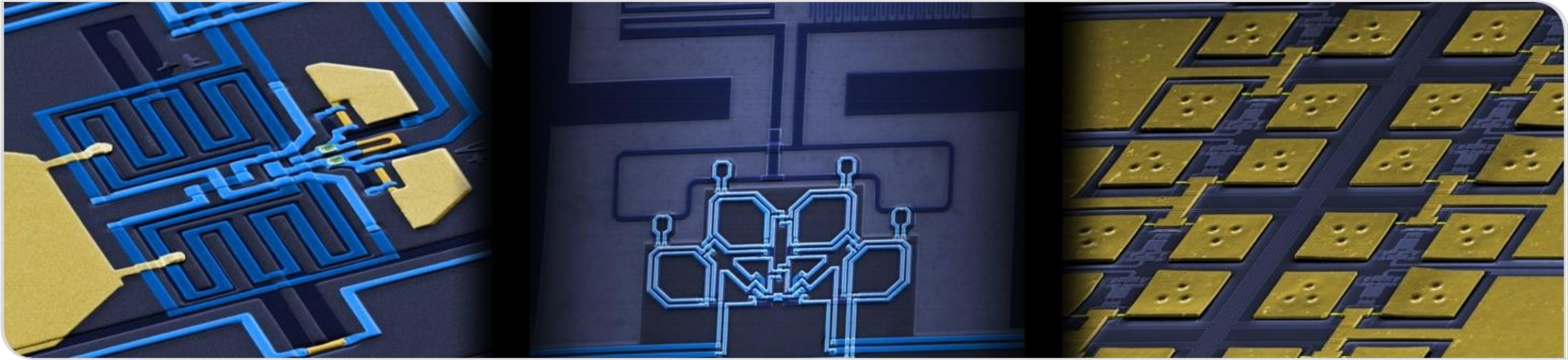
DELight's Approach to tackle Low-Energy Excess (LEE)

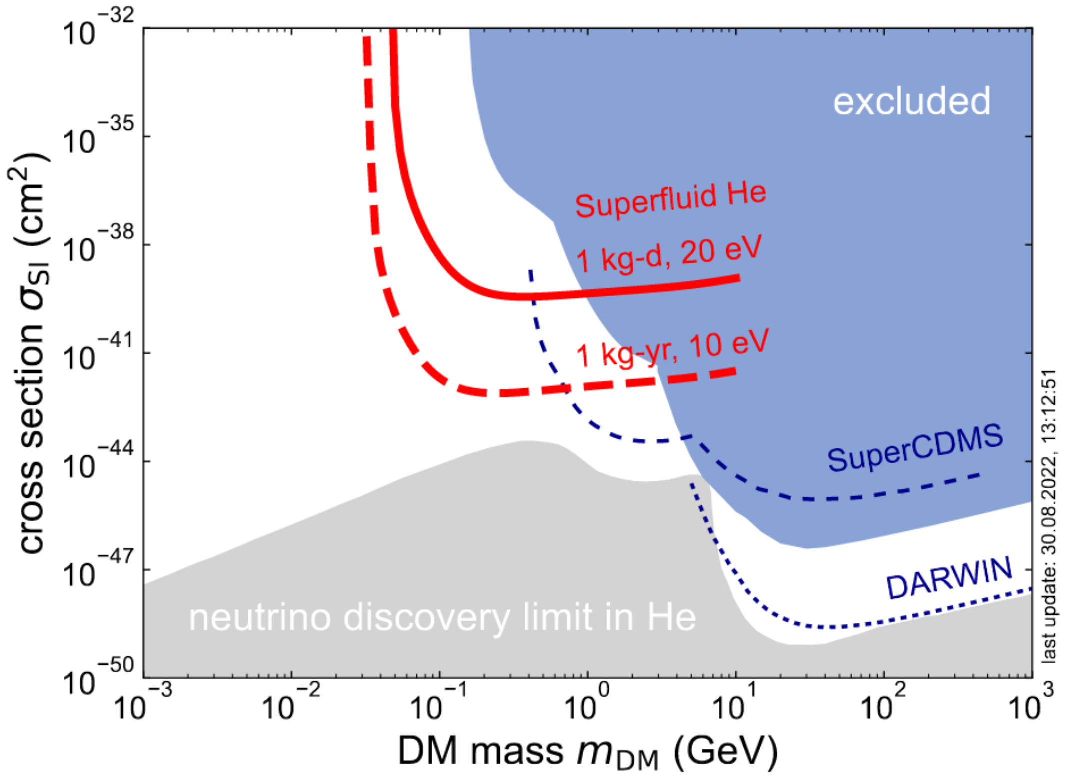
L. Hauswald on behalf of the DELight Collaboration



Direct search experiment for Light Dark Matter with Superfluid Helium (DELight)

- Search for DM in the **sub-100 MeV** mass range with a detection **threshold <20 eV**

- Superfluid **helium-4** as target material:
  - sensitive to low DM masses
  - radiopure and compact low-background target
  - three independent and distinguishable signal channels



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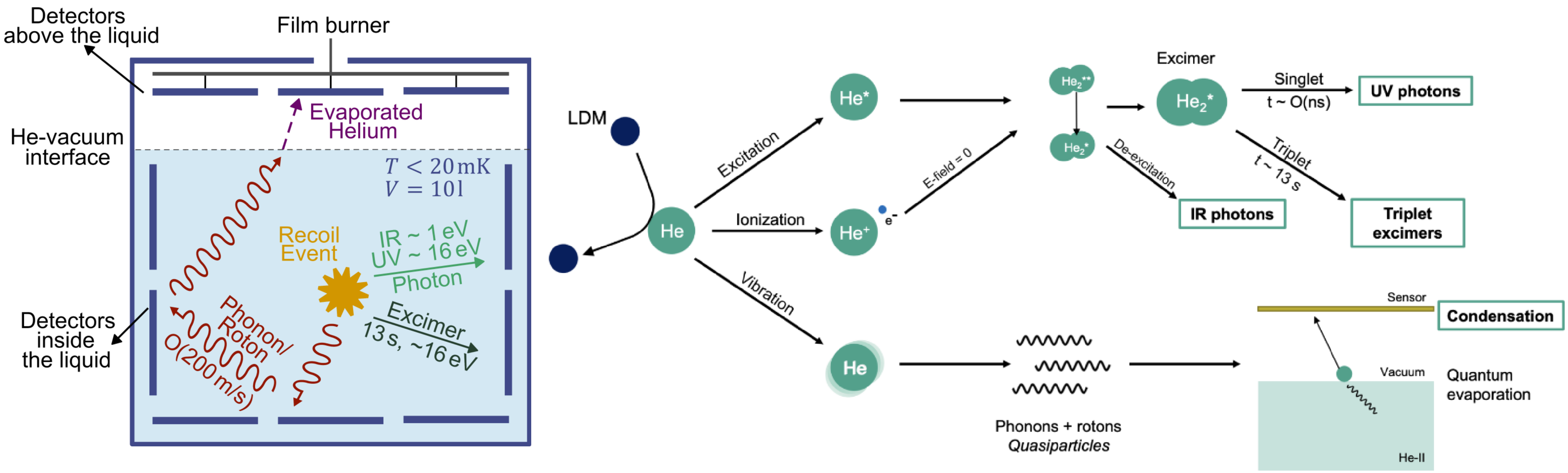
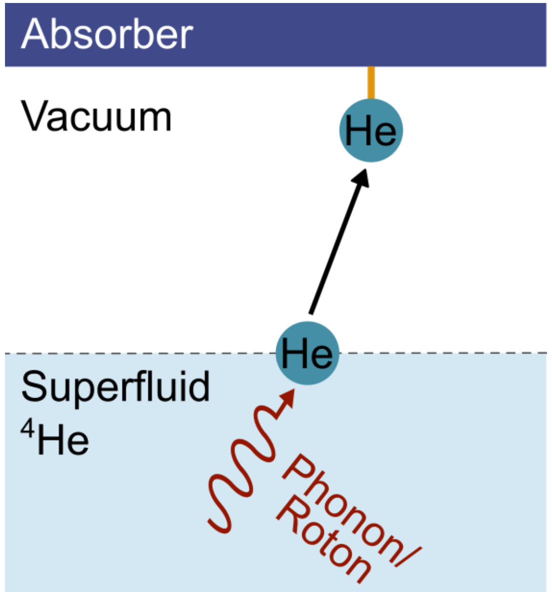
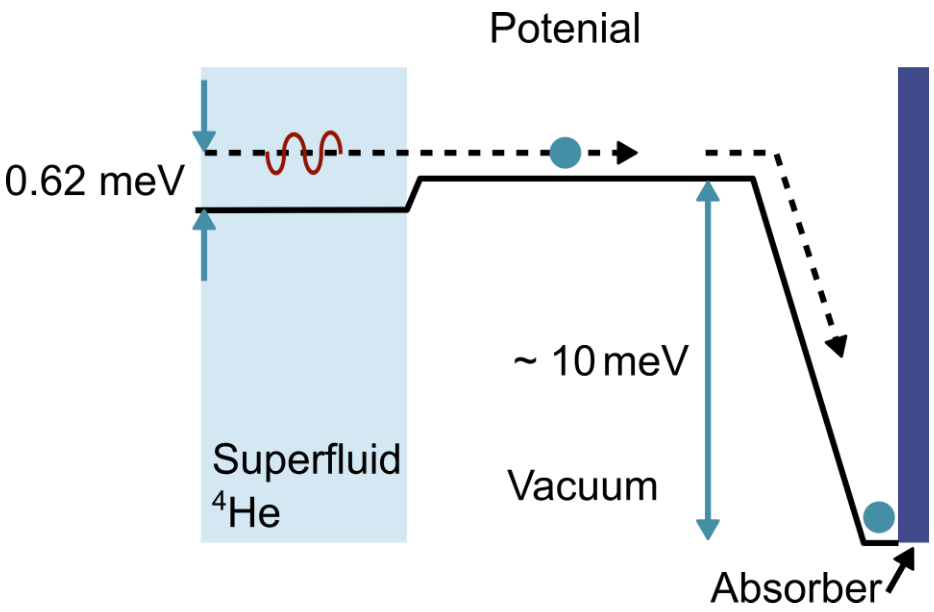


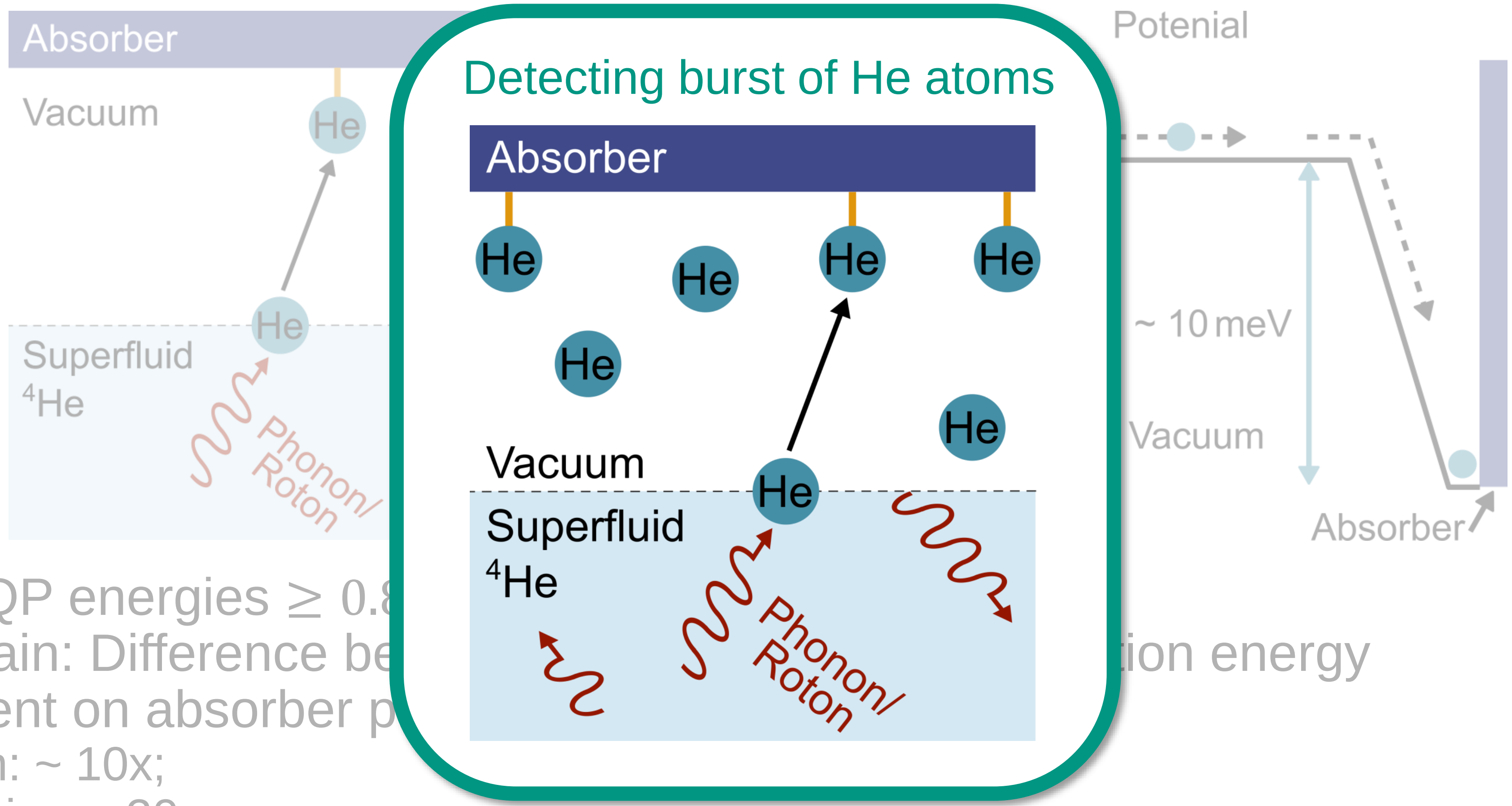
Quasiparticle detection





- Typical QP energies $\geq 0.8\ \mathrm{meV}$
- Signal gain: Difference between evaporation and adsorption energy
- Dependent on absorber properties:
  - Silicon: ~ 10x;
  - Sapphire: ~ 20x

