The DELight experiment

***D**irect search **E**xperiment for **Light** dark matter using superfluid helium-4*

Francesco Toschi on behalf of the DELight collaboration

IDM2026 – Zaragoza, Spain

03.06.2026

The DELight collaboration

Who?

>20 scientists from 4 institutions

What?

Probing LDM below 1 GeV

How?

Using superfluid helium-4

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What?

Probing LDM below 1 GeV

How?

Using superfluid helium-4

Why superfluid helium-4?

DFG

DELight’s target material

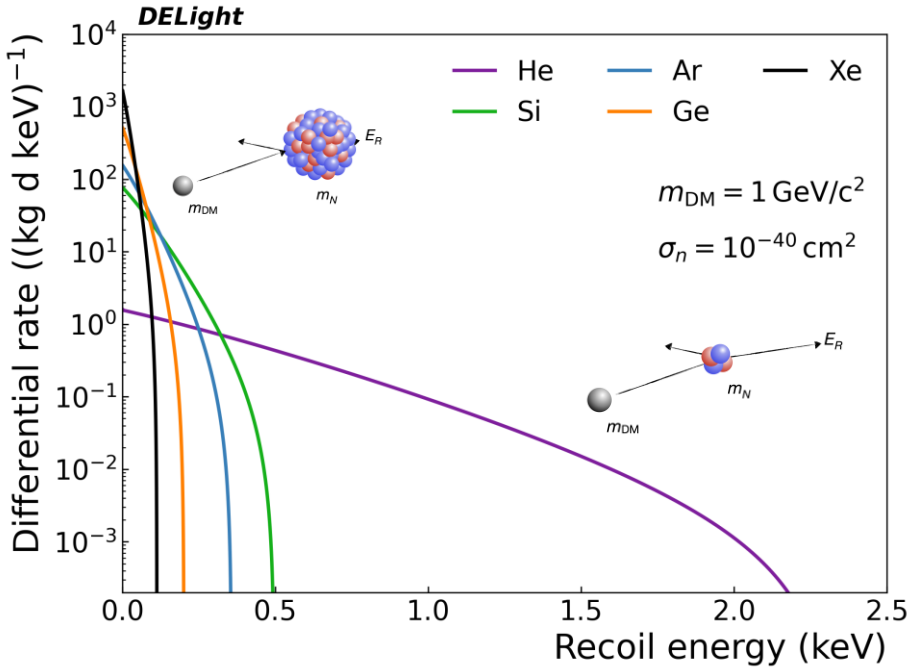
Superfluid Helium-4

DELight's target material

Superfluid Helium-4

Radiopure target material

Maximize energy transfer (kinematic matching, i.e., similar mass to DM particle)



DELight's target material

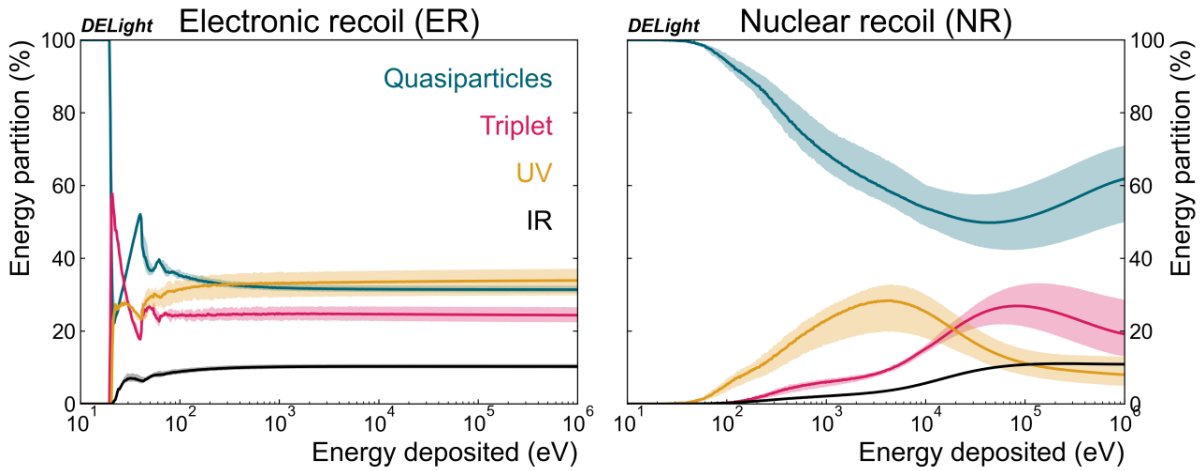
Superfluid Helium-4

Freezing out impurities @ 20 mK

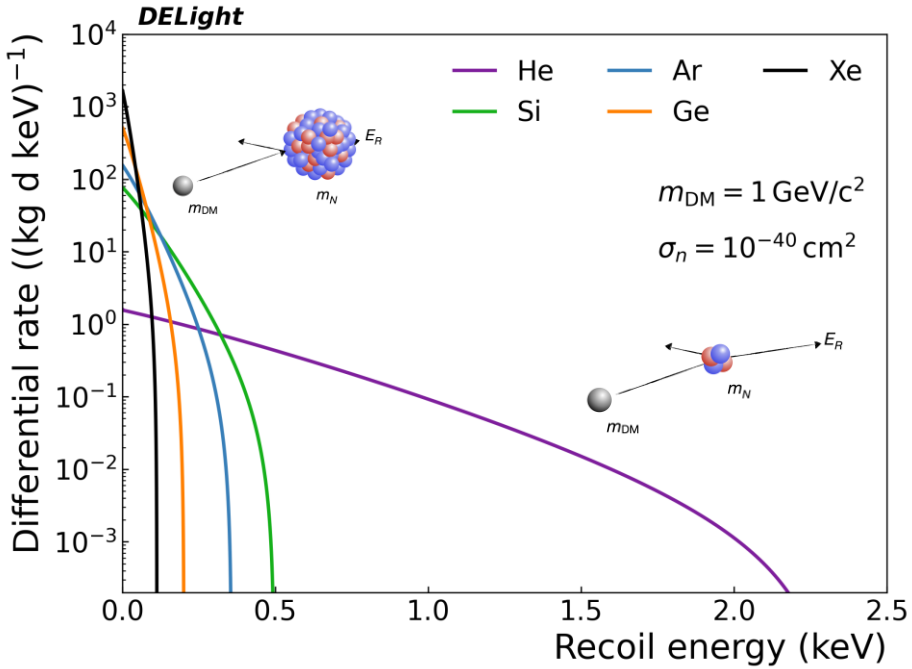
Multiple signals (ER/NR discrimination, energy and position reconstruction, etc.)

Radiopure target material

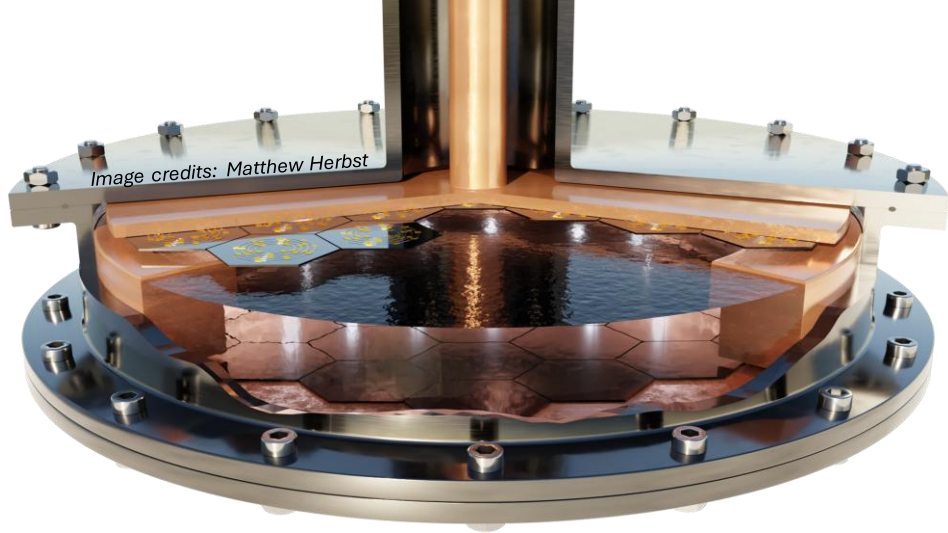
Maximize energy transfer (kinematic matching, i.e., similar mass to DM particle)

