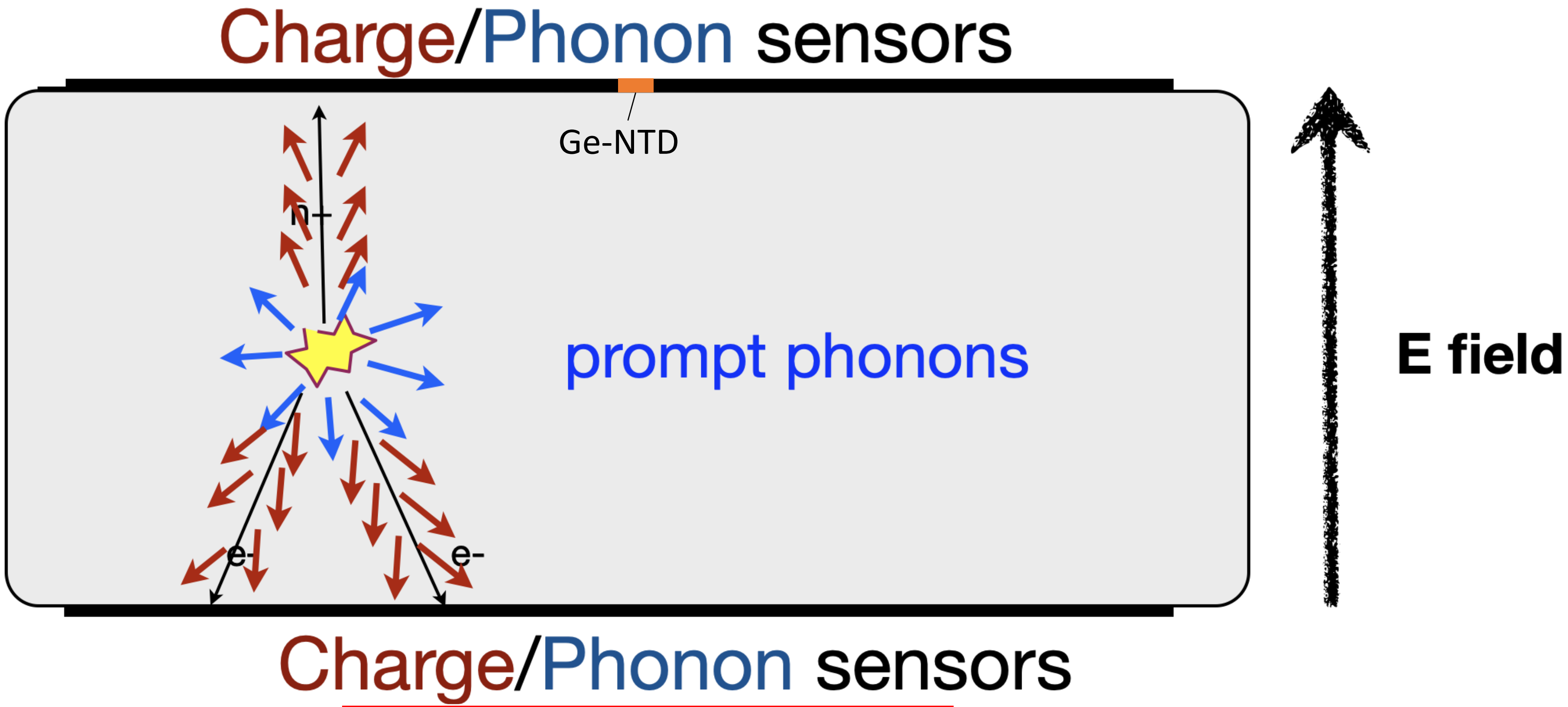


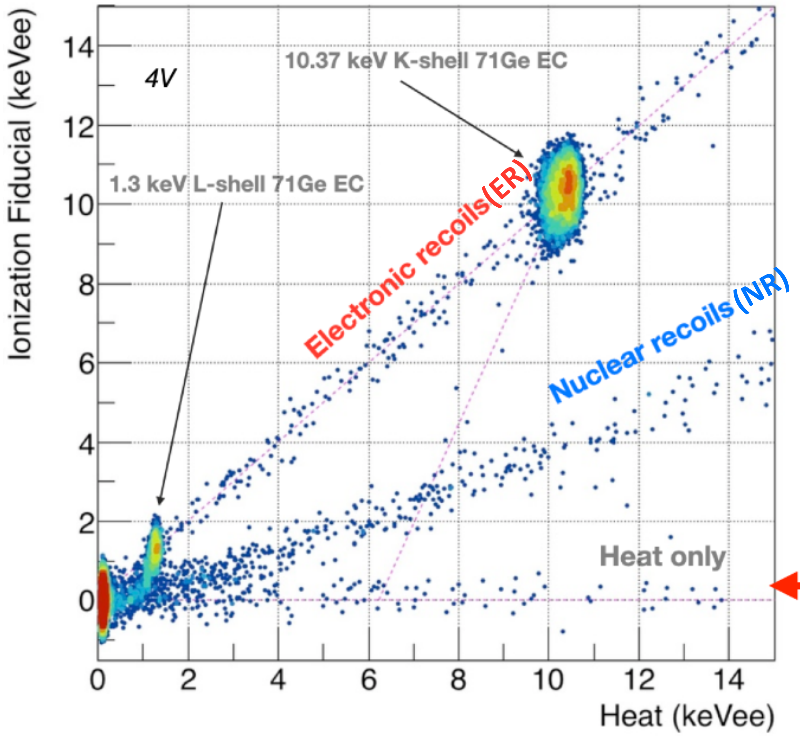
$$
\begin{aligned}
E_{total} &= E_{recoil} + E_{NTL} \\
&= E_{recoil} + \frac{1}{\varepsilon_{Ge}} E_{ion} \Delta V
\end{aligned}
$$