Quasiparticle detection



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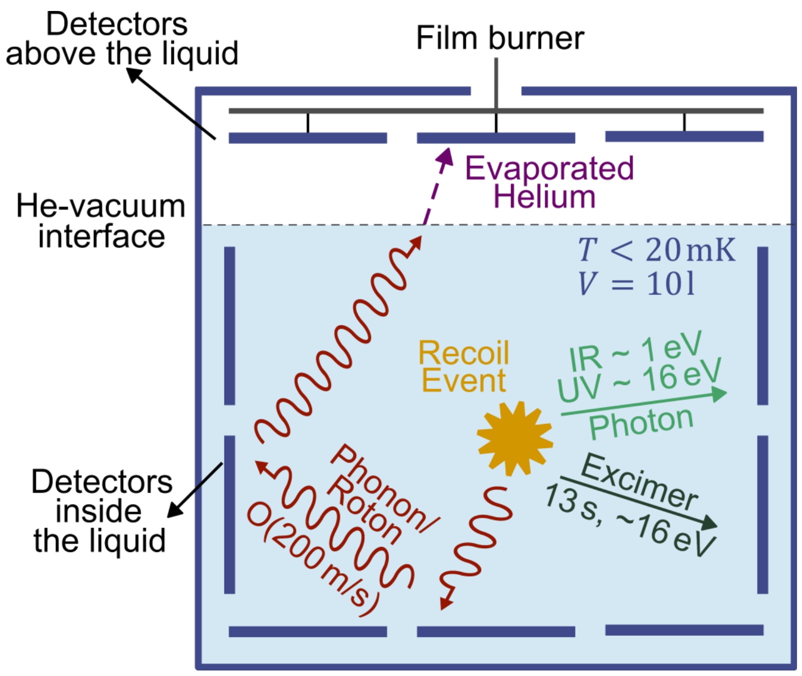

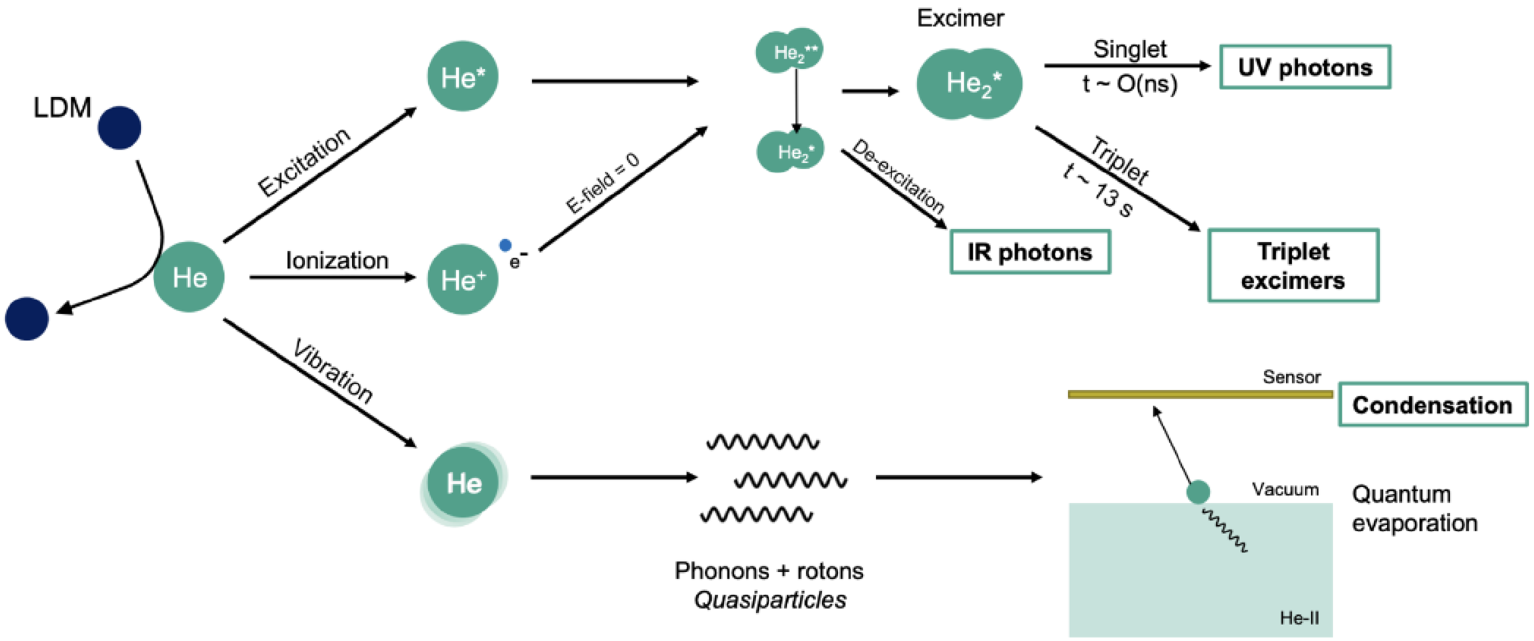

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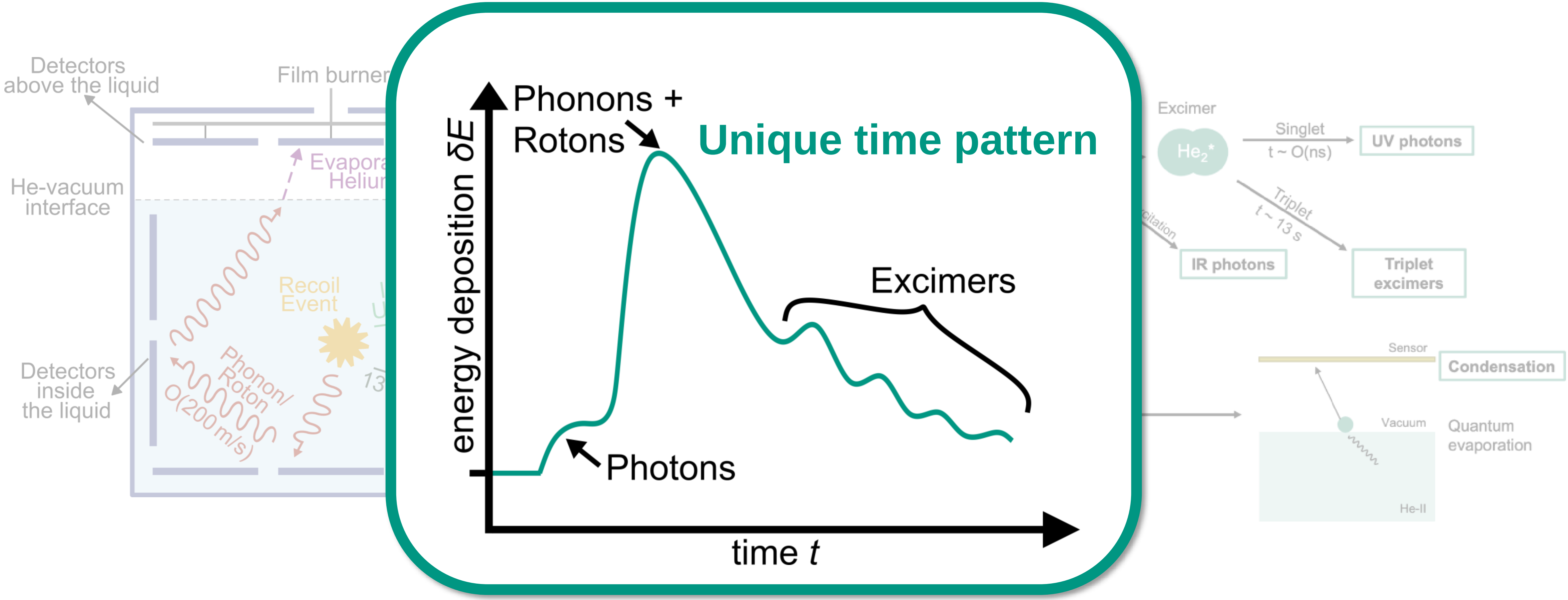
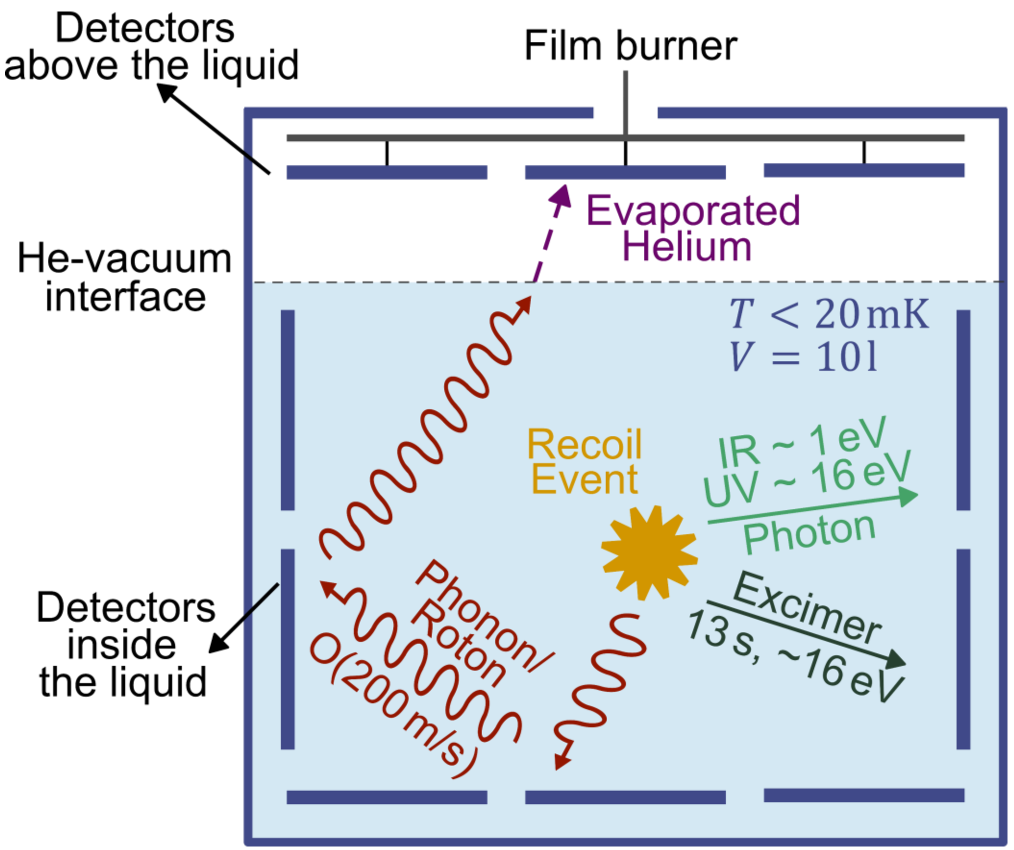