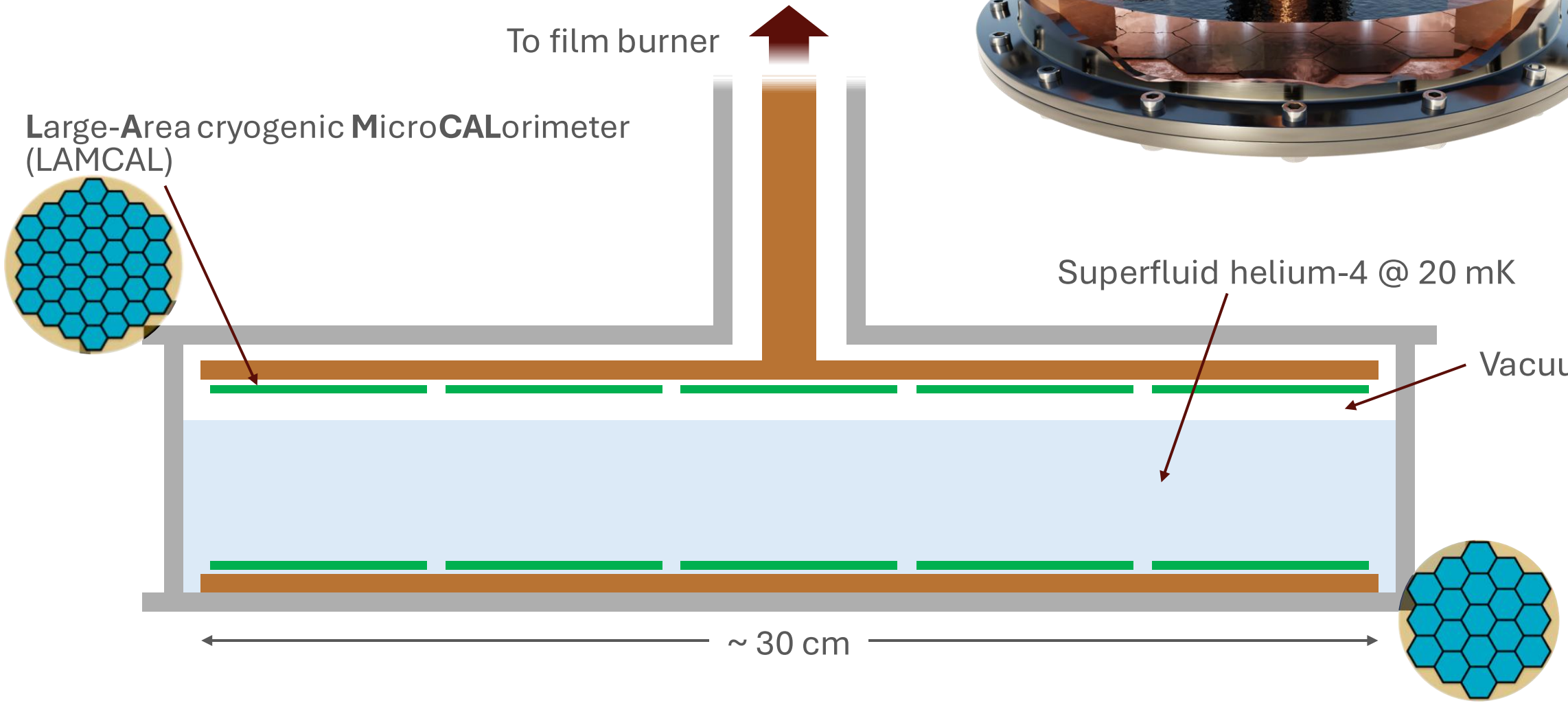


Phys. Rev. D **111**, 032013

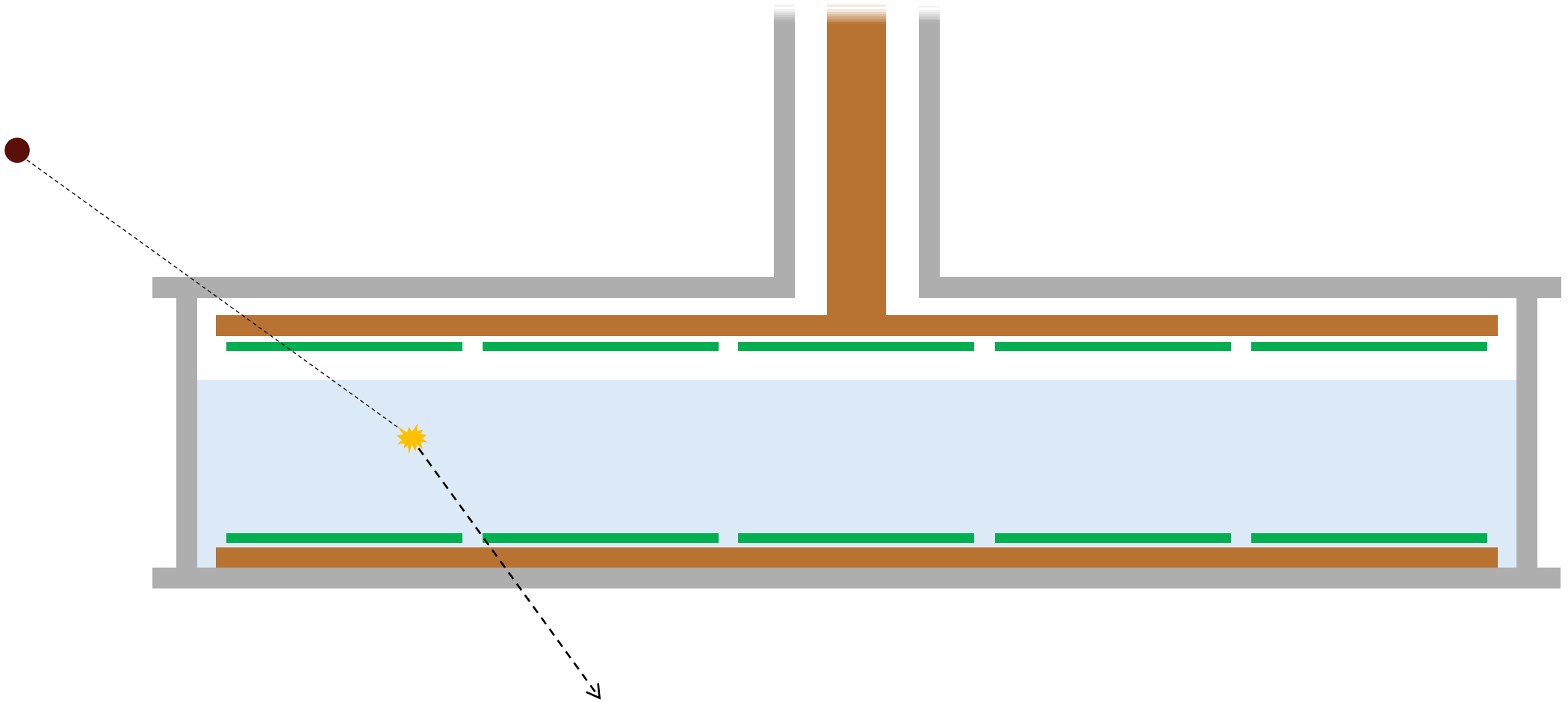


The DELight detector





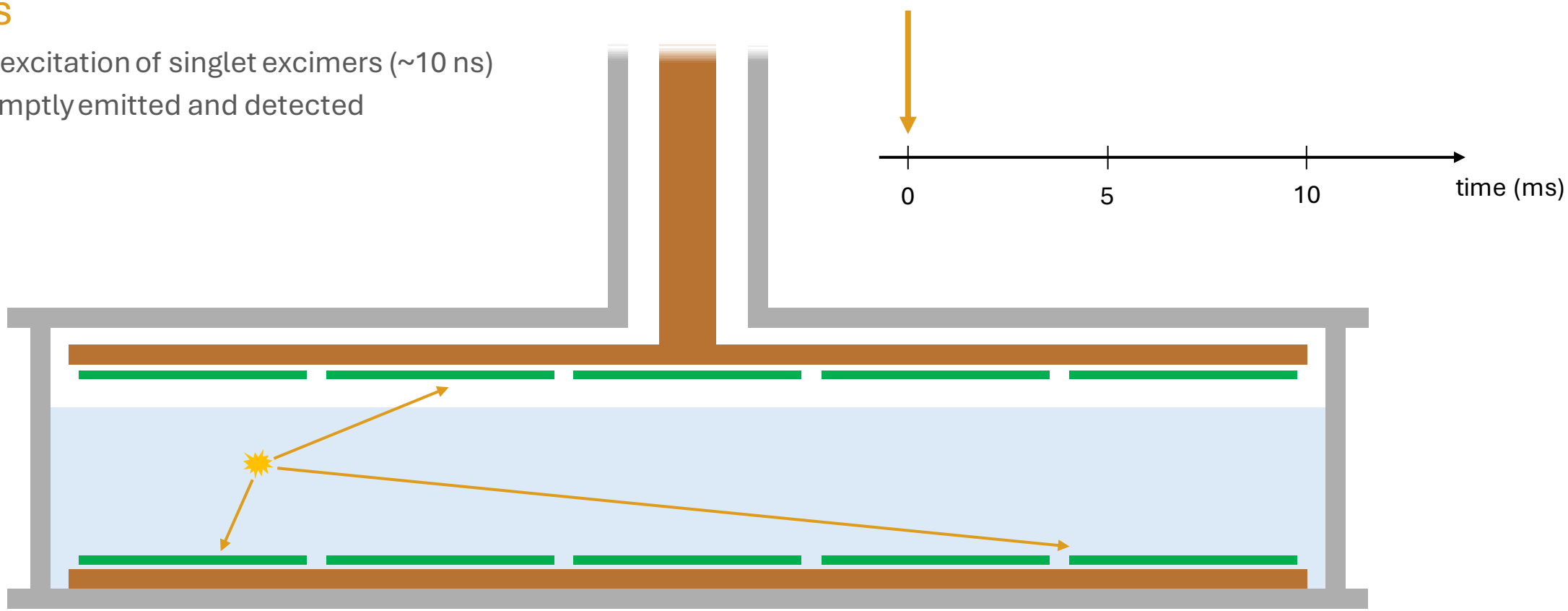
Working principle



Working principle

Photons

- De-excitation of singlet excimers (~10 ns)
- Promptly emitted and detected

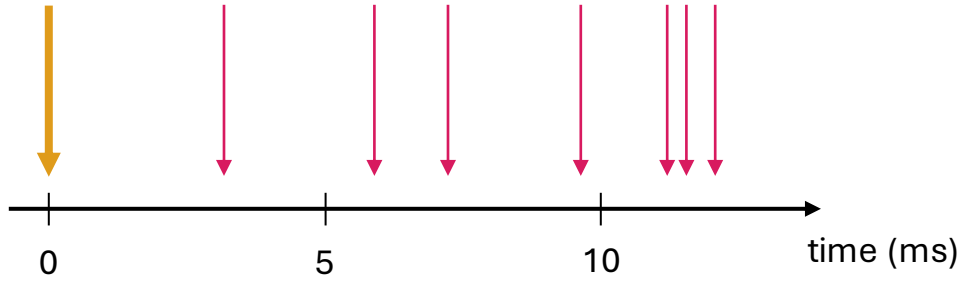


Working principle

Photons

Triplets

- De-excitation of triplet excimers (~13 s)
- Slow ballistic propagation
- Forced decay when reaching a surface



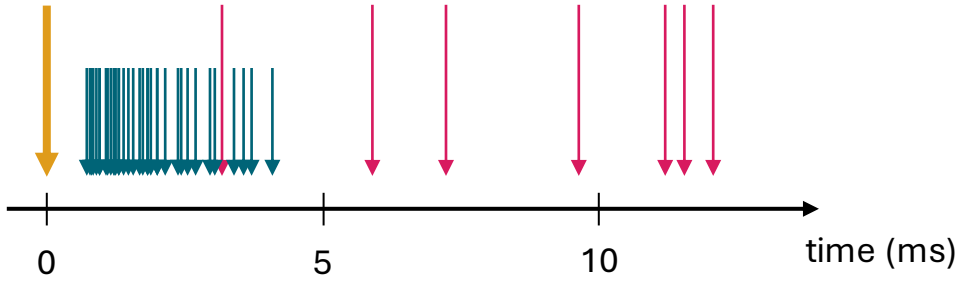