B. S. Neganov and V. N. Trofimov, Otkryt. Izobret., 146, 215 (1985)
P. N. Luke, J. Applied Phys. 64,6858 (1988)

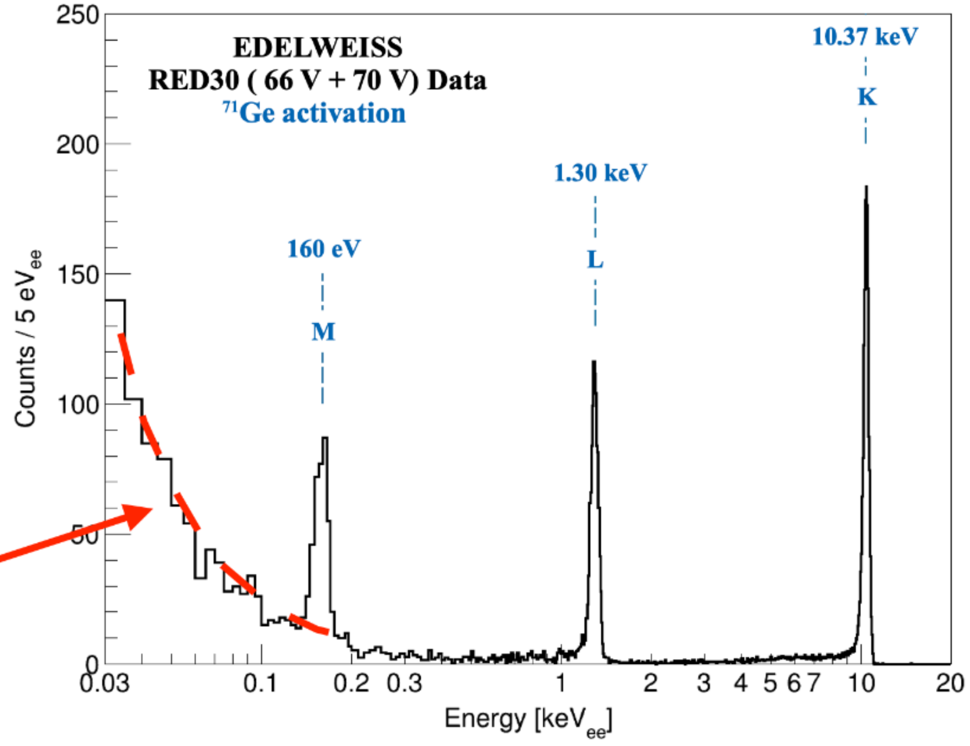
Low Voltage (LV) & High Voltage (HV) Mode

$$E_{total} = E_{recoil} + E_{NTL}$$
$$= E_{recoil} + \frac{1}{\varepsilon_{Ge}} E_{ion} \Delta V$$

Low Voltage mode (ΔV~4V)
Particle identification possible
Optimal for **NRDM**



High Voltage mode (ΔV~50V)
Signal boosted, lower threshold
Optimal for **ERDM**

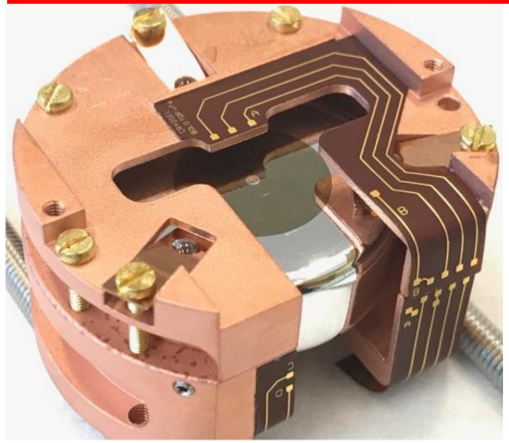


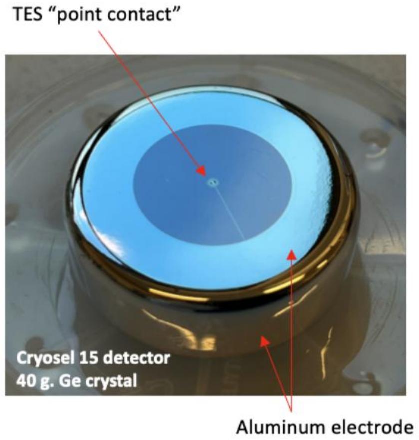
LEE

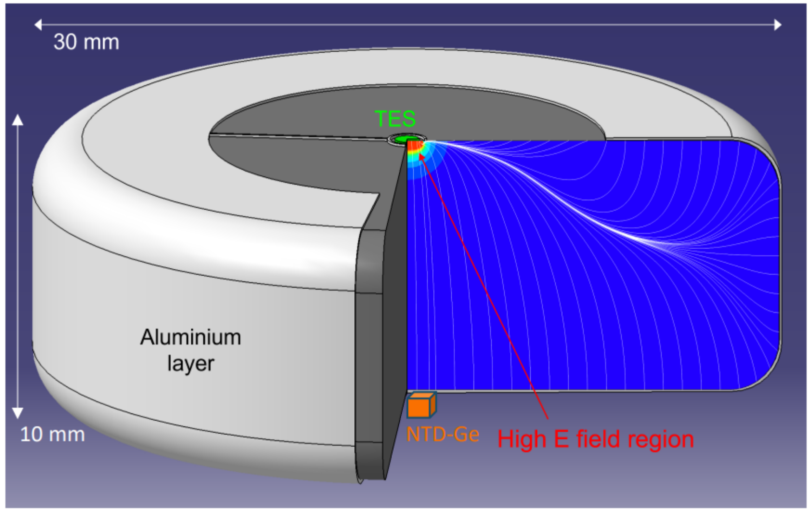
High Voltage Ge detectors

$$\boxed{\begin{aligned} E_{total} &= E_{recoil} + E_{NTL} \\ &= E_{recoil} + \frac{1}{\varepsilon_{Ge}} E_{ion} \Delta V \end{aligned}}$$

($\Delta V \sim 50V$) → amplification of ionization signal with NTL effect to reach single-electron sensitivity







- Large Al electrodes ($V_{NTL} \sim 50V$) + « point contact » TES ($V \sim 0V$)

  → High electric field region
  → Most of the NTL athermal phonons created in this region
  Strong enhancement of the TES response