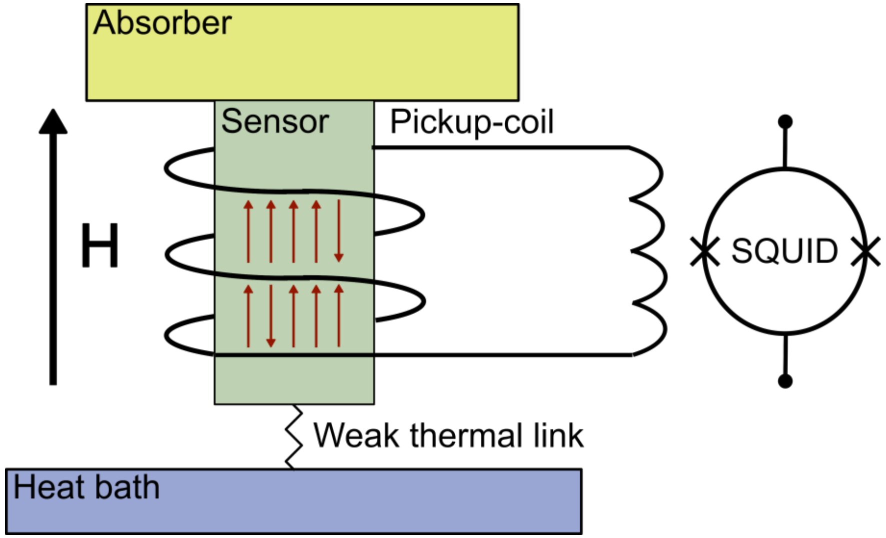
Direct search experiment for Light Dark Matter with Superfluid Helium (DELight)

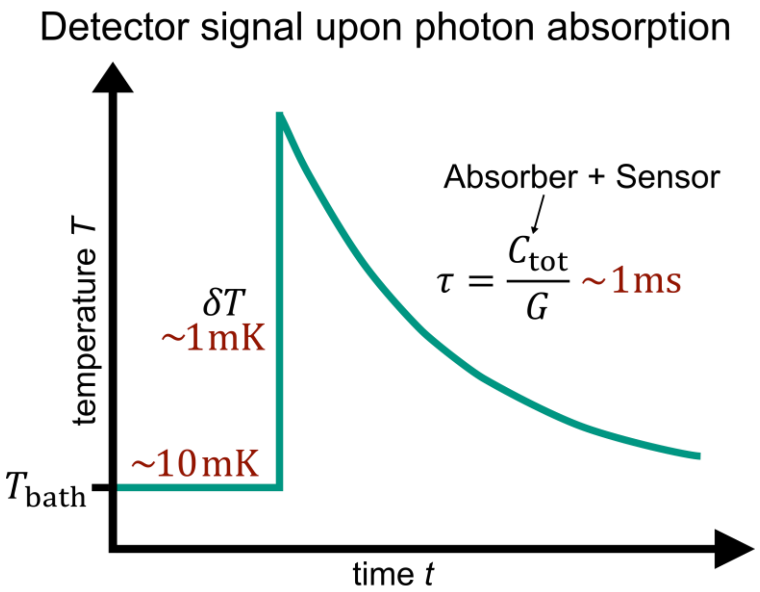
- **Detector specifications:**
  - High detection efficiency → large-scale wafer calorimeters covering entire surface of the helium cell
  - Excellent energy and time resolution



Magnetic Microcalorimeter (MMC) – based athermal phonon detectors

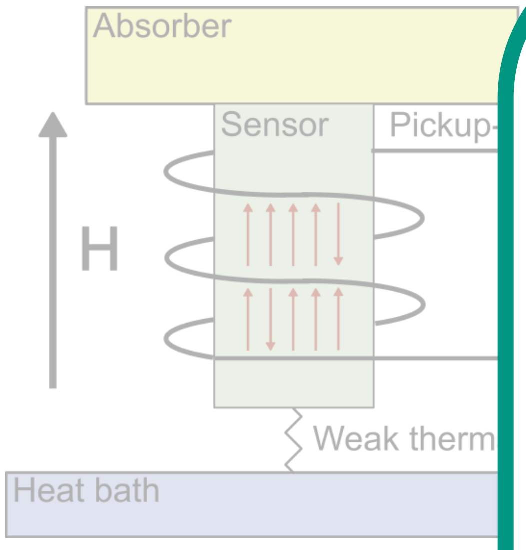
Basic principles of Magnetic Microcalorimeters



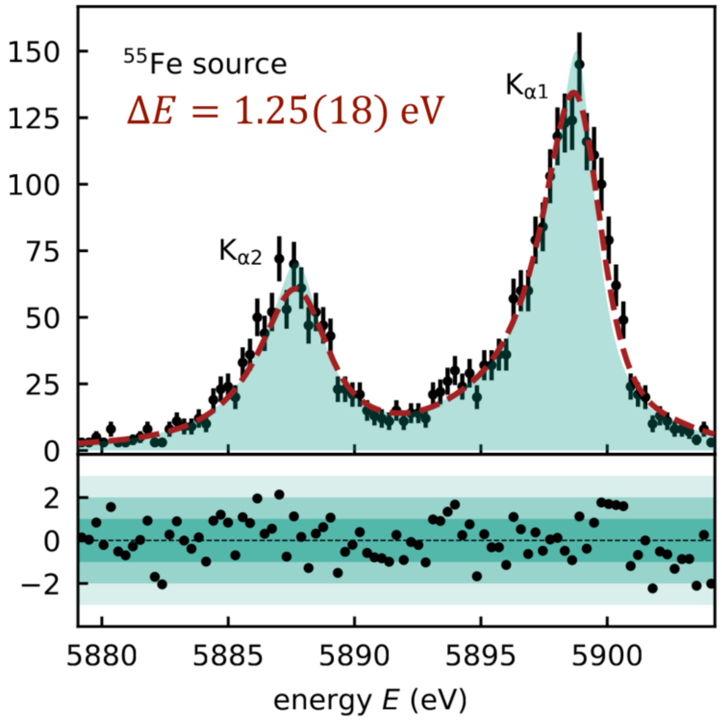


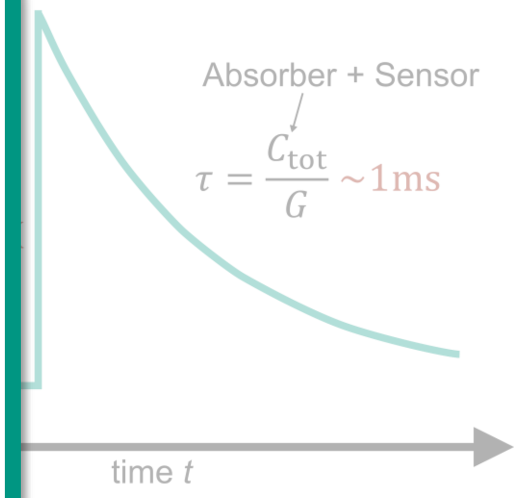
Energy deposition	Temperature rise	Change in sensor magnetisation	Flux change in SQUID
δE	$\delta T \simeq \frac{\delta E}{C_{tot}}$	$\delta M \sim \frac{\partial M}{\partial T}\delta T$	$\delta\phi \propto \frac{\partial M}{\partial T}\frac{\partial E}{C_{tot}}$

Basic principles of Magnetic Microcalorimeters



World record
energy resolution





Energy deposition

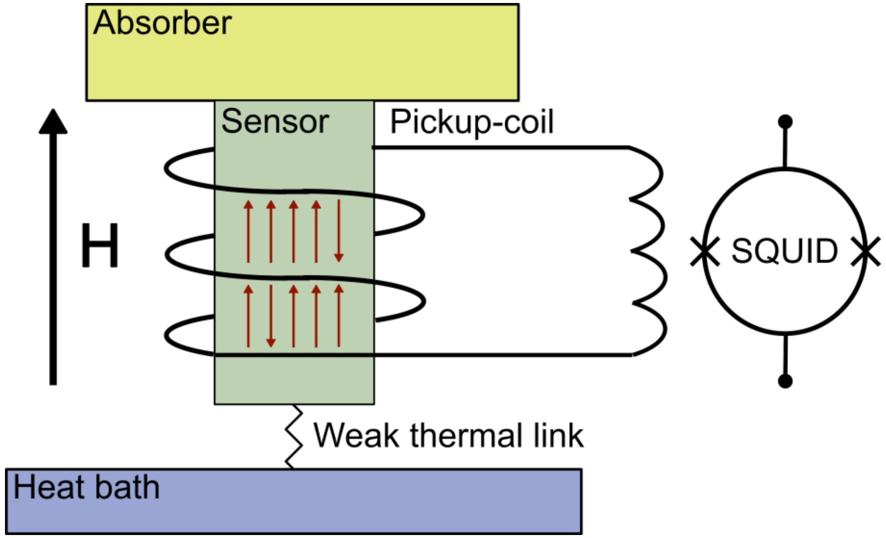
δE

Temperature rise

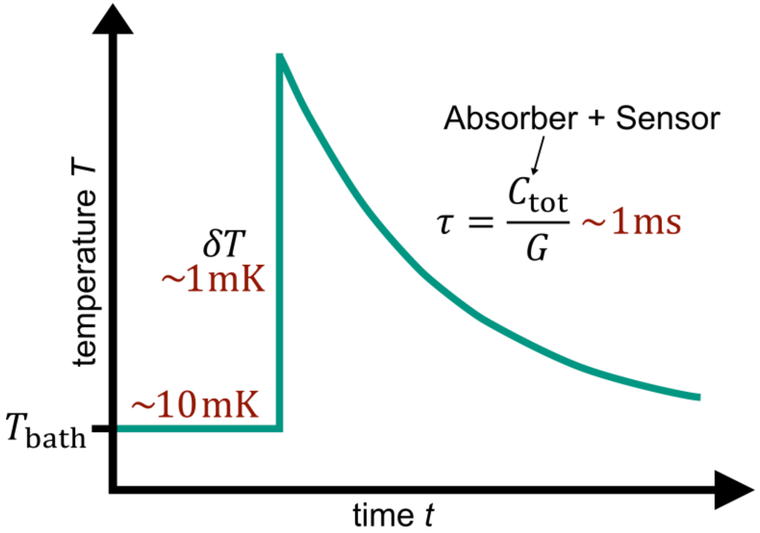
$\delta T \simeq \frac{\delta E}{C_{tot}}$

M. Krantz *et al.*, Appl. Phys. Lett. 124, 032601 (2024)

Basic principles of Magnetic Microcalorimeters



Detector signal upon photon absorption



Energy deposition		Temperature rise		Change in sensor magnetisation		Flux change in SQUID
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Basic principles of Magnetic Microcalorimeters