Working principle

Photons

Triplets

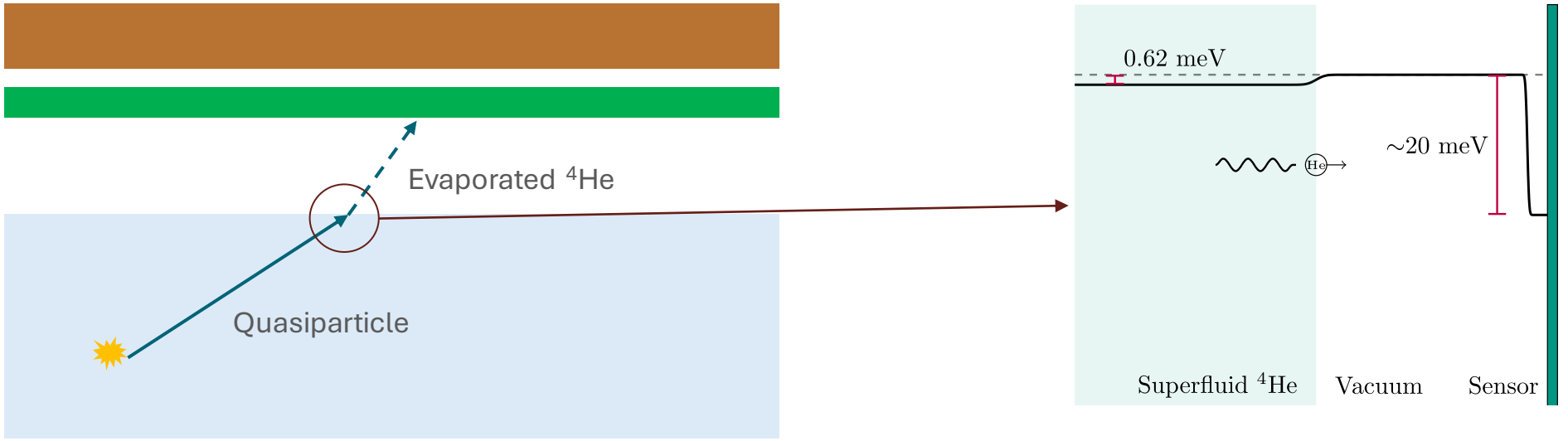
Quasiparticles

- Propagated ballistically and reflected
- Detected ONLY via quantum evaporation



Quantum evaporation

- Quasiparticle energy is larger than He-He binding energy
  - Evaporation of single He atom!
- He adsorbed onto LAMCAL surface
  - Noise-free physical signal amplification as $E_{LAMCAL\text{-}He} \sim 20 \times E_{He\text{-}He}$ for sapphire (Al_2O_3)



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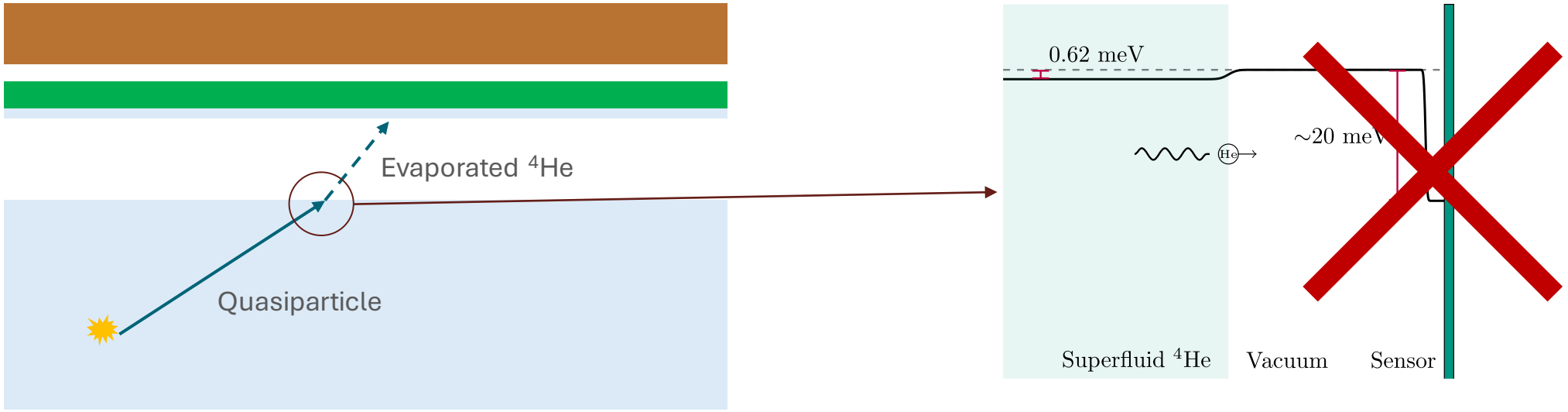