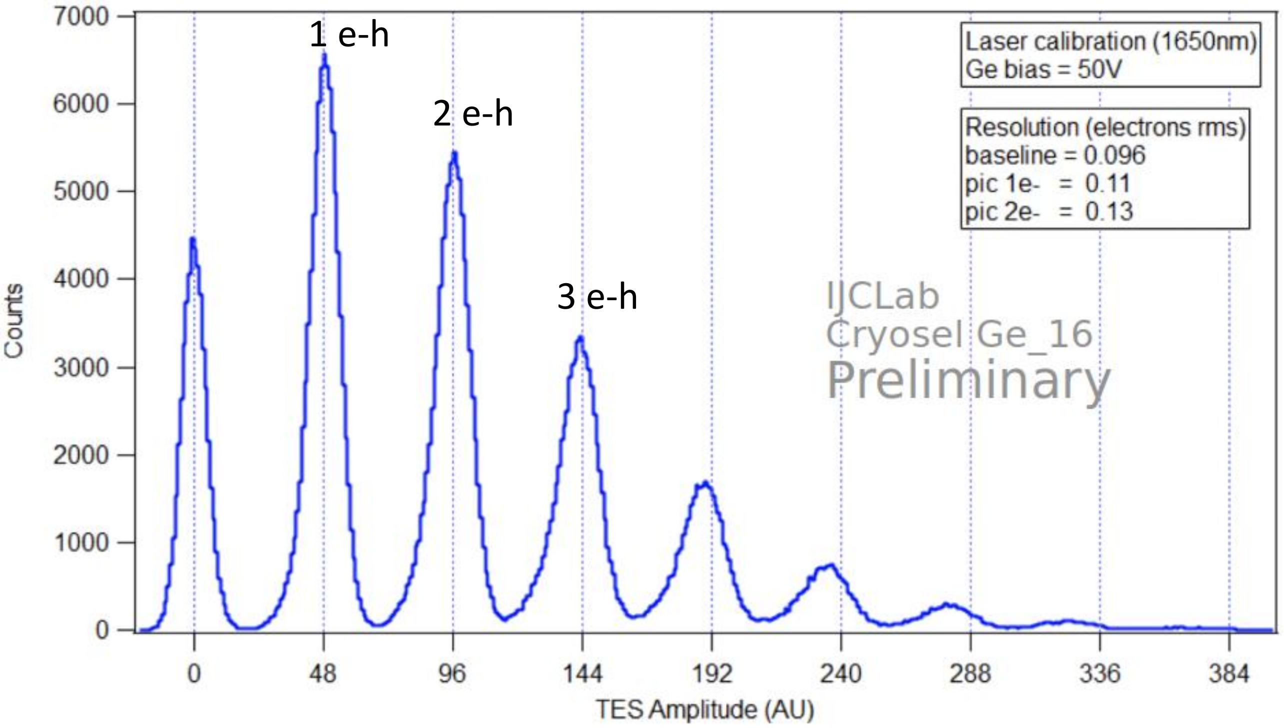
- NTD-Ge glued at the bottom surface

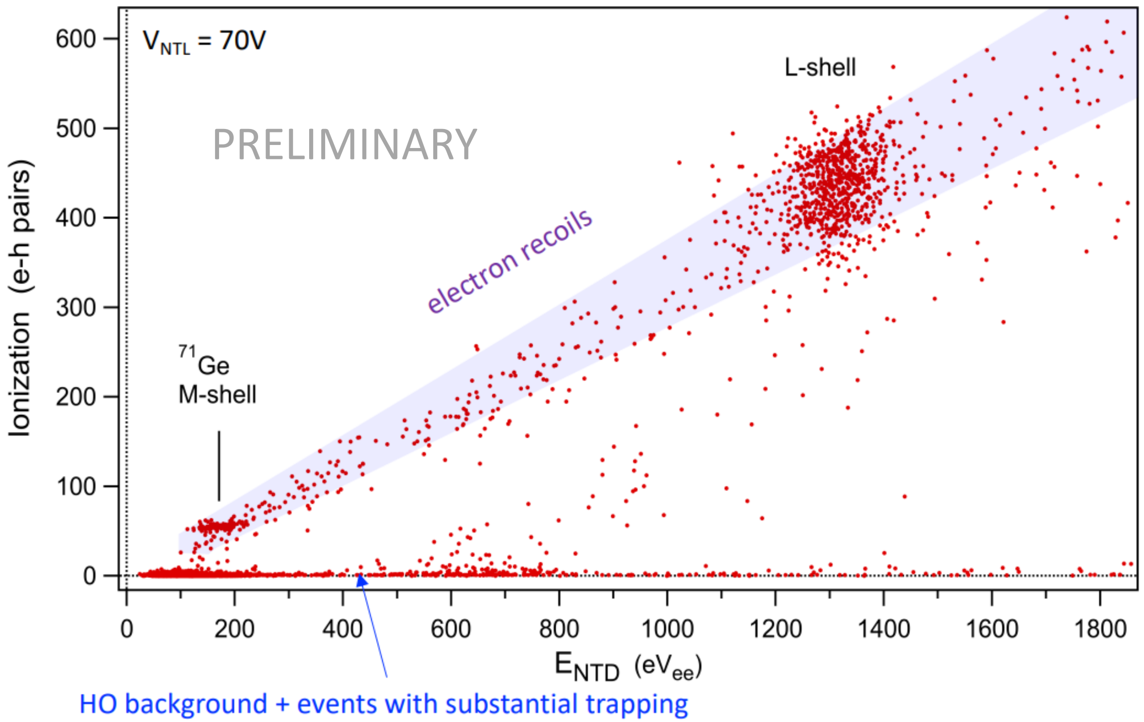
  → Measures the recoil energy $E_{NTL} + E_R$
  Discrimination of non ionizing events (LEE discrimination)

High Voltage Ge detectors

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

- Baseline resolution ~ 0.1 e-h pair





- Clear separation of ER band and non-ionizing band
- Energy discrimination threshold limited by NTD-Ge sensitivity
- ER/NR identification in progress
- **Article in preparation!**

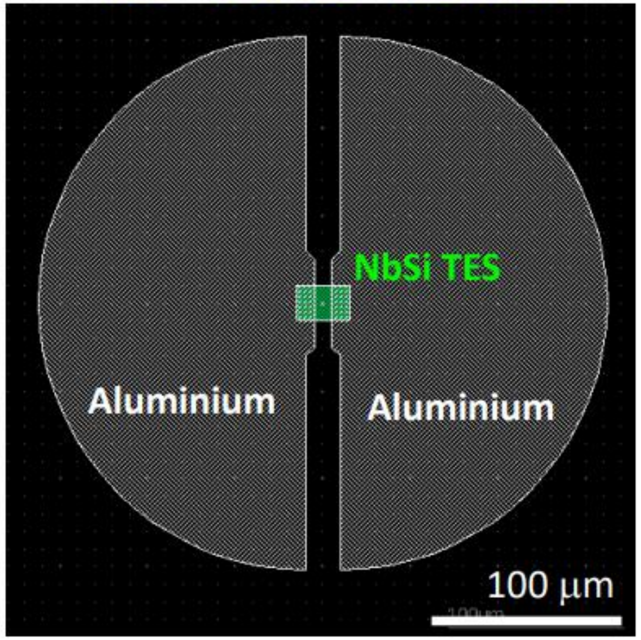
High Voltage Ge detectors: Future prospects