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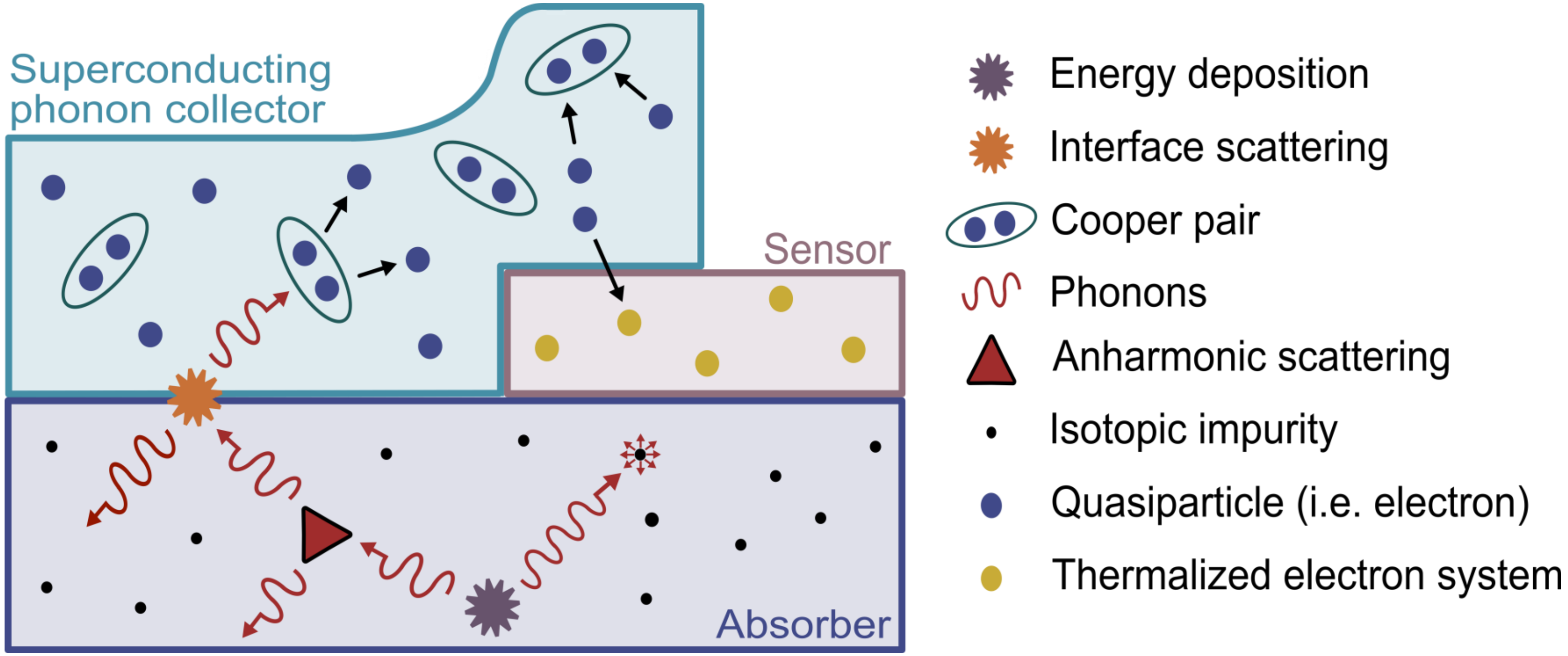
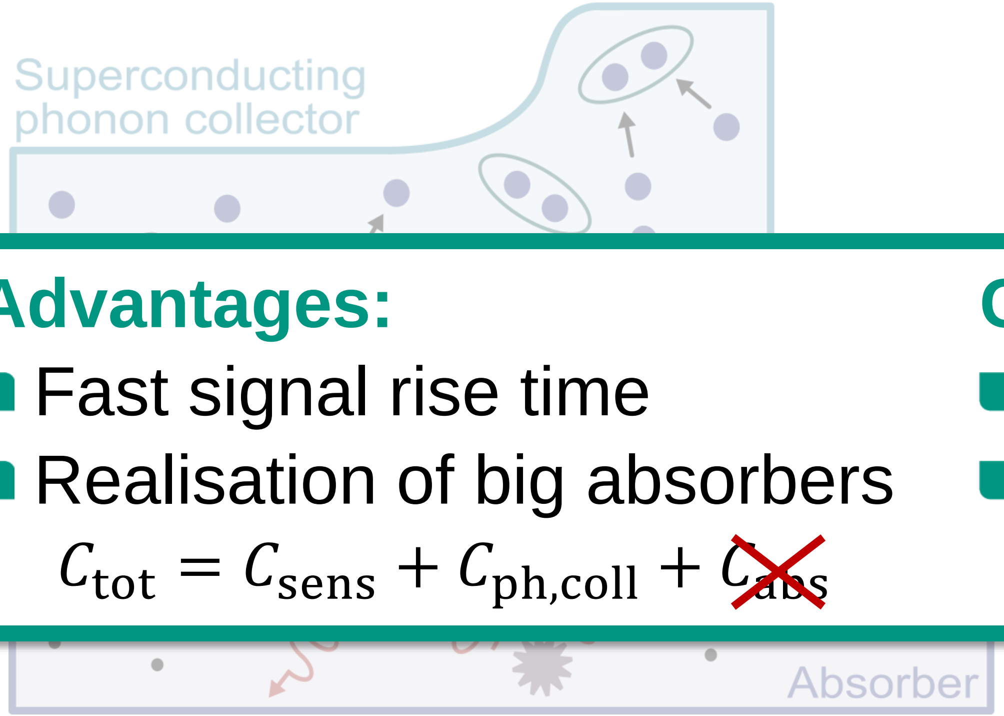
Athermal phonon detector



Creation of athermal phonons → Cooper pair breaking; Quasiparticles (QPs) creation → (Diffusion) Thermalization through electron-electron interactions within temperature sensor

Athermal phonon detector



Energy deposition

Interface scattering

Advantages:

- Fast signal rise time
- Realisation of big absorbers

$$C_{\mathrm{tot}} = C_{\mathrm{sens}} + C_{\mathrm{ph,coll}} + \cancel{C_{\mathrm{abs}}}$$

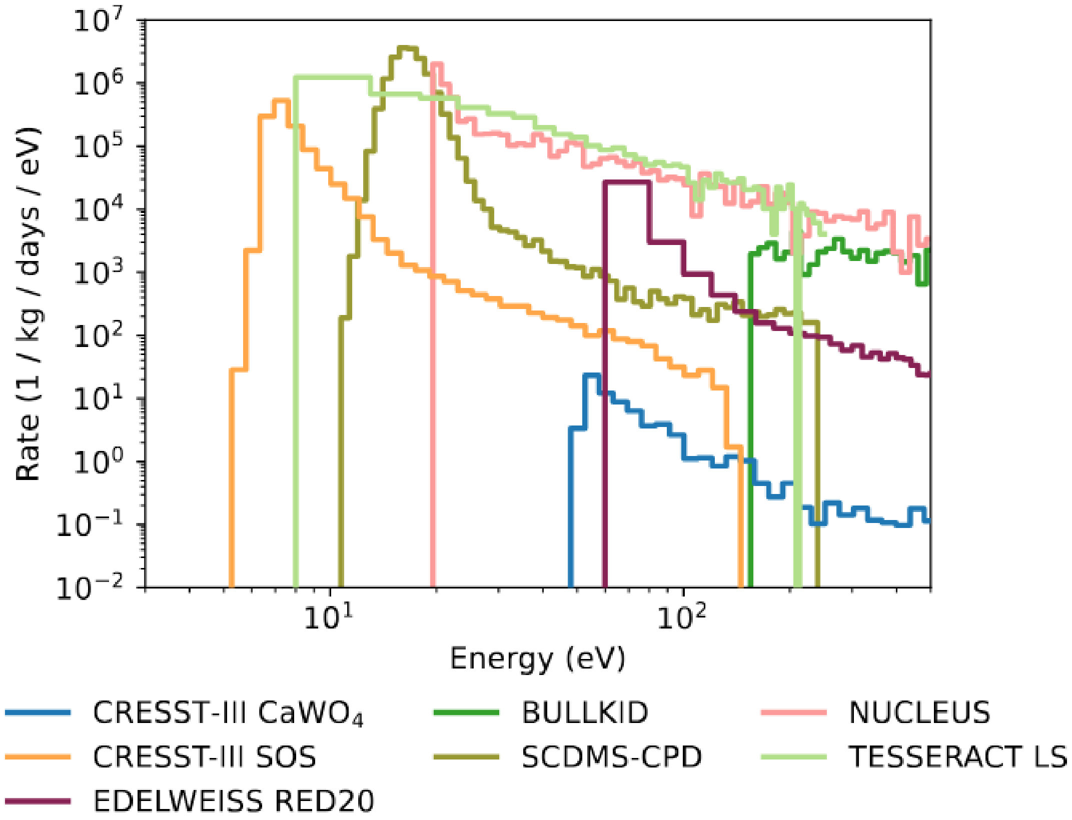
Challenges:

- Phonon collection time
- QP loss

Creation of athermal phonons → (Interface scattering) → Cooper pair breaking; Quasiparticles (QPs) creation → (Diffusion) → Thermalization through electron-electron interactions

Low Energy Excess

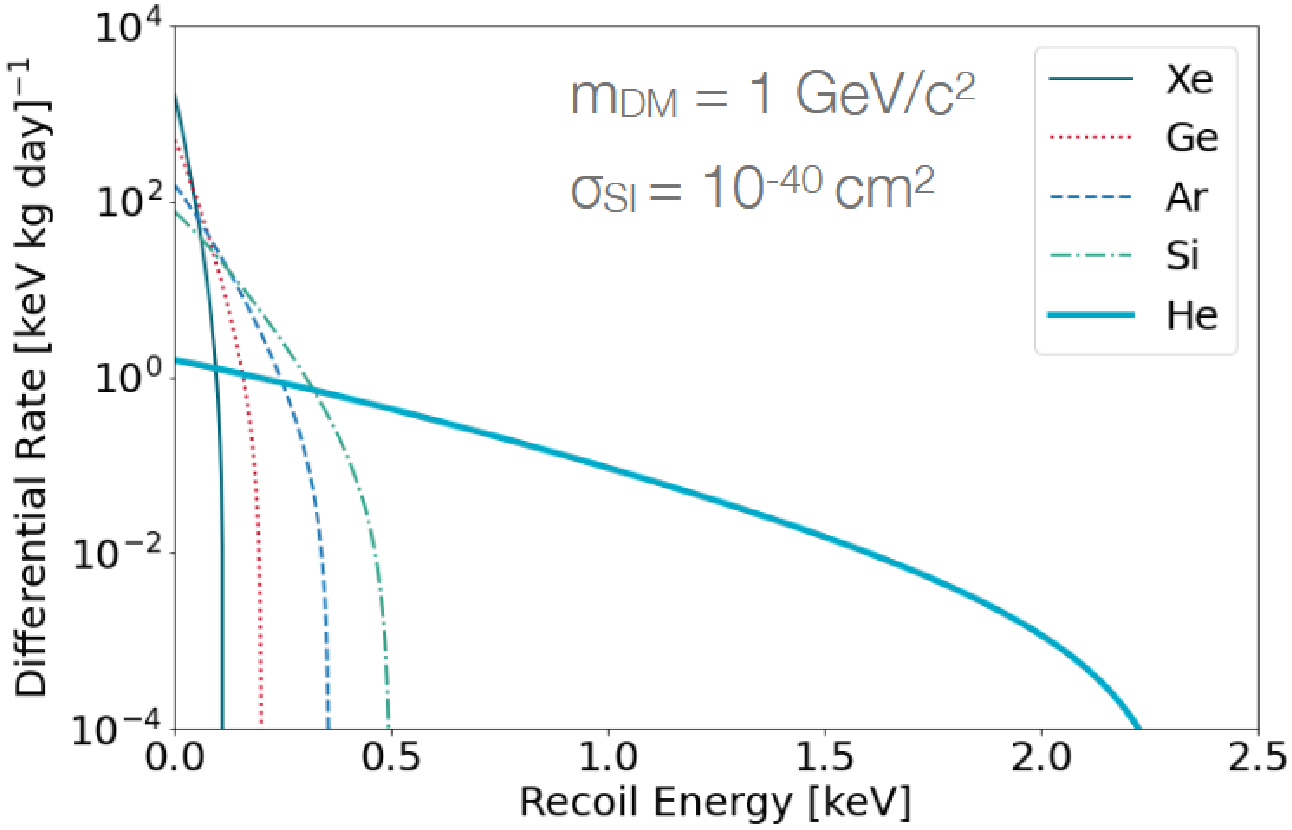
- Unknown singles in the eV energy range
- Rate increases towards lower energy
- Possible / verified causes:
  - Excess quasiparticle population
  - Stress:
    - Surface stress (different thin film properties)
    - Detection support stress (mechanical stress)
    - Sensor stress (thin films)
  - Defect states



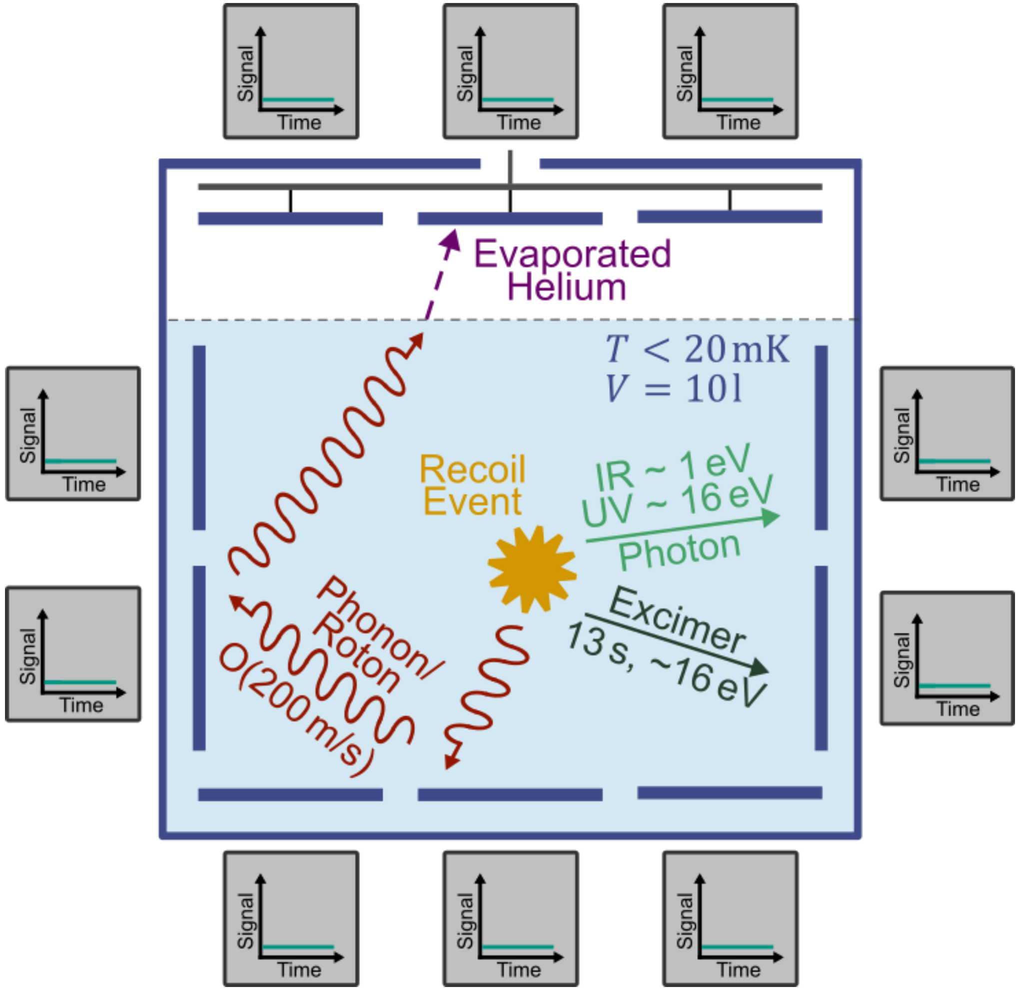
Baxter *et al.*, Low-Energy Backgrounds n Solid-State Phonon and Charge Detectors, arXiv:2503.08859v1 (2025)