Quantum evaporation

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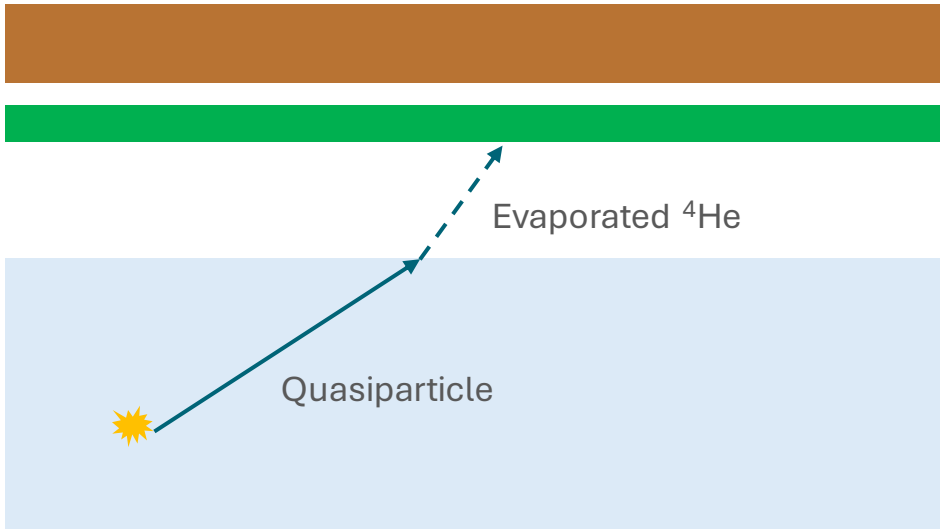
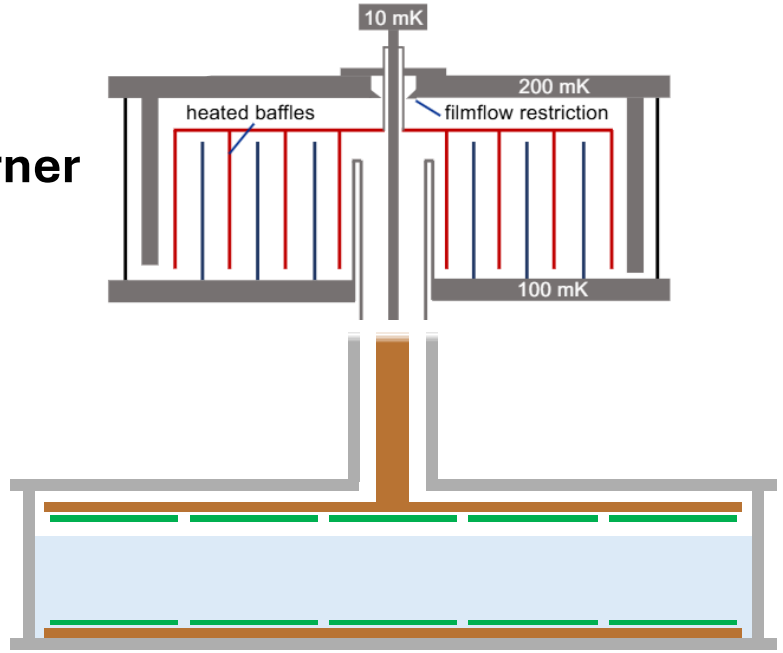
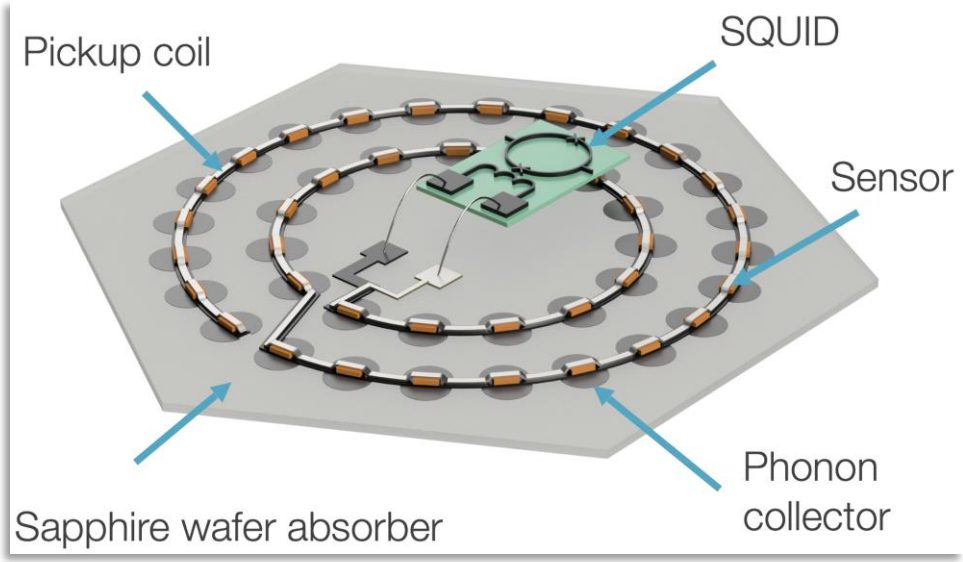


Film burner

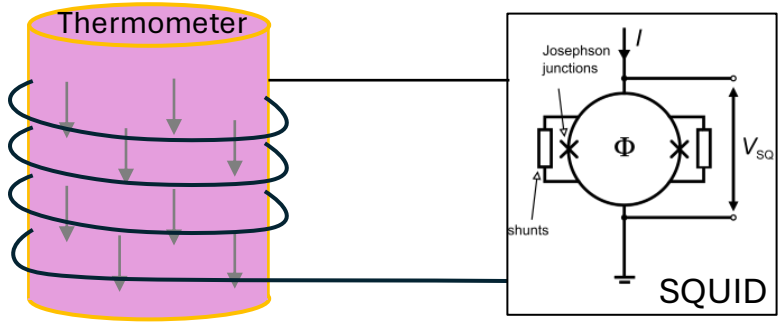


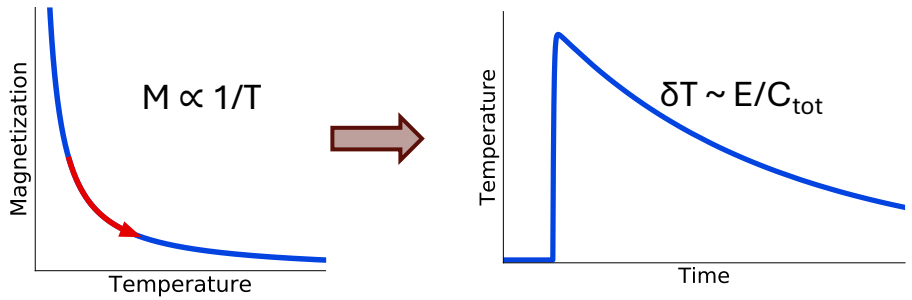
LAMCAL

- Large-area cryogenic microcalorimeter
  - Sapphire wafer instrumented with MMCs
  - O(1 eV) expected resolution → **20 eV NR threshold**



Magnetic **M**icro**C**alorimeter





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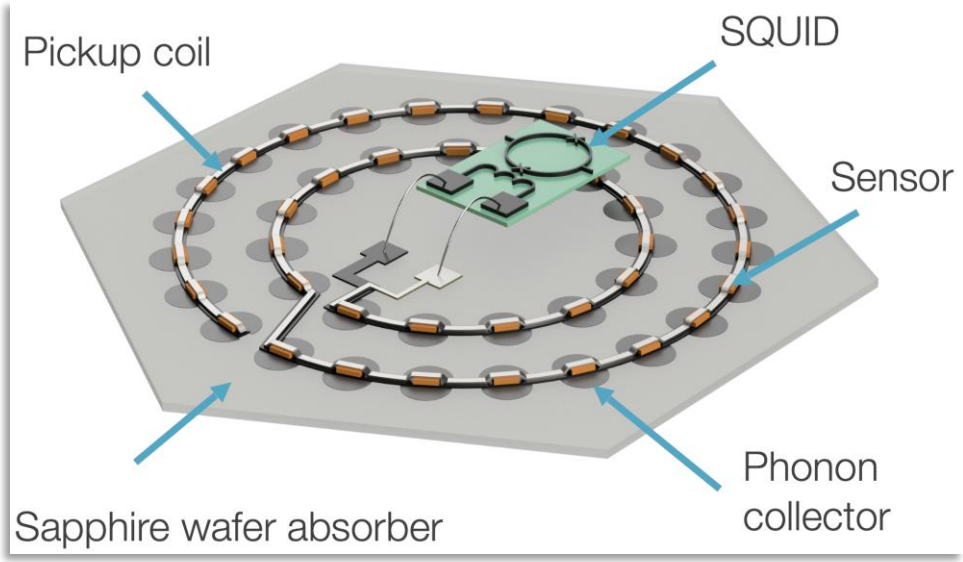

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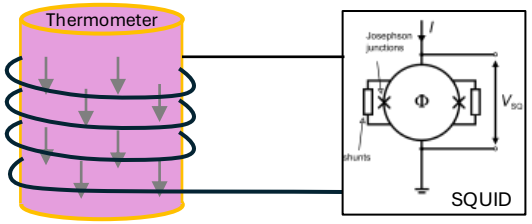
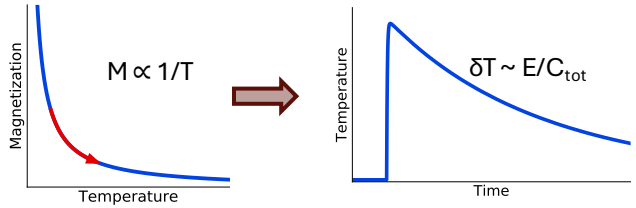
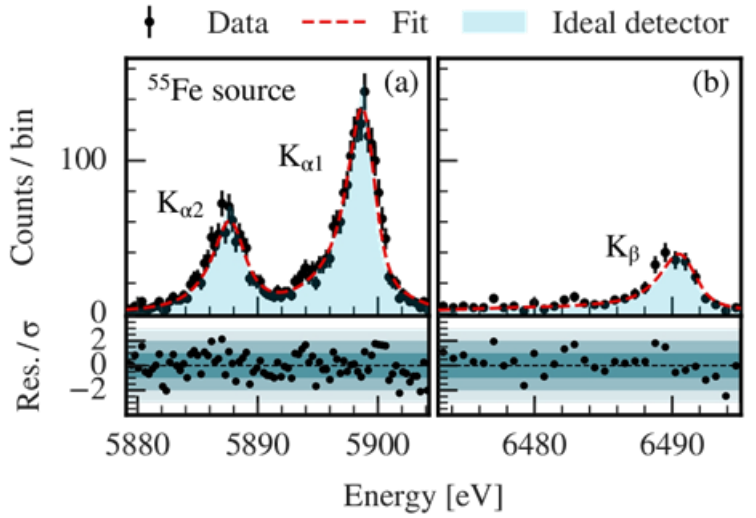