- Total payload of 4 x 40g Ge HV detectors

- Development of simulations for charge drift and athermal phonon propagation/collection efficiency

- Switch from NTD Ge to QET (Quasiparticle-trap-assisted Electrothermal-feedback TES sensors)
  → Phonon resolution ~ 10eV
  → Discrimination of ER/NR at low energy + LEE rejection

QET = NbSi TES + two Al fins

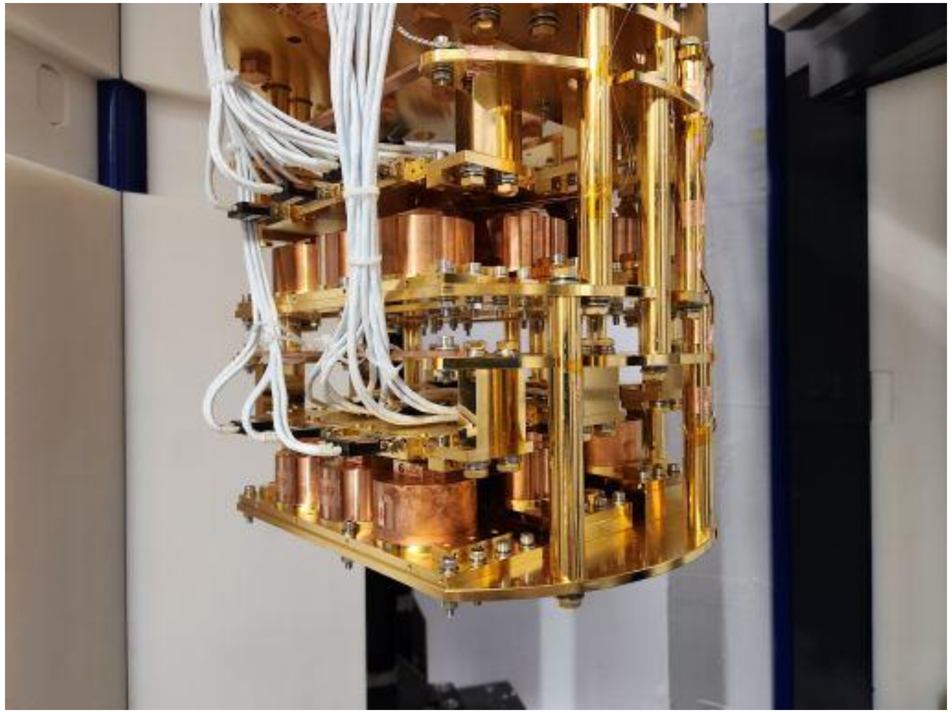


Low Voltage Ge detectors

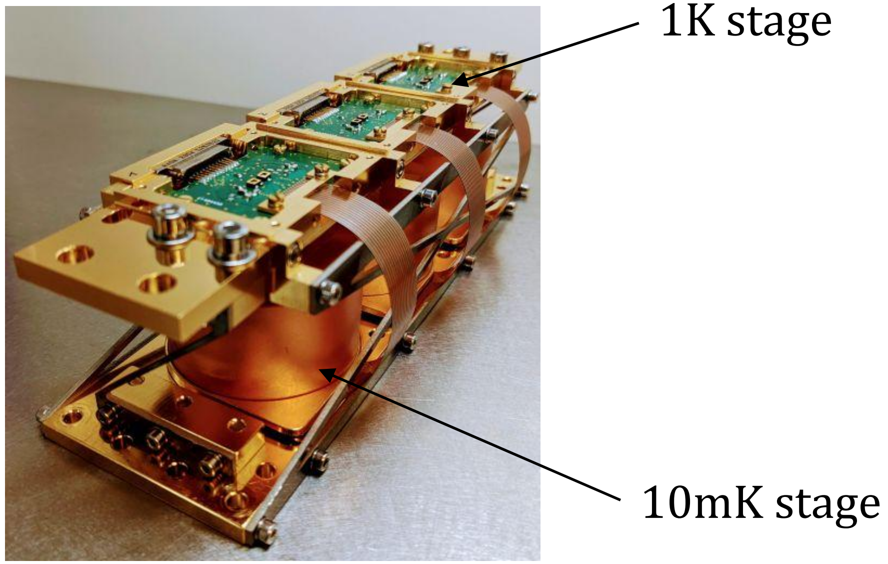
$$\boxed{\begin{aligned} E_{total} &= E_{recoil} + E_{NTL} \\ &= E_{recoil} + \frac{1}{\varepsilon_{Ge}} E_{ion} \Delta V \end{aligned}}$$