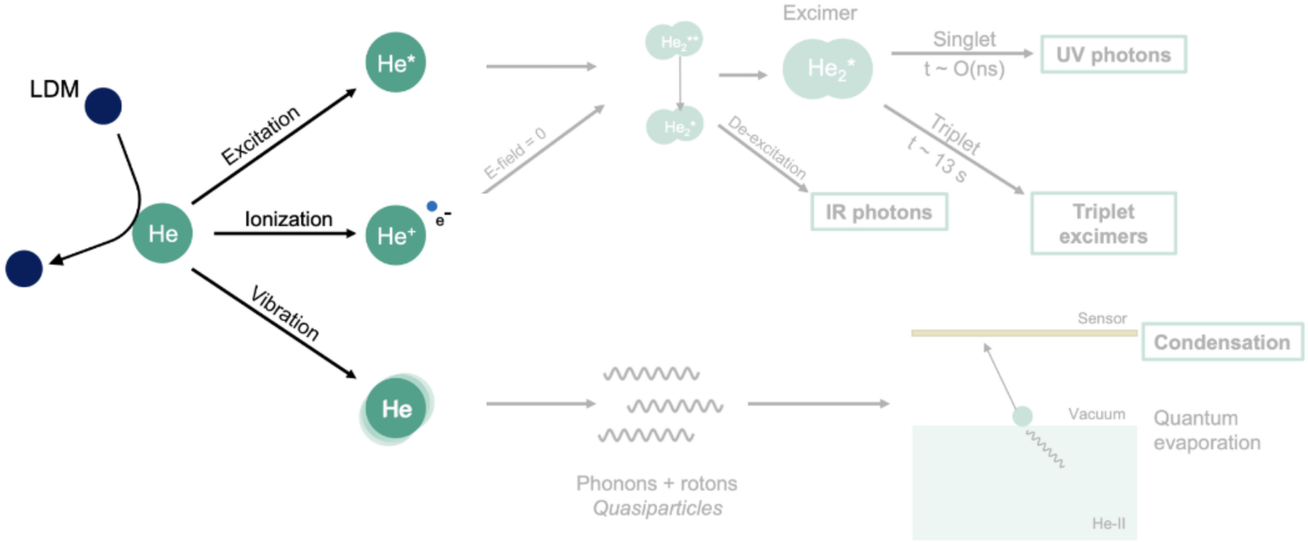
Target advantages

- Superfluid → no interface stress between target and absorber
- „LEE-free“ target
- High recoil energy
- Several signal channels



Differentiation between LEE and DM events





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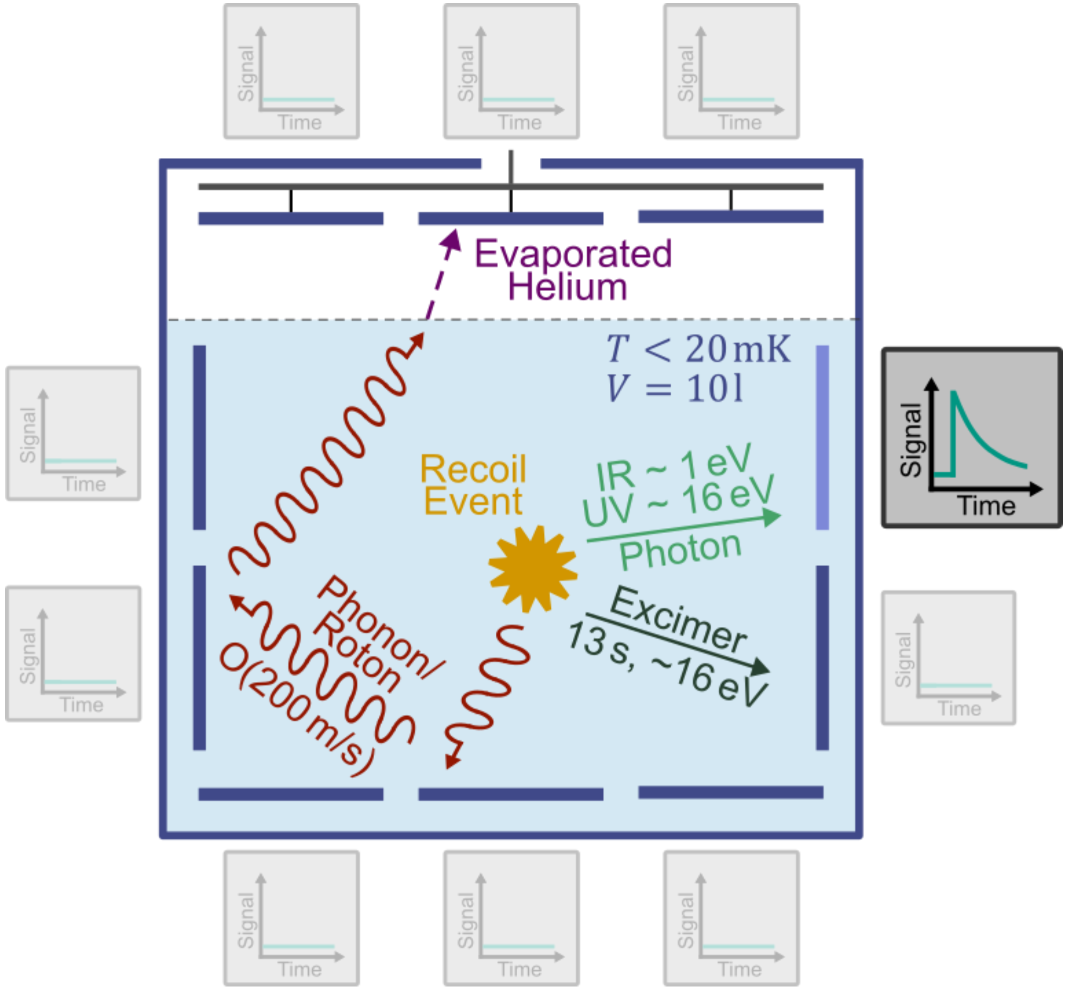

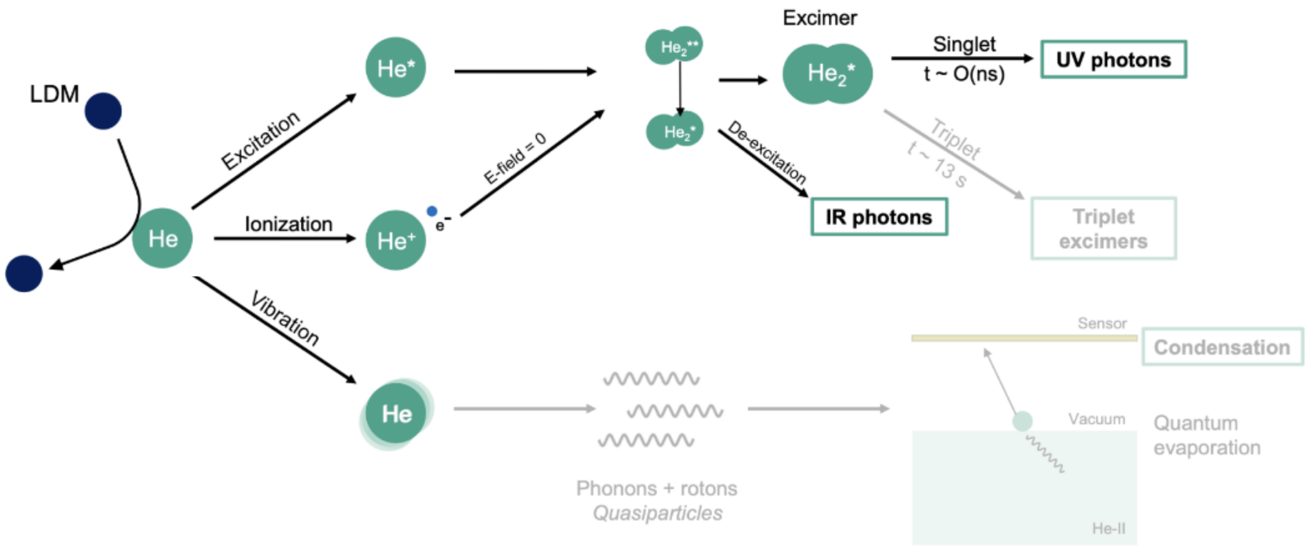

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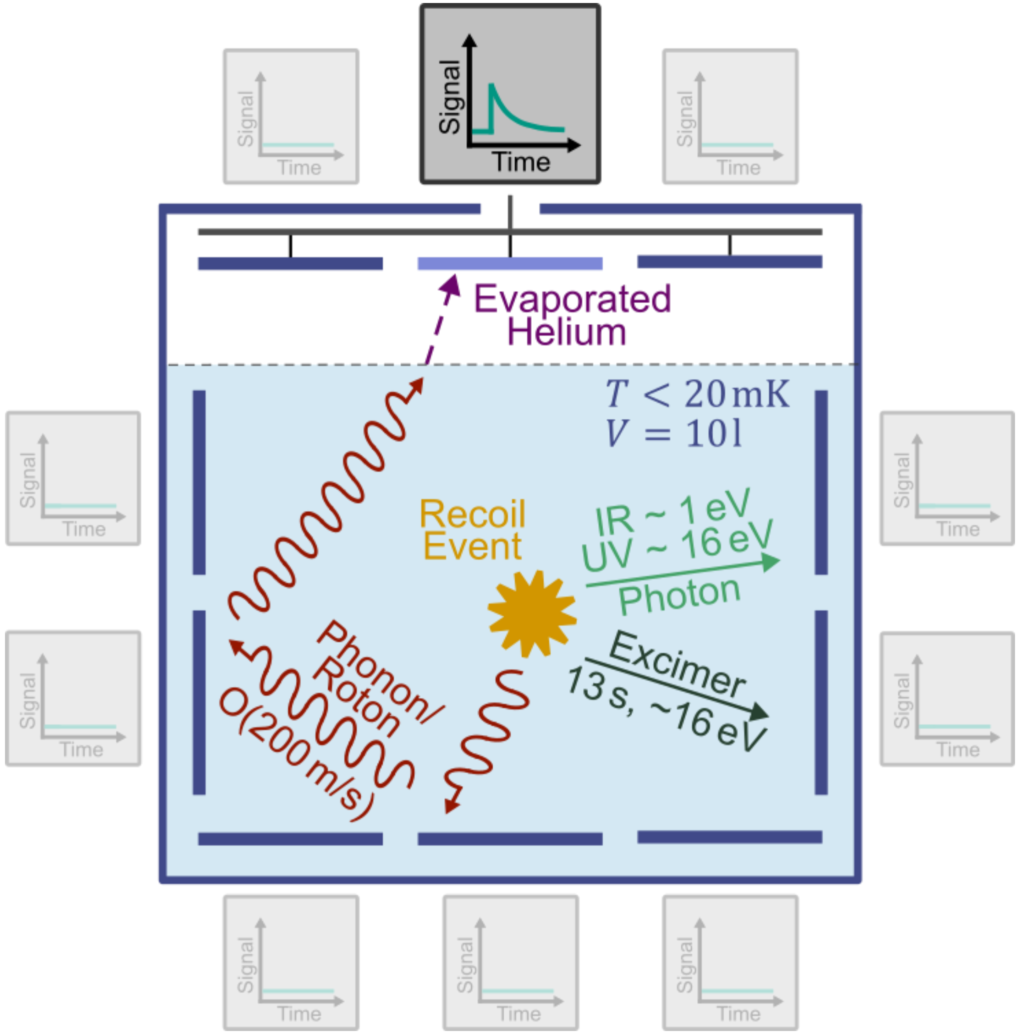