World-best resolving power for x-rays:

ΔE_{FWHM} = **1.25(18) eV** @ 5.9 keV (^{55}Fe source)



Phys. Rev. D 109, 043035 (2024)
Appl. Phys. Lett. 124, 032601 (2024)

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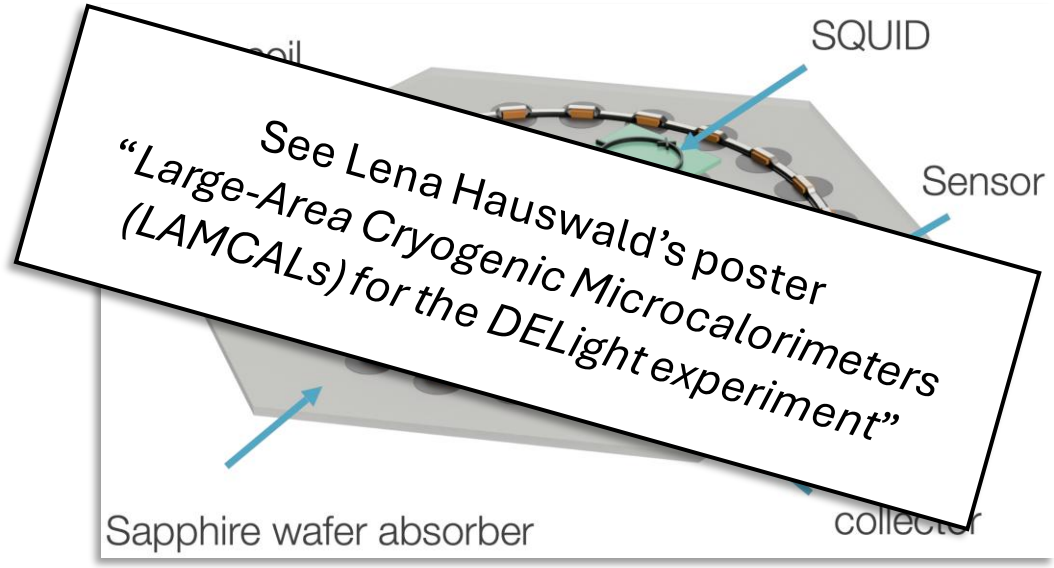
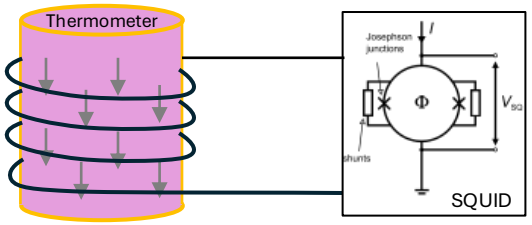
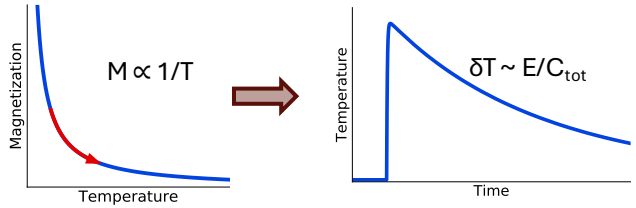


See Lena Hauswald's poster
"Large-Area Cryogenic Microcalorimeters (LAMCALs) for the DELight experiment"

Magnetic **M**icro**C**alorimeter





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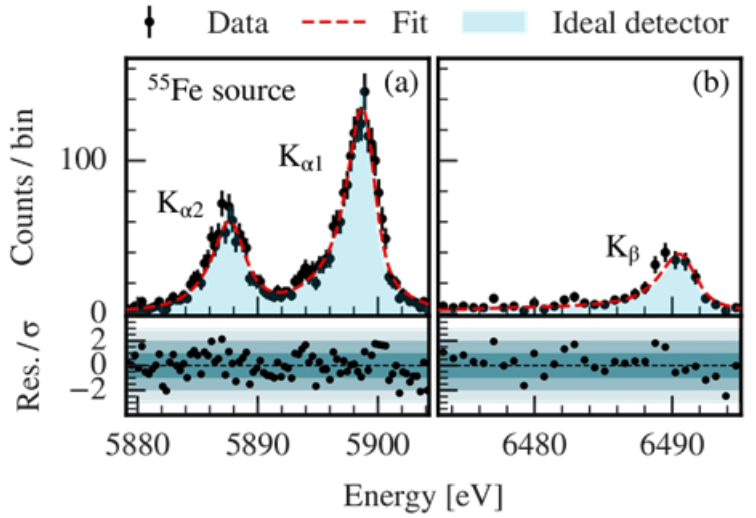

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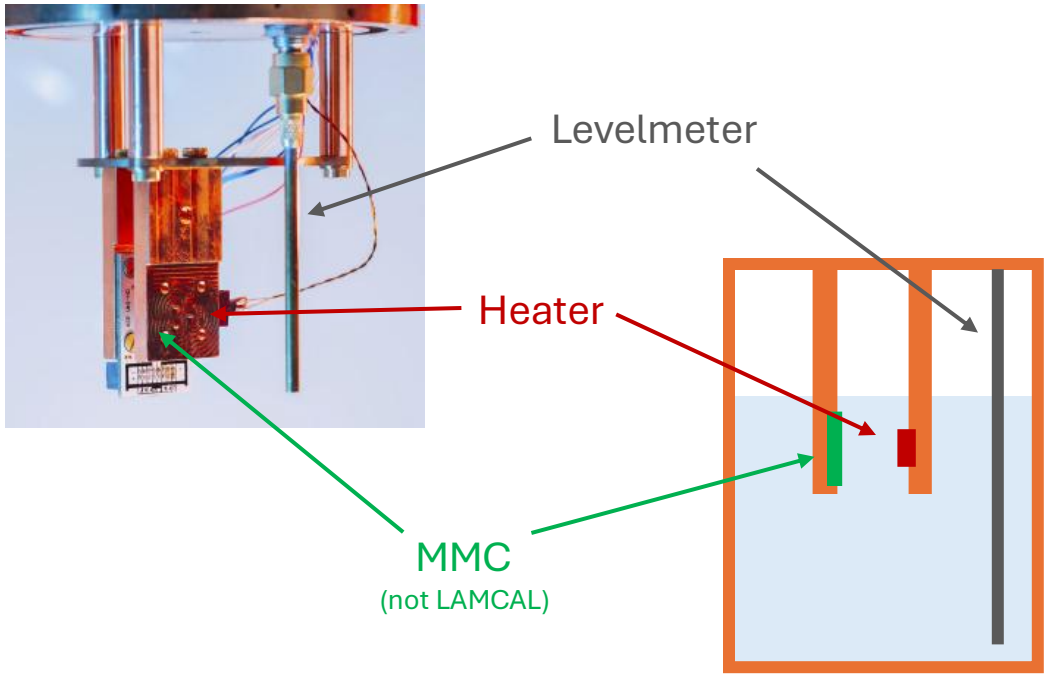
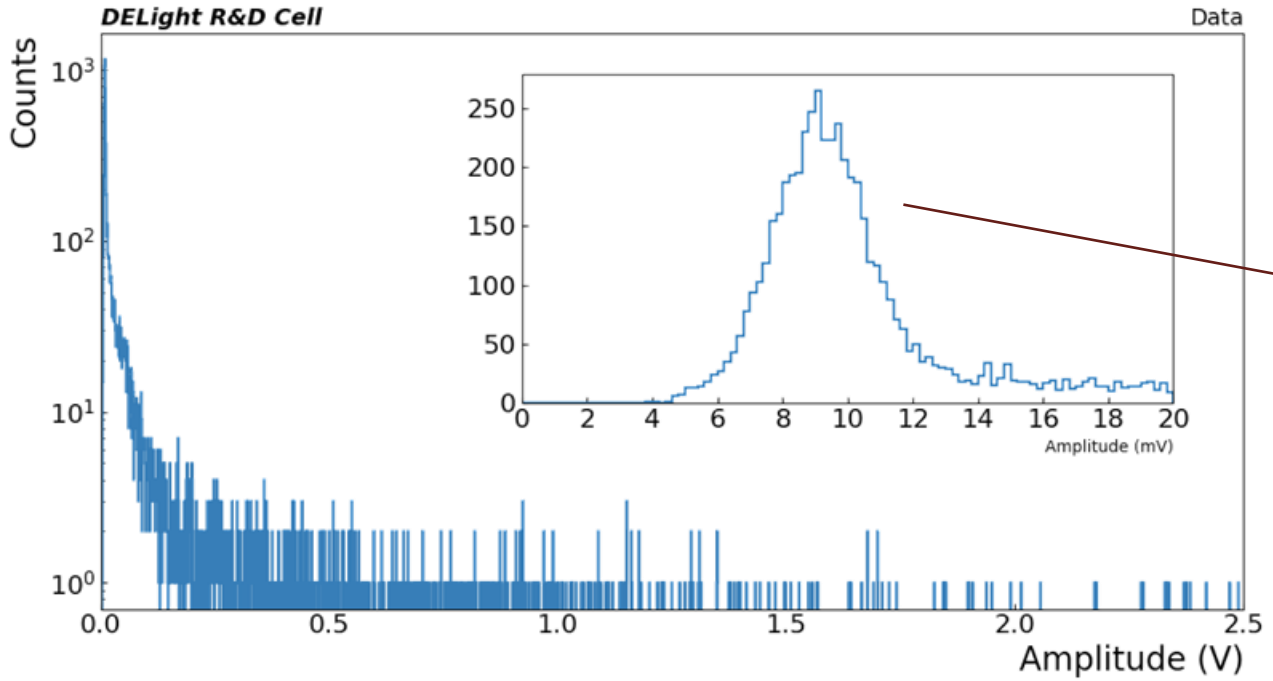
Ongoing R&D