($\Delta V \sim 4V$) → discrimination of NR/ER/LEE

State of the art from Ricochet



Ricochet cryostat at the Institut Laue Langevin



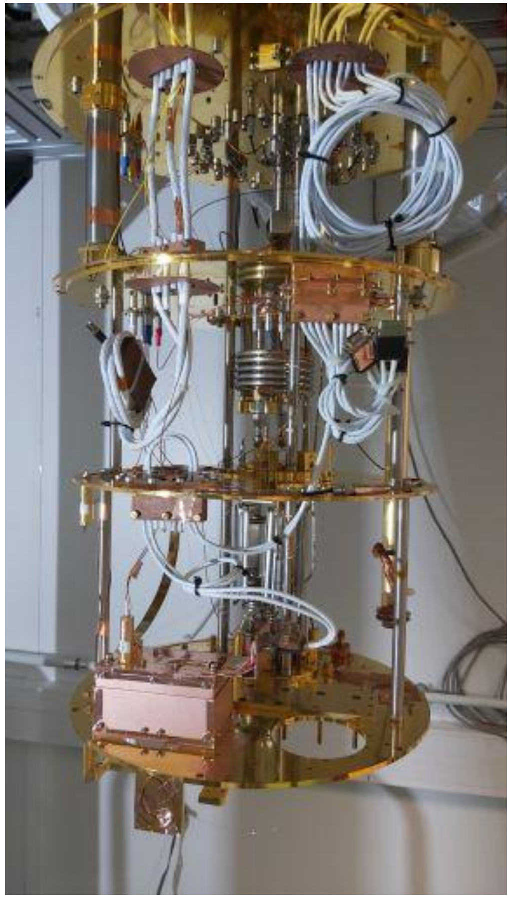
42g Ge detector

Phys. Rev. D 112, 112019

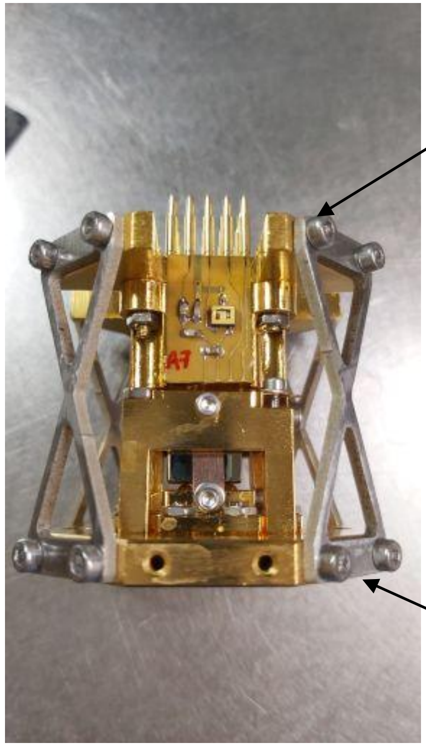
Ricochet commissioning performances:

- 18 x 42g Ge detectors
- Ionisation resolution ~ 40 eVee
- Phonon resolution ~ 50 – 80 eVph

Low Voltage Ge detectors

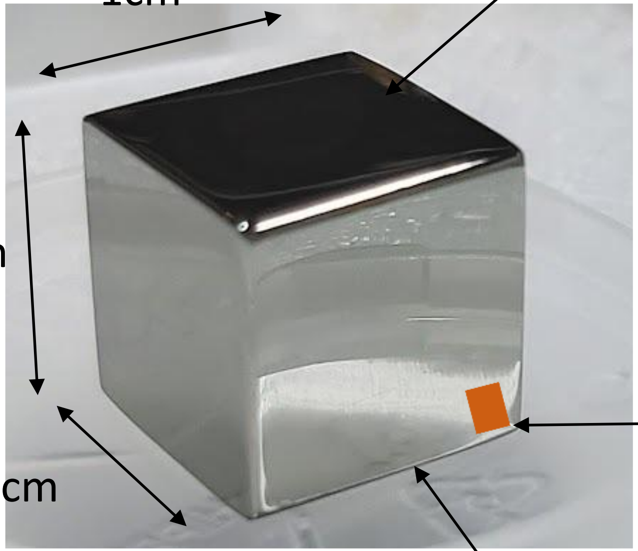


R&D cryostat at Lyon



100mK holder

10mK holder



Electrode A

1cm

1cm

1cm

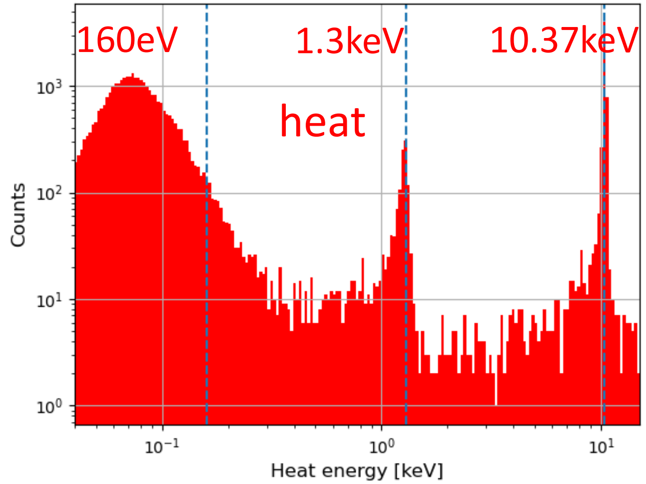
NTD Ge –
phonon sensor

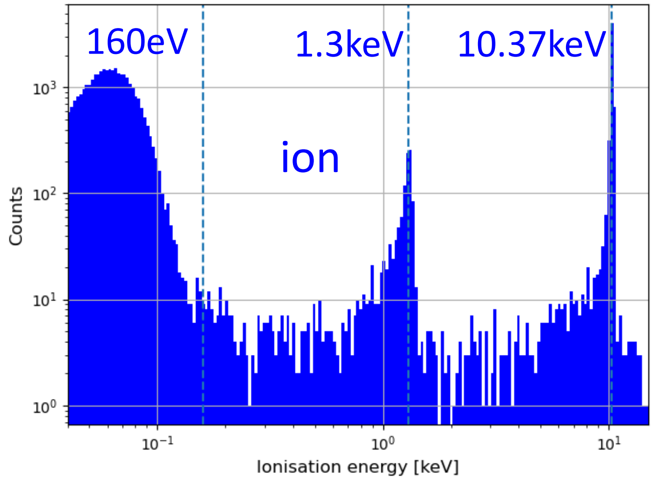
Electrode B

5g Ge crystal

Low Voltage Ge detectors

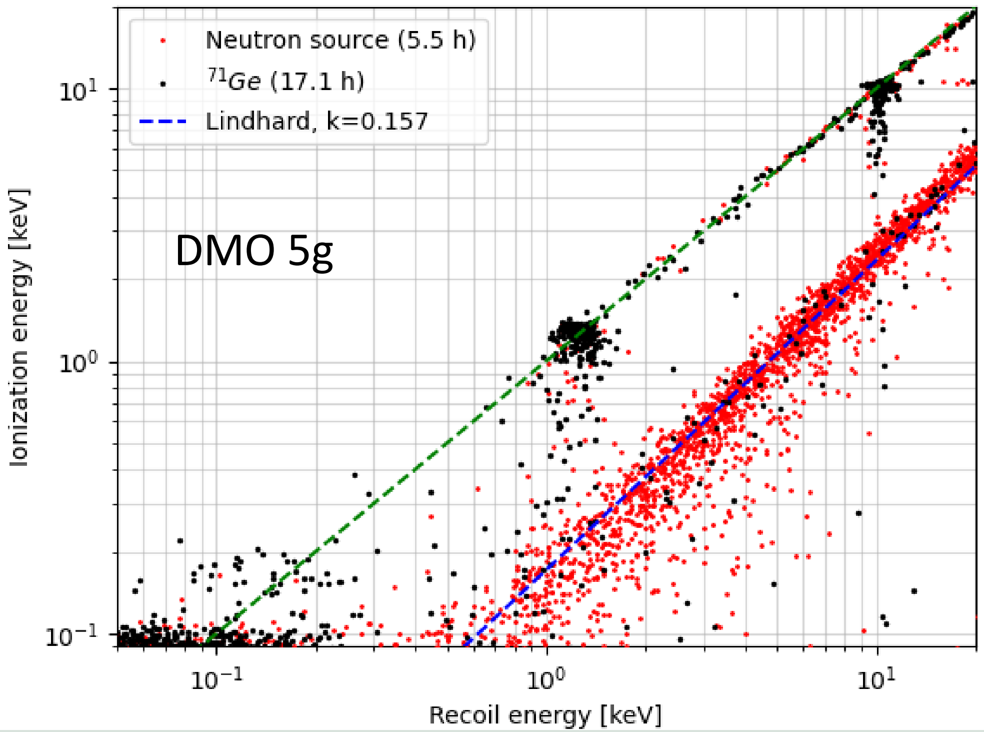
Calibration using K,L,M shell of Ge71
after neutron activation