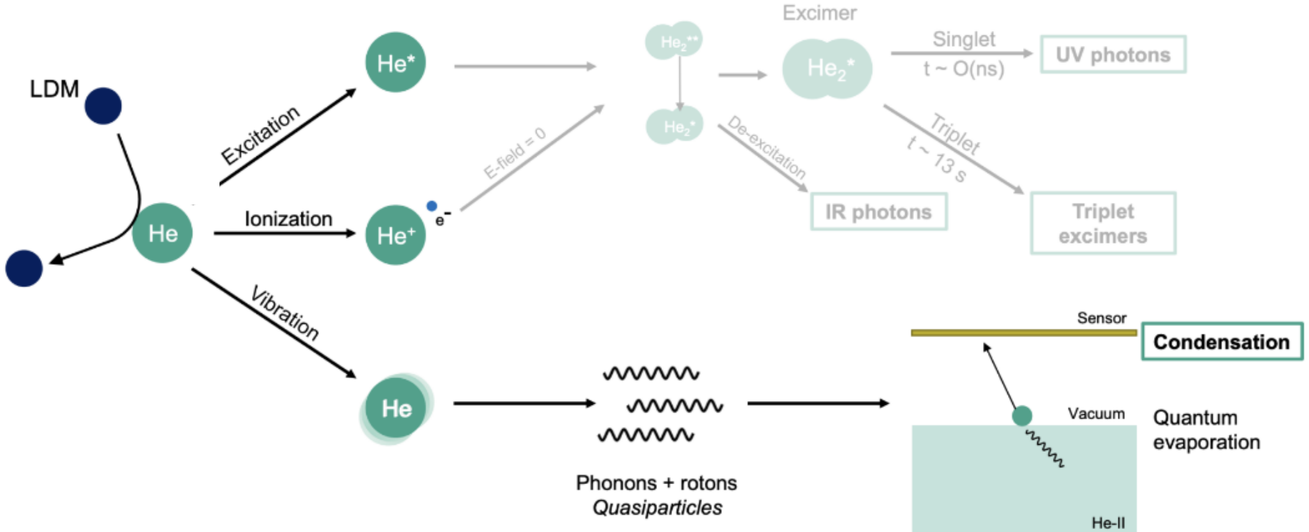

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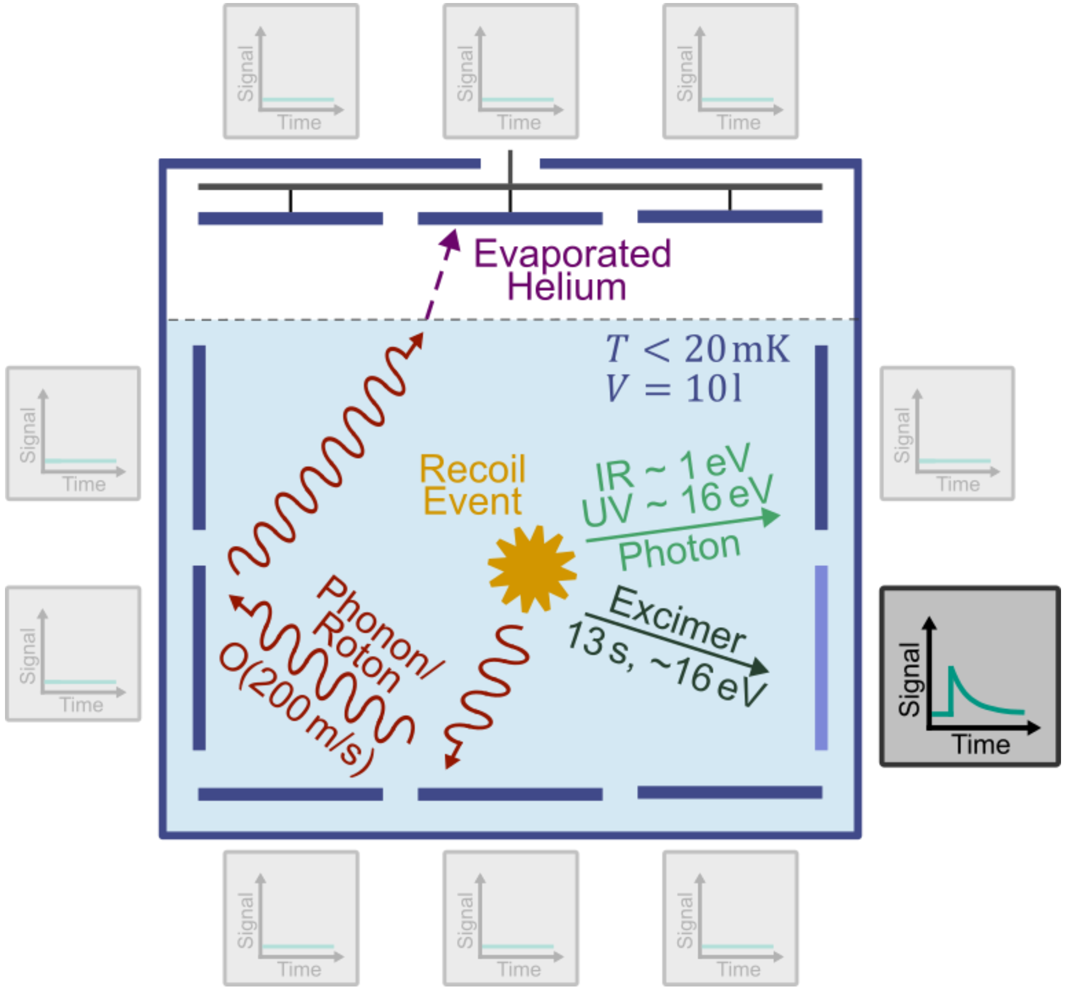

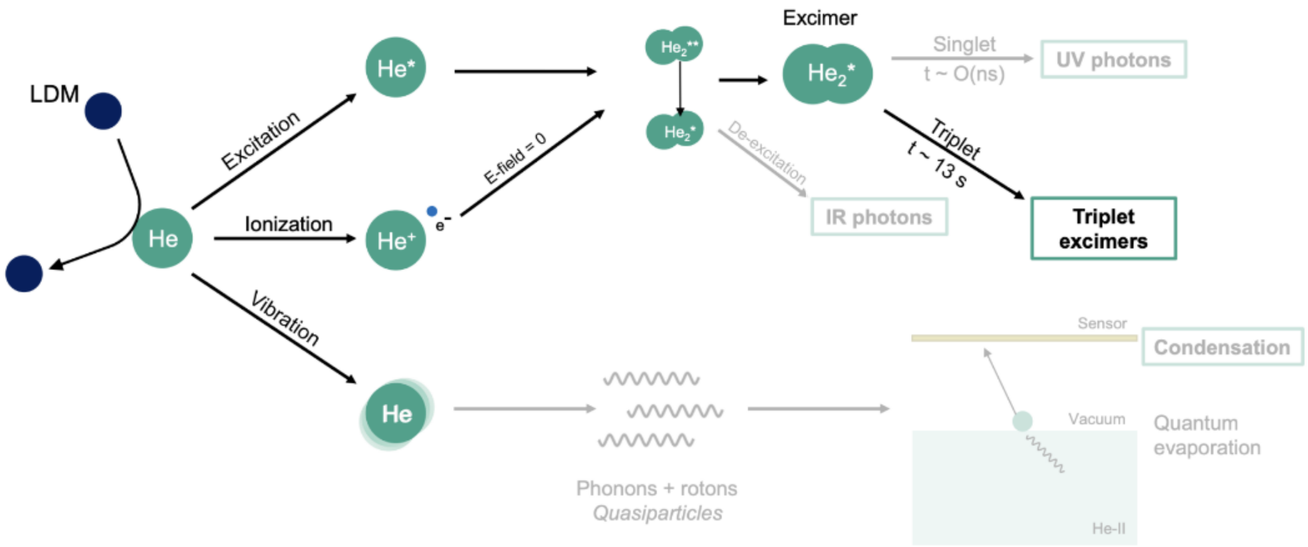

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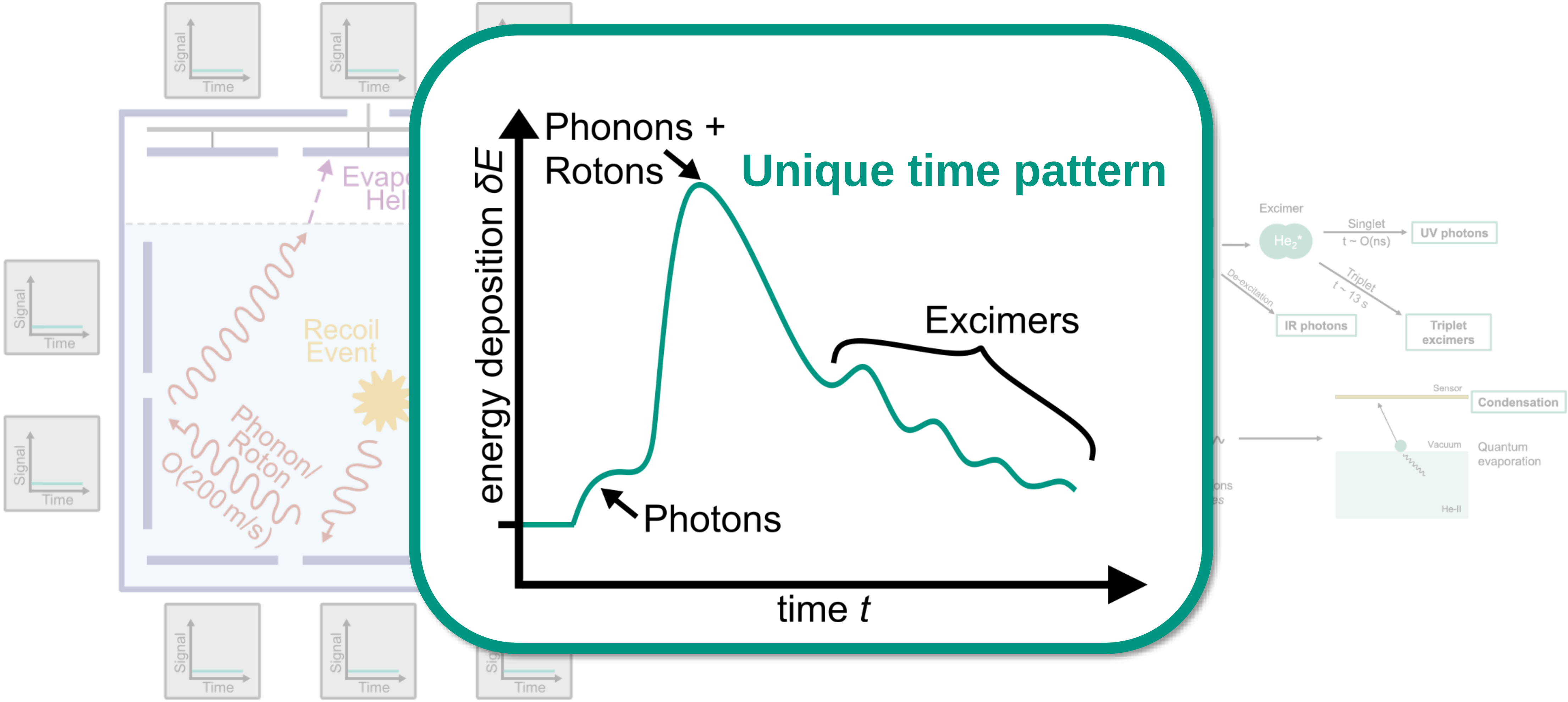