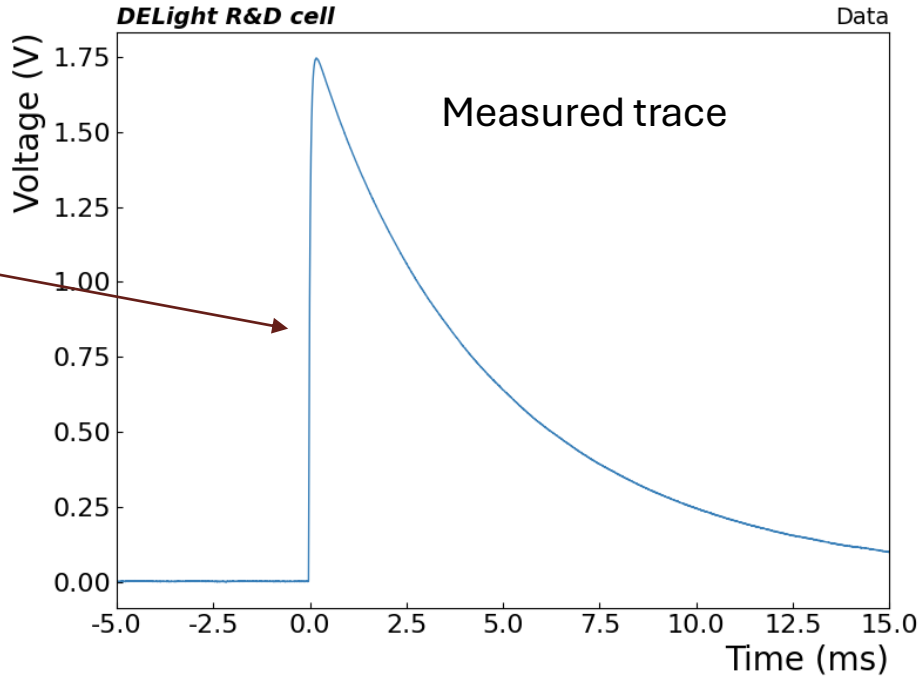
- R&D cell in operation in Heidelberg
- Filled with helium @ 15 mK
- Measurement of muon signals in helium using MMC



First measurements

- No calibration source
- Muon spectrum with peak expected at *O*(100 keV)
- Ongoing simulations to understand collection efficiencies





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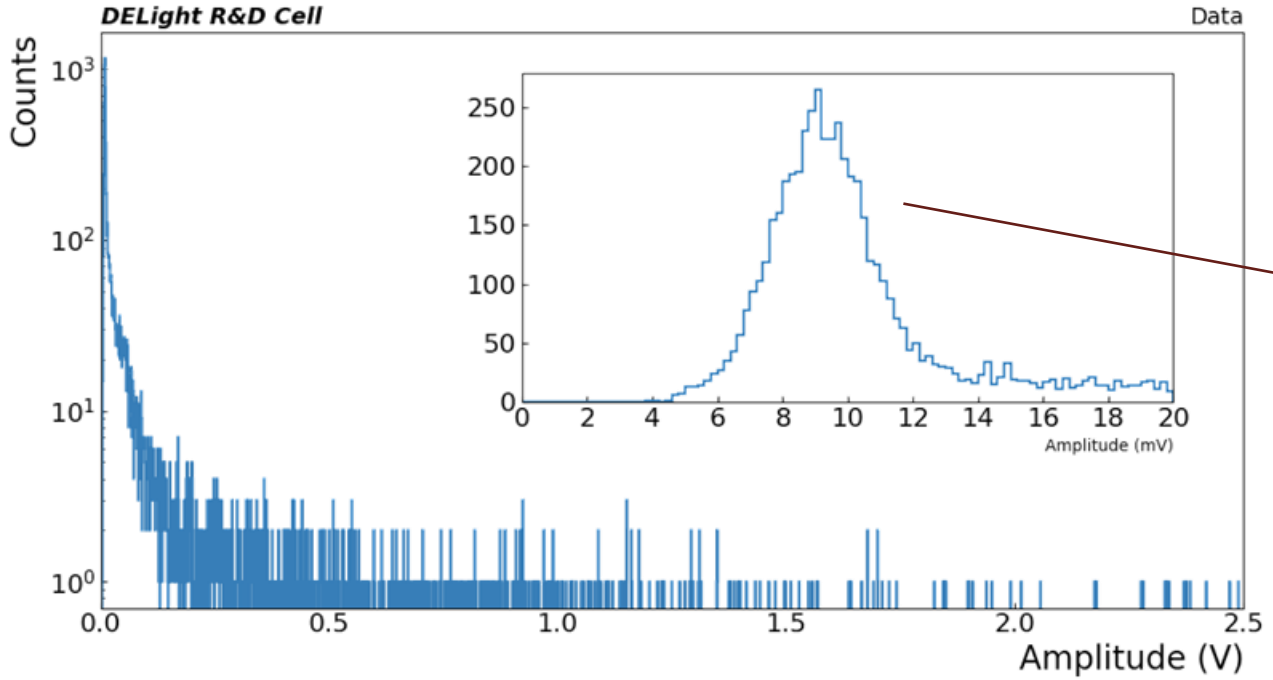
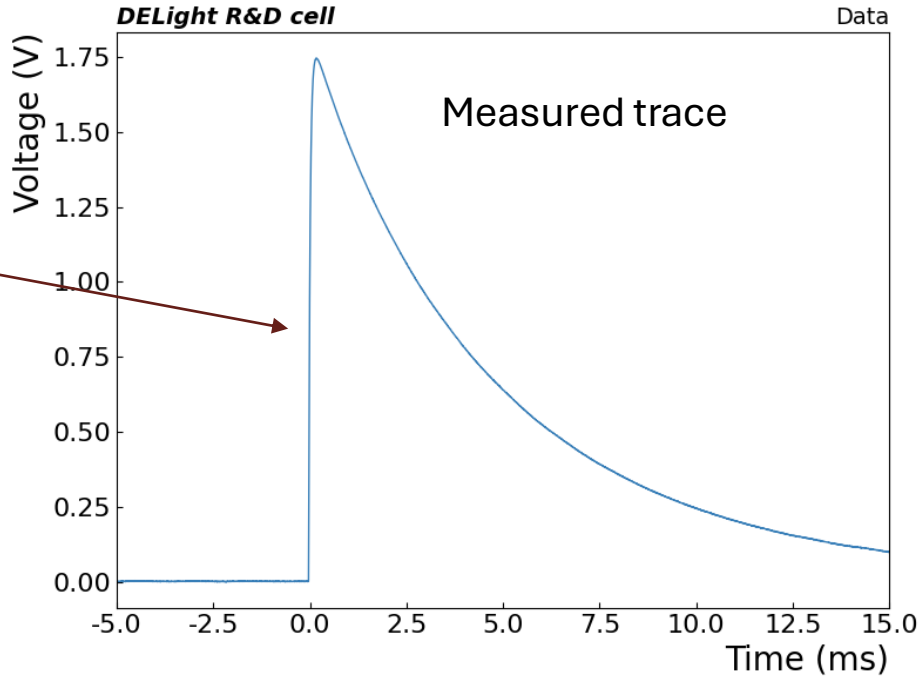
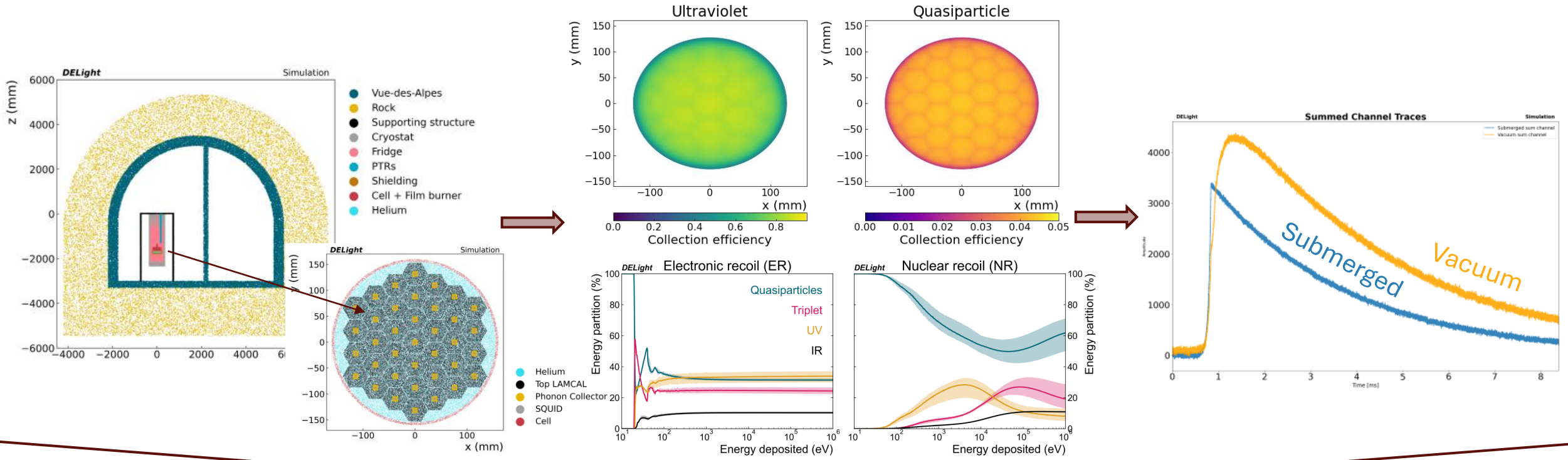
See Anna Bertolini's talk
"Towards the DELight Experiment: First Results from a Superfluid Helium R&D Cell"