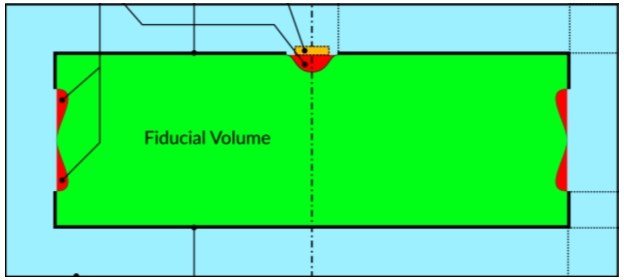
Tesseract Ge LV First prototype performances:

- 5g Ge detector
- Ionization resolution ~ 22 eVee
- Phonon resolution ~ 20 eVph
- Clear identification of NR/ER bands



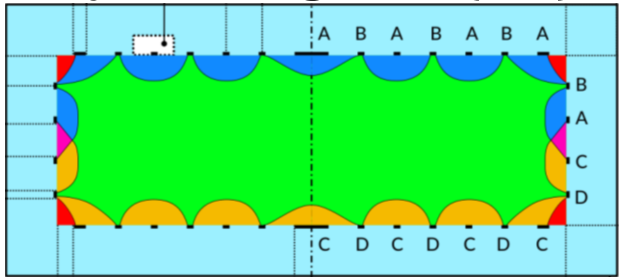
Low Voltage Ge detectors: Electrodes Geometry

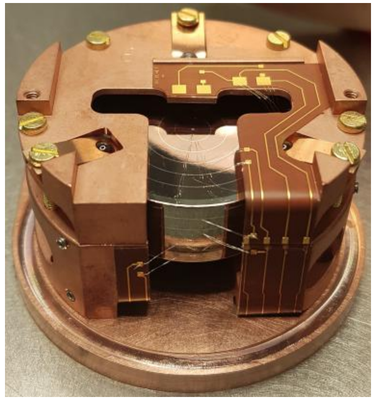
Planar



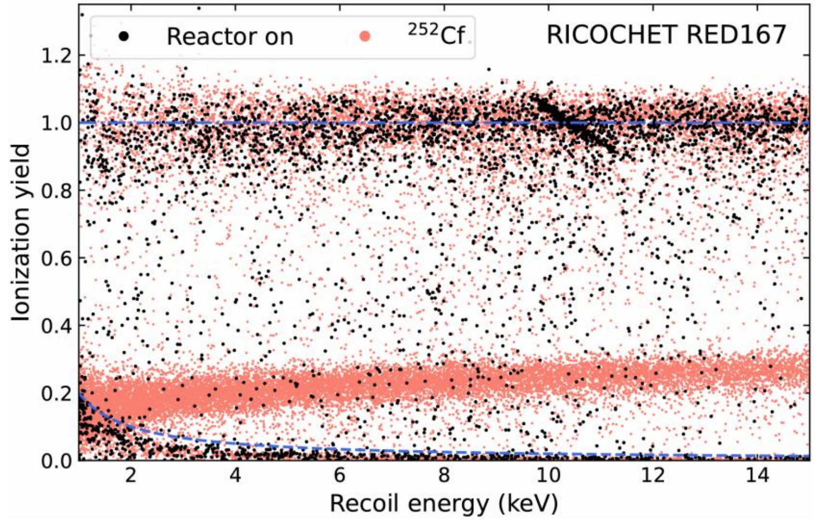
Planar detector in Ricochet

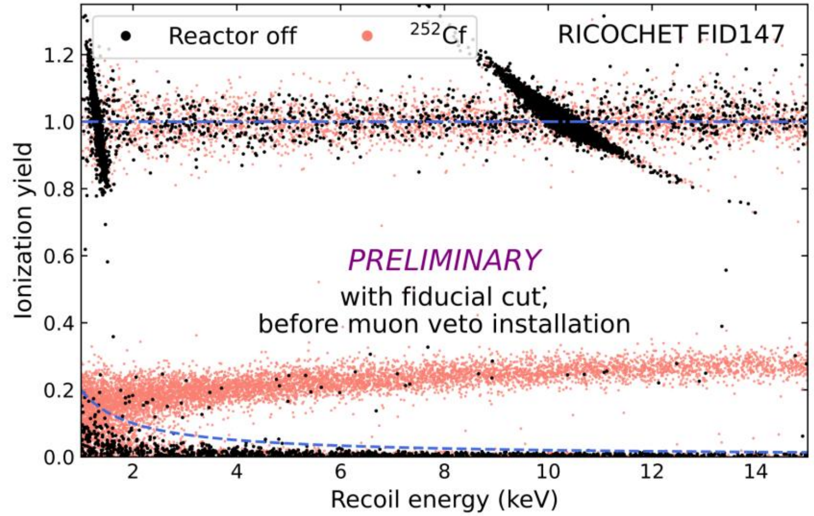
Fully Inter-Digitized (FID)





Fiducial detector in Ricochet



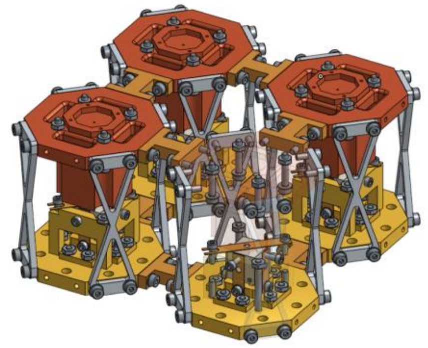


- **No surface** event **rejection**
- 2 fiducial electrodes
- Fiducial volume **100%**