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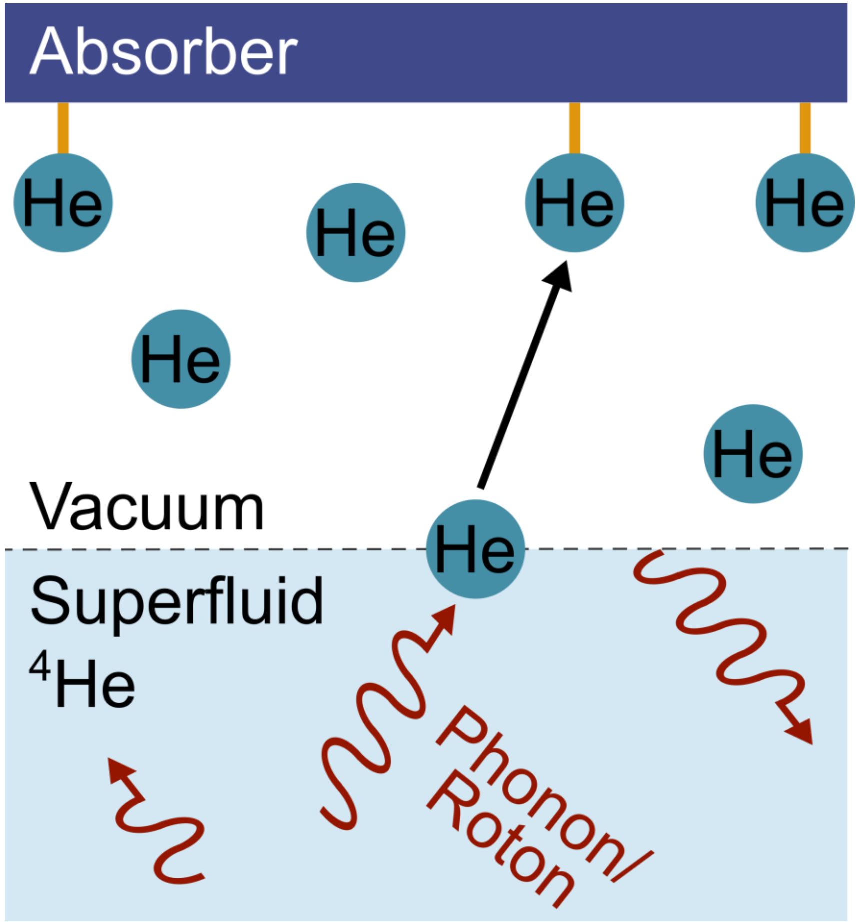
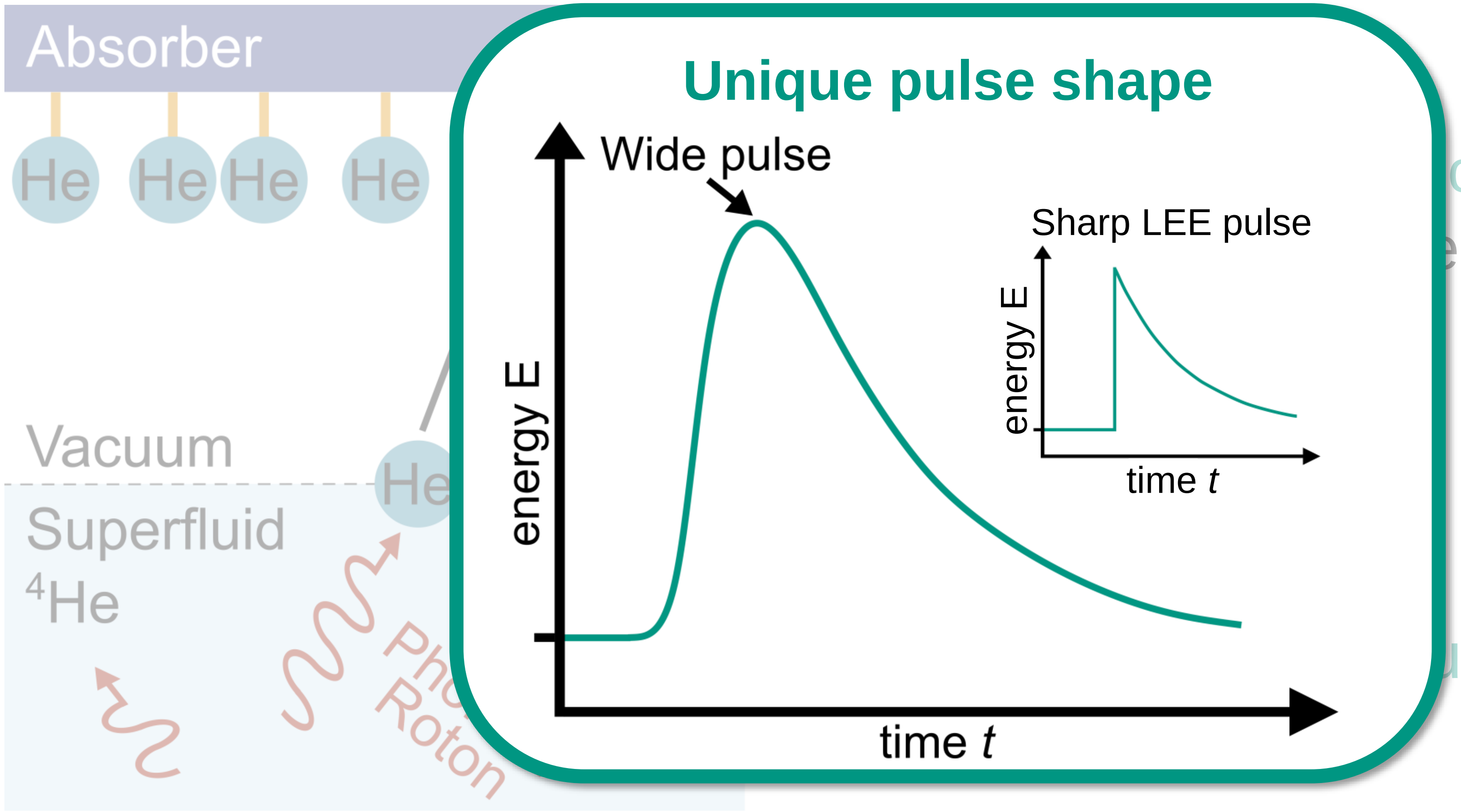


Quasiparticle detection:

- Typical QP energies $\geq 0.8\ \mathrm{meV}$
- Adsorption gain:
  - Silicon 10x
  - Sapphire 20x

➡ Detecting burst of He atoms

Differentiation between LEE and DM events



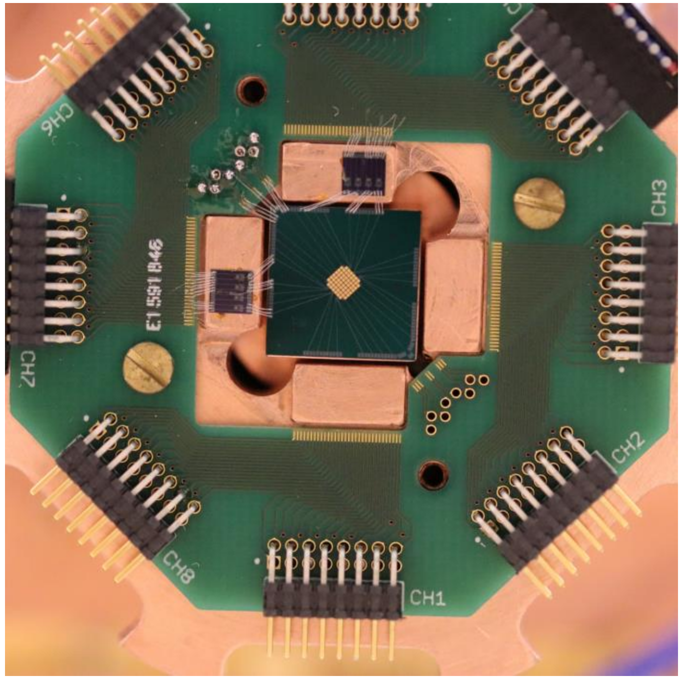
on:

es $\geq$ 0.8 meV

rst of He atoms

Detector support structure

- Support structure for „old detectors“

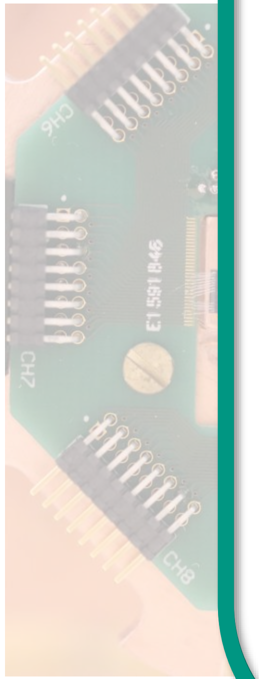


Full-surface gluing
with GE varnish

Clamping

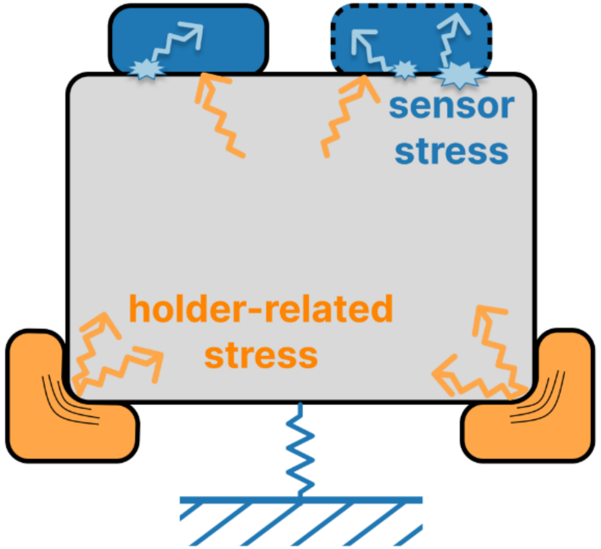
Detector support structure

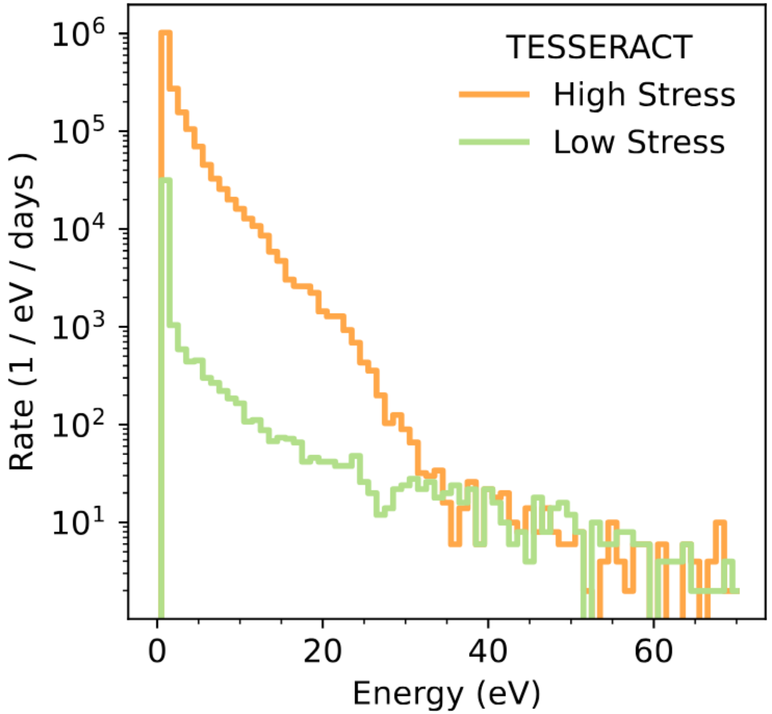
- Old holdin



Gluing

Increased LEE background due to holding stress





Baxter *et al.*, Low-Energy Backgrounds n Solid-State Phonon and Charge Detectors, arXiv:2503.08859v1 (2025)

Detector support structure

- Challenges:
  - Well-defined thermal connection
  - Supressing mechanical vibrations
  - Fixation of the wafer (for bonding, etc.)
  - Reducing holding stress

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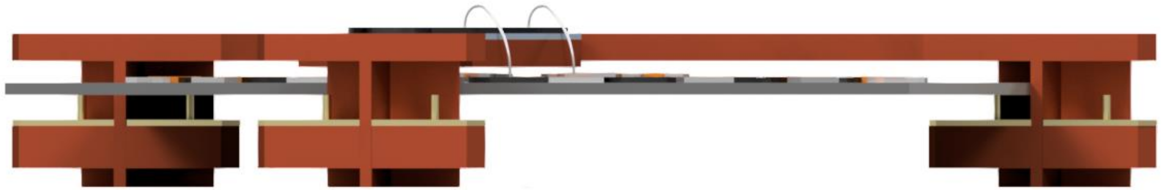
→ Gravity loaded detector holding