Simulations

- Geant4 model of preliminary geometry and laboratory
- Implementation of signal propagation (optical photons and quasiparticles)
- Full chain: from energy deposit to expected trace

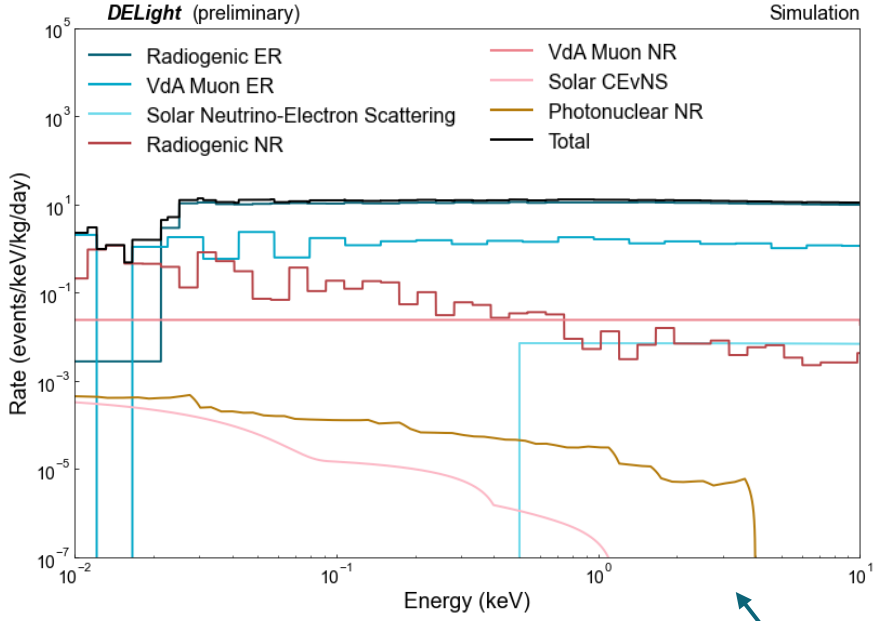


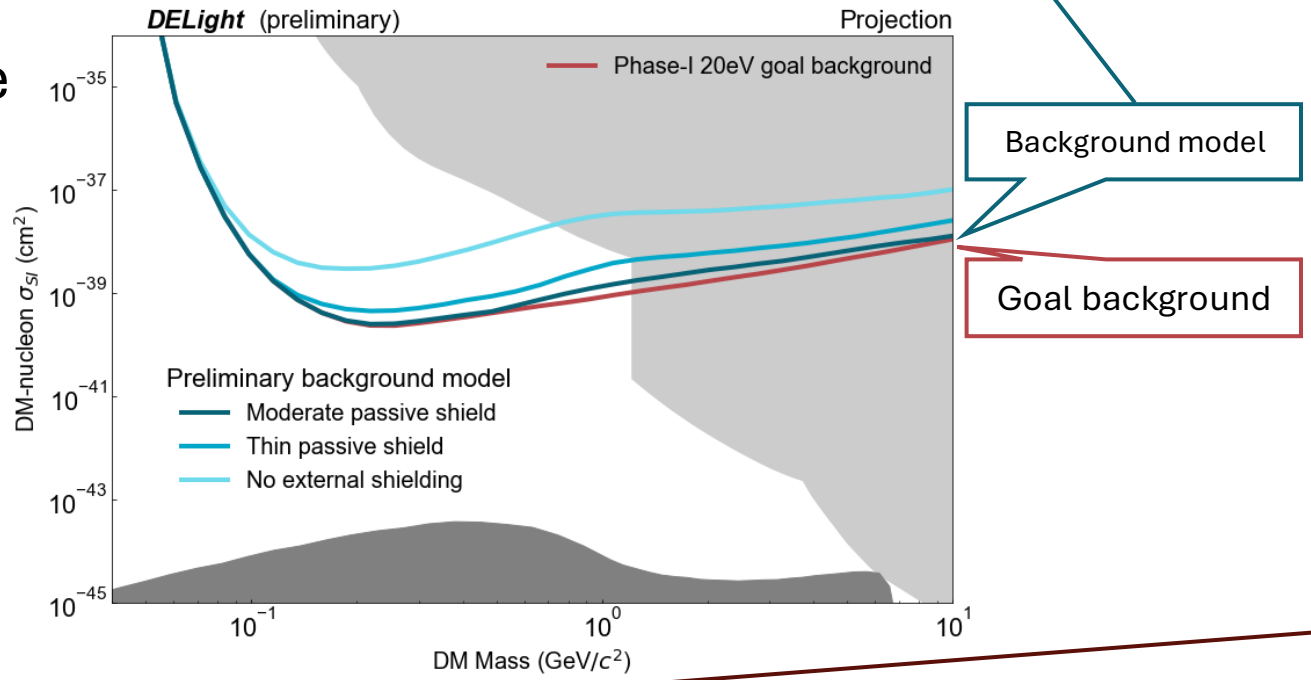
Phys. Rev. D **111**, 032013

Sensitivity projections

- Comprehensive background model
- Sensitivity via PLR method
  - Considering different scenarios
- Leading results for just **1 kg·d** exposure
- No ER/NR discrimination considered

And more possibilities (e.g., Migdal)