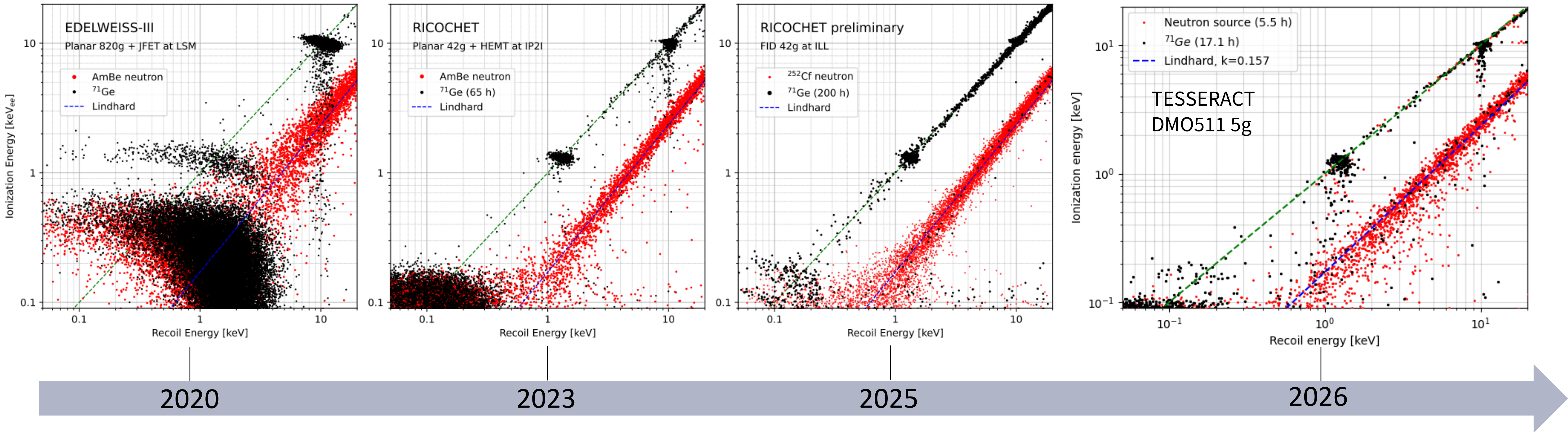
- **Surface event rejection** possible
- 2 veto electrodes + 2 fiducial electrodes
- **Reduced** fiducial volume

Low Voltage Ge detectors: Future prospects

- Total payload of 4 x 5g LV Ge
- Switch from NTD Ge to TES
- Resolutions goal: ionization < 10 eVee, phonon 100 meV
- ER/NR discrimination down to 100 eVnr



Total payload: 4 x 5.35 g



Conclusion

TESSERACT will allow for **different dark matter interaction** searches thanks to **multiple target** approach.

Semi-conductor program:

Low Voltage
- Optimal for NRDM
- Already proved ER/NR/LEE discrimination

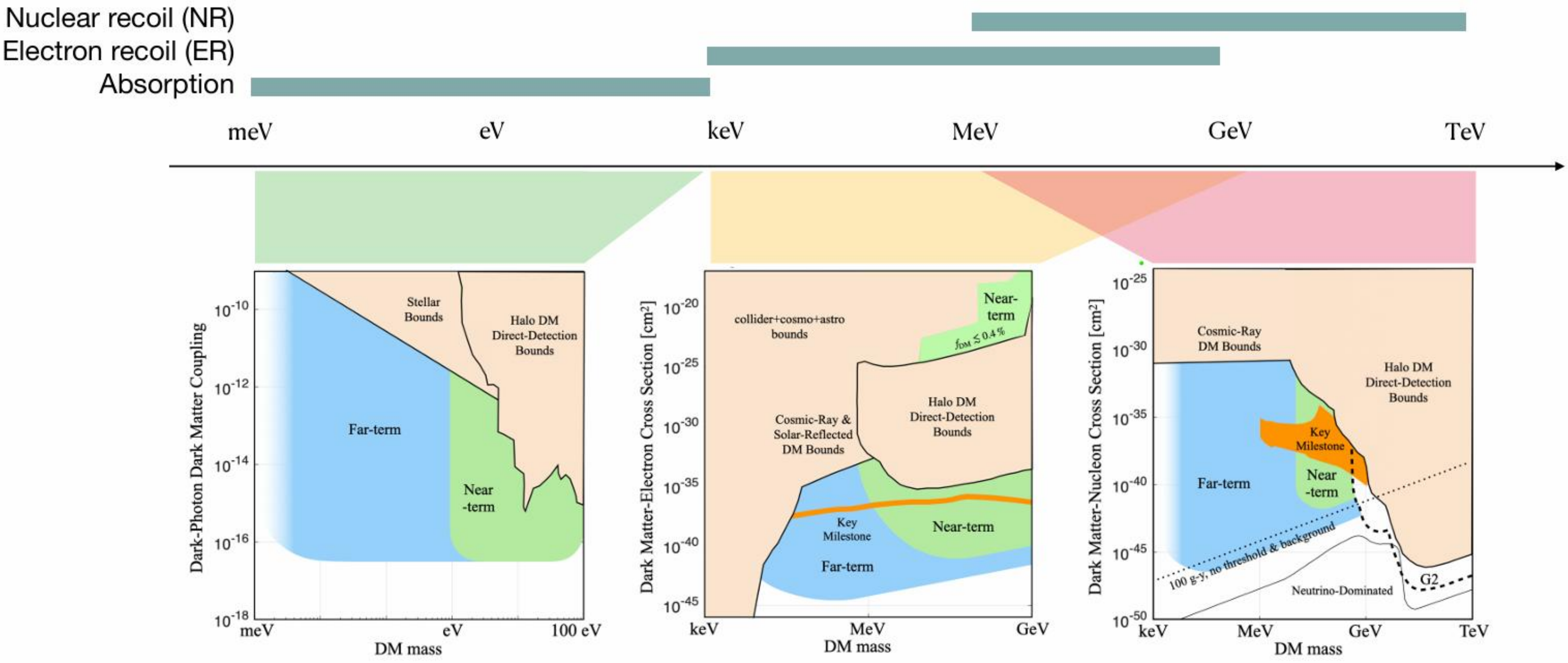
High Voltage
- Optimal for ERDM
- Already demonstrated single electron-hole pair sensitivity