Detector support structure

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  - We
  - Sup
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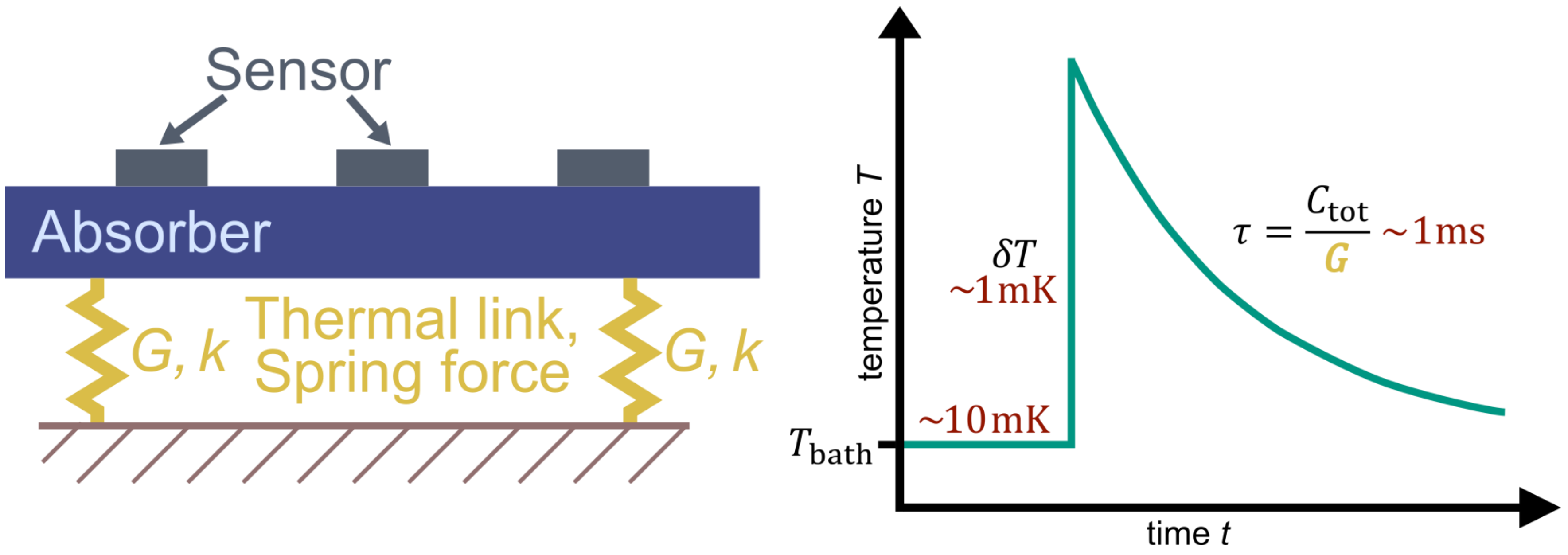
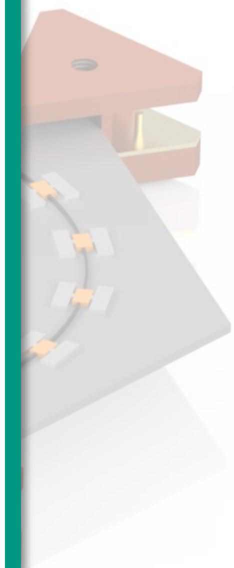
  - Rec

→ Grav

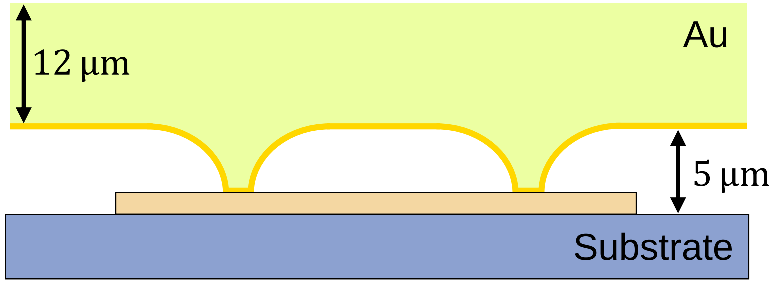
Gravity loaded holding

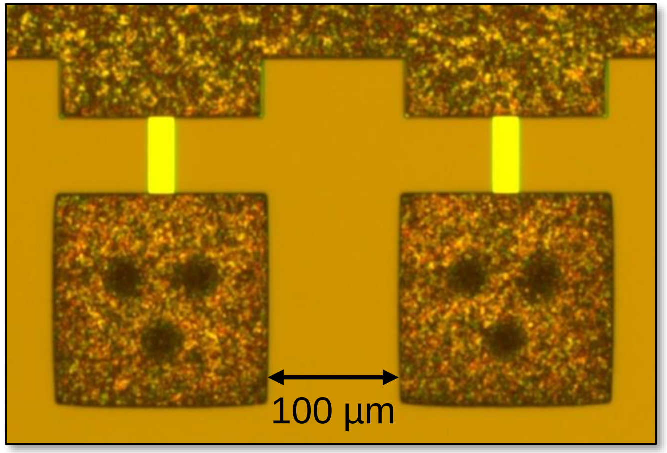


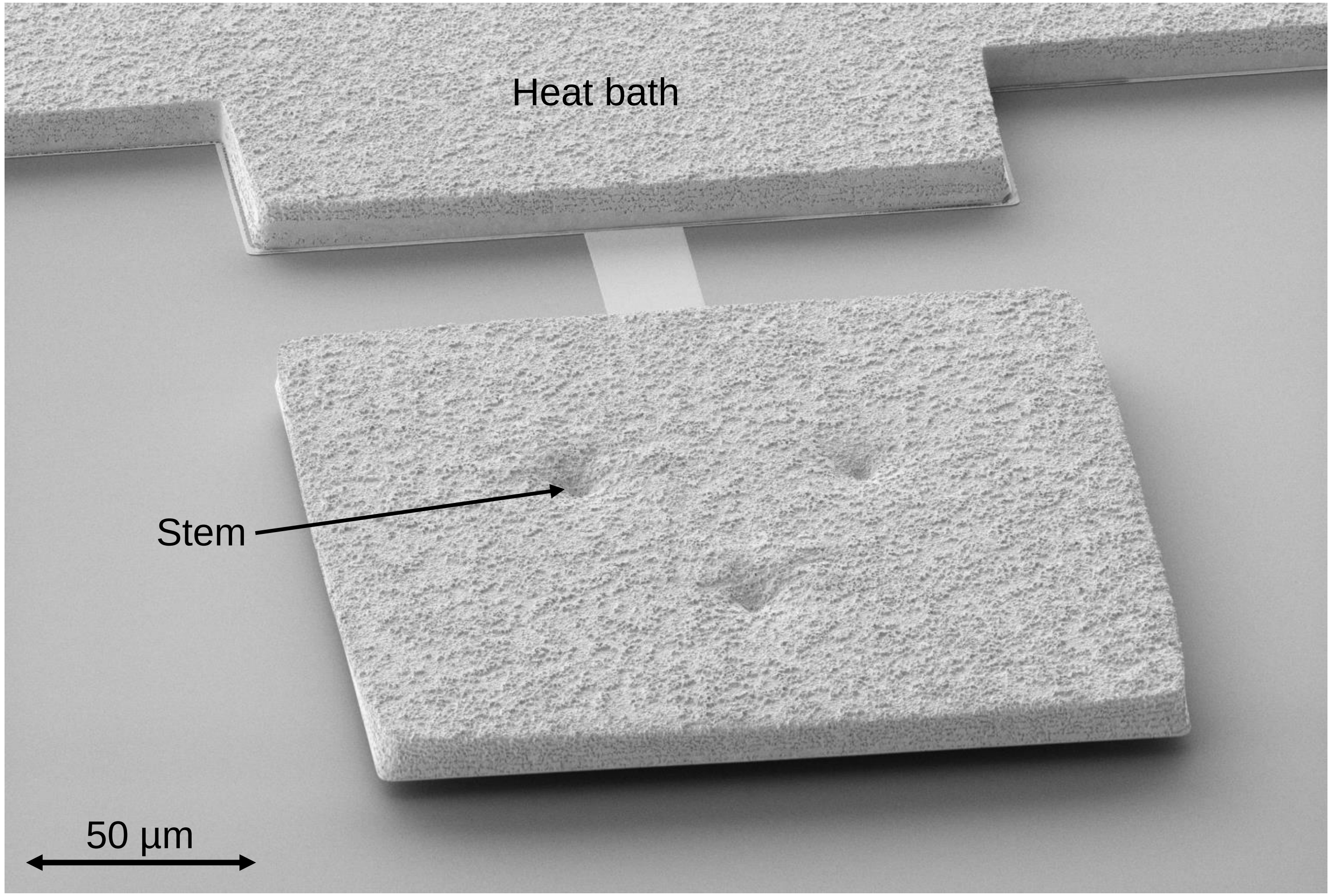
Definition of spring force and thermal coupling (and thus decay time) via gold stem geometry (diameter and height)



Absorber on gold stems (PrimA-LTD Project)

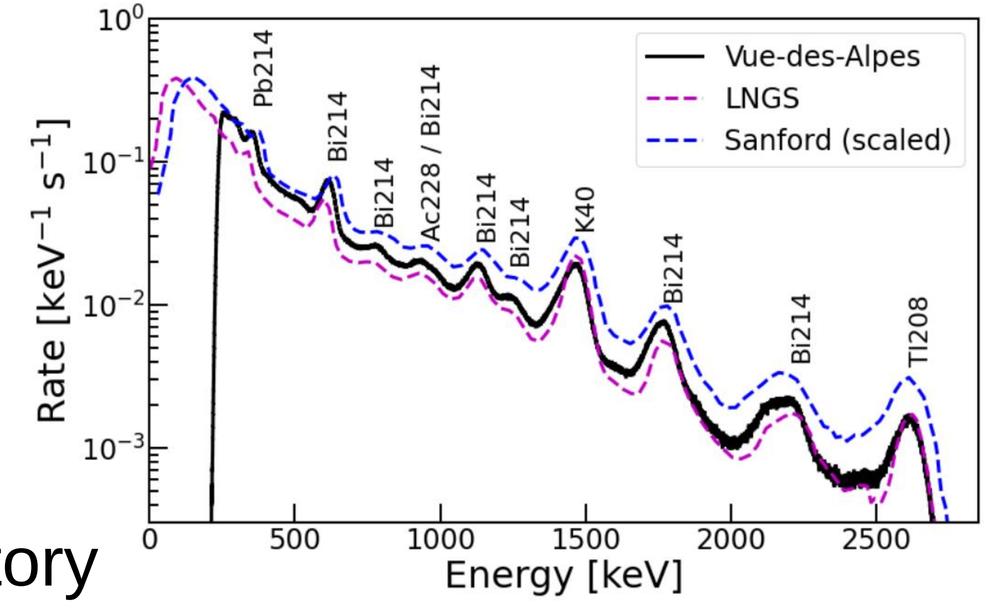






Excess quasiparticle population

- Vibration, enviromental radioactivity, IR radiation
- Cosmic rays:
  - High QP densities
  - Difficult to shield

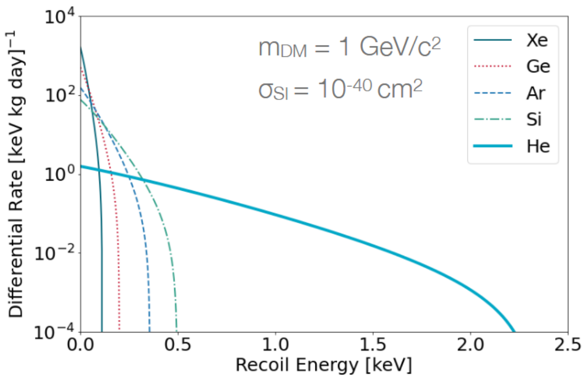


- Vue-des-Alpes (VdA) underground laboratory
  - Road tunnel (Neuchâtel and La Chaux-de-Fonds Switzerland)
  - 230 m rocks equivalent to 600 m water
  - Cosmic neutron flux reduced to zero
  - Decrease of muon flux ~ 2000
  - Gamma background surounding rocks and concrete

Summary

Superfluid helium as target material

- No interface stress
- Several signal channels



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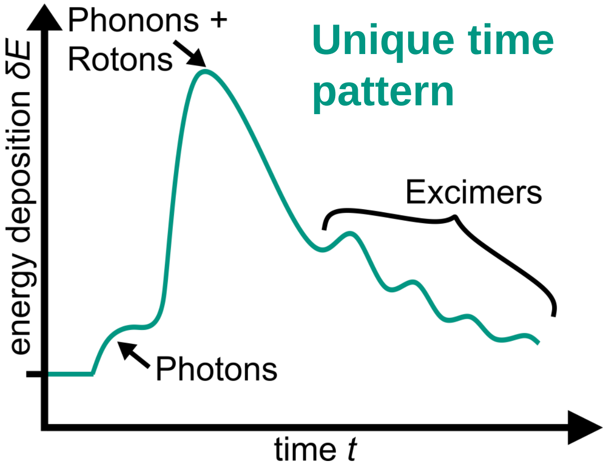

Possible sources of LEEs

- Cosmic rays
- Holding stress

Gravity loaded detector holding