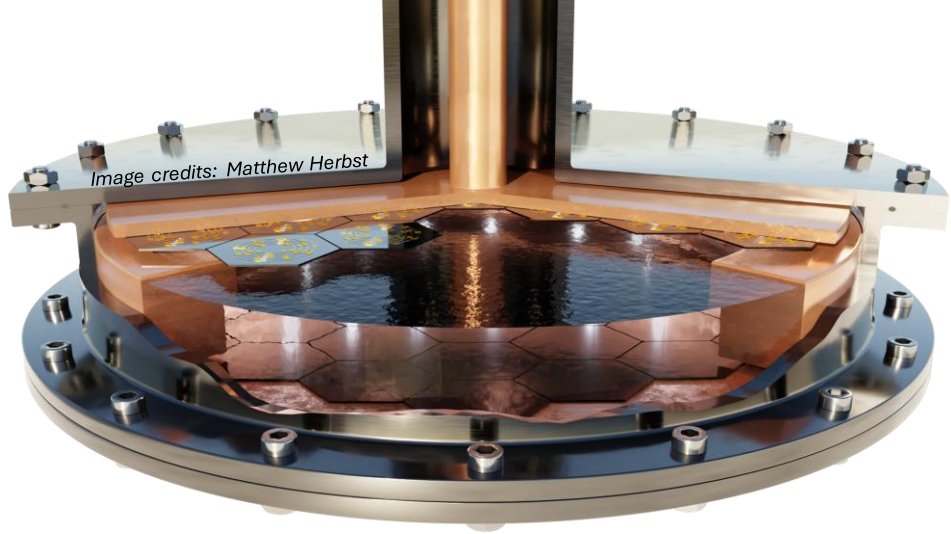


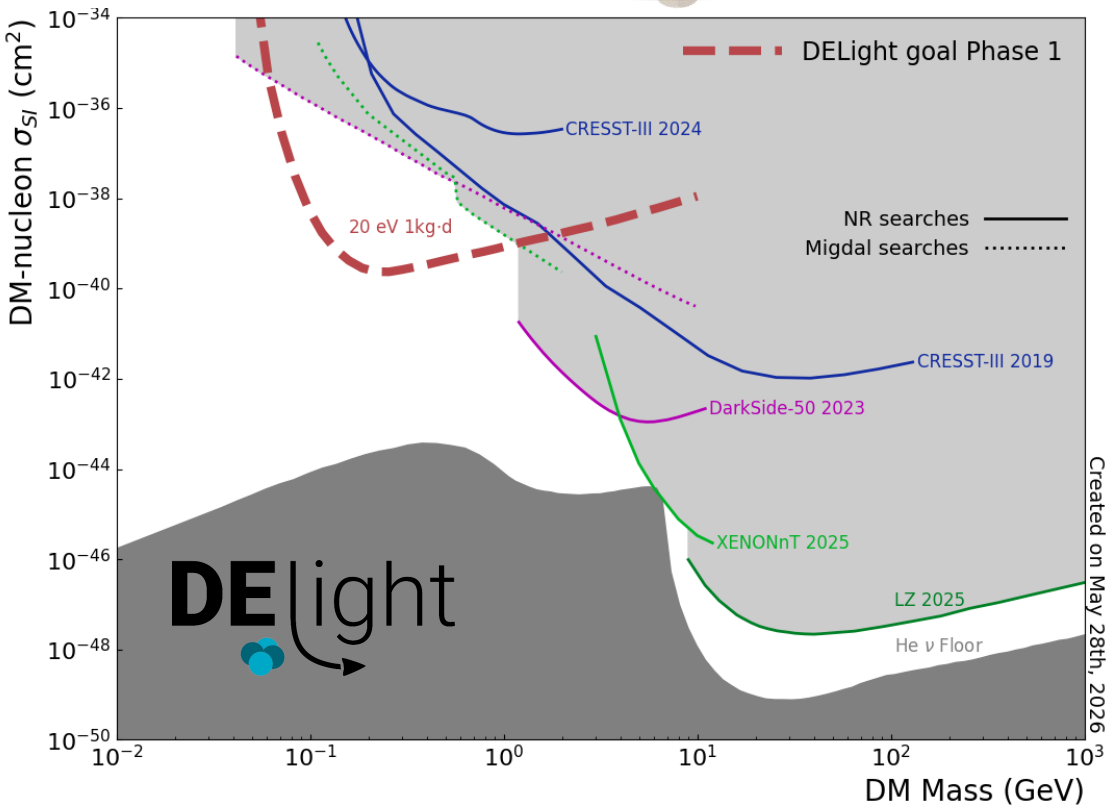


Summary

- DELight is funded and in its design phase
  - Currently operating demonstrator and R&D

- **Phase-I**
  - 20 eV threshold
  - 1 kg·d exposure (~1 week)
  - Already probing new parameter space



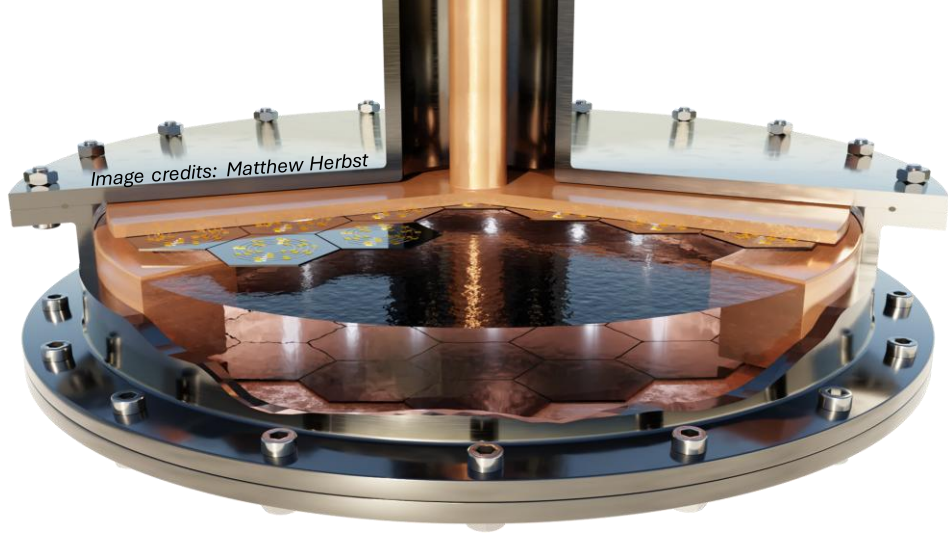


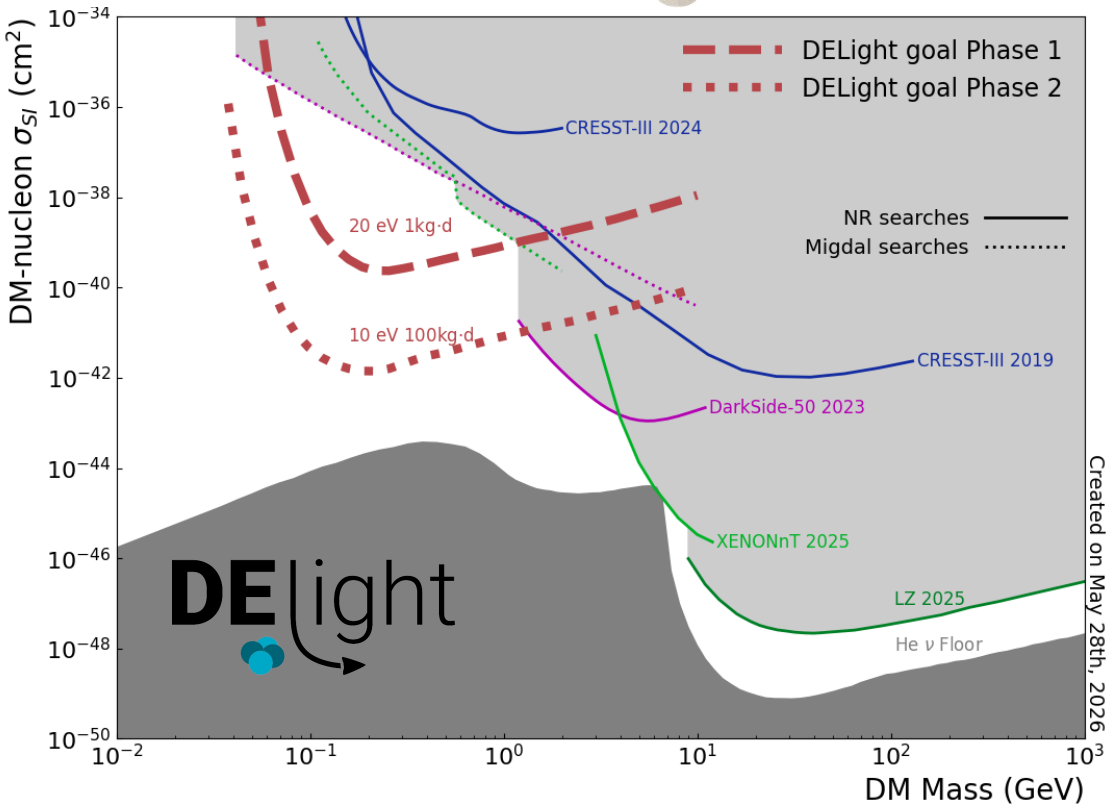
Summary and the future

- DELight is funded and in its design phase
  - Currently operating demonstrator and R&D

- **Phase-I**
  - 20 eV threshold
  - 1 kg·d exposure (~1 week)
  - Already probing new parameter space

- **Phase-II**
  - 10 eV threshold
  - ~100 kg·d exposure
  - Closer to neutrino fog!

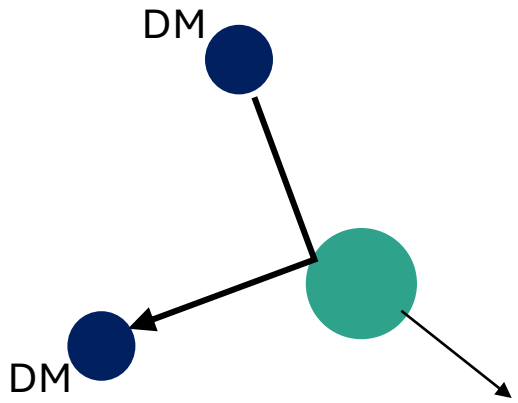