R&D work in progress to achieve exquisite performances

More on TESSERACT by D. McKinsey tomorrow

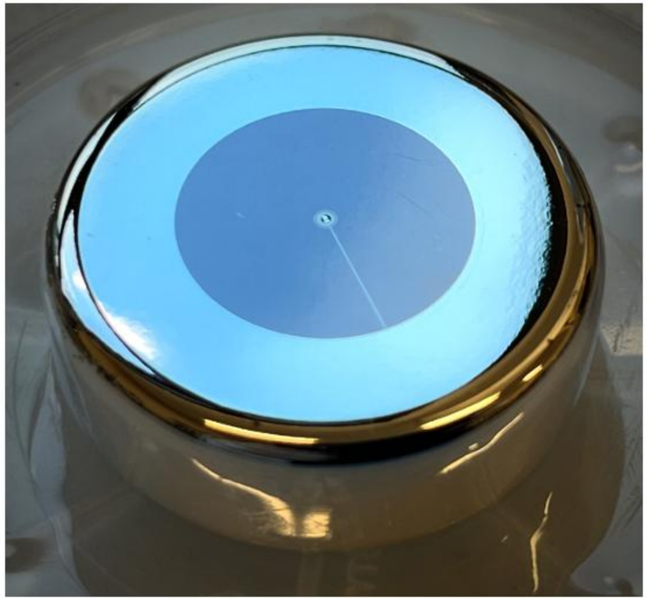
BACKUP slides

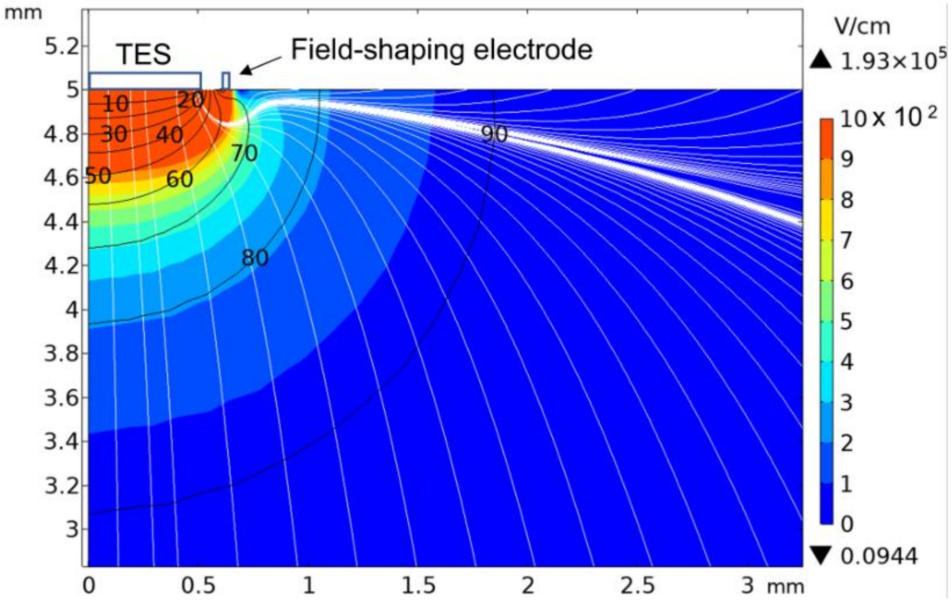
Looking for a wide range of DM masses



R. Essig et al., ArXiv: 2203.08297

HV

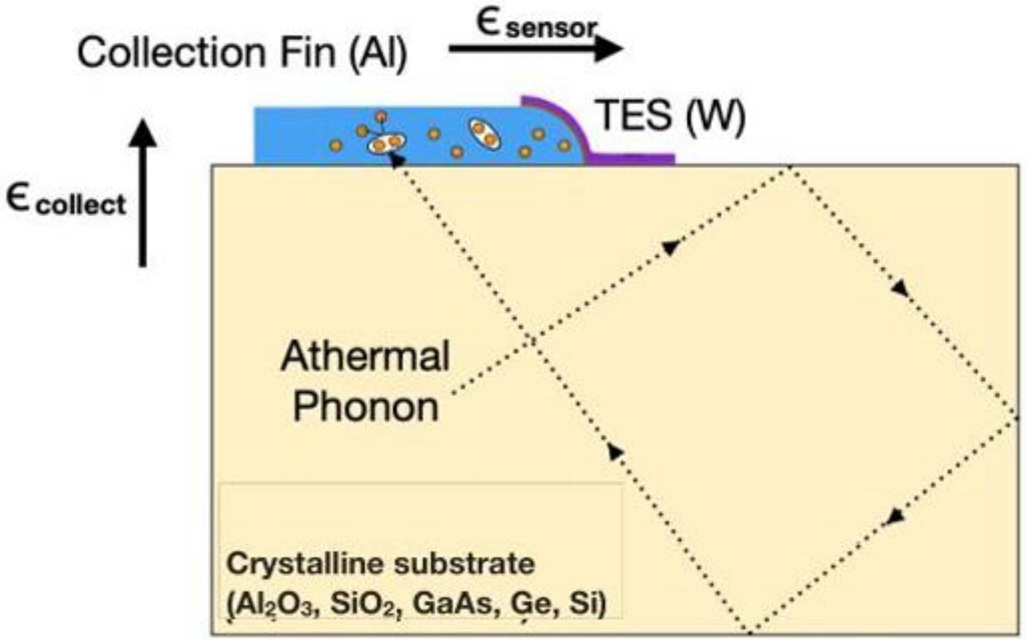




- TES = 50nm thick NbSi film
- Most of the NTL region are emitted in the red region (1-2 mm under the TES)
- TES measures the athermal phonons E_{NTL} → phonons from ionising events
- NTD measures $E_{NTL} + E_R$ → phonons from ionising + non ionising events

E_{NTL}/ E_R allows the discrimination of ER/NR/LEE

Transition Edge Sensors



$$\sigma_E \sim \frac{\sqrt{4k_bT_c^2G(\tau_{collect}+\tau_{sensor})}}{\epsilon_{collect}\epsilon_{sensor}}$$

$$\sigma_E \propto V_{det}^{1/2}T_c^3$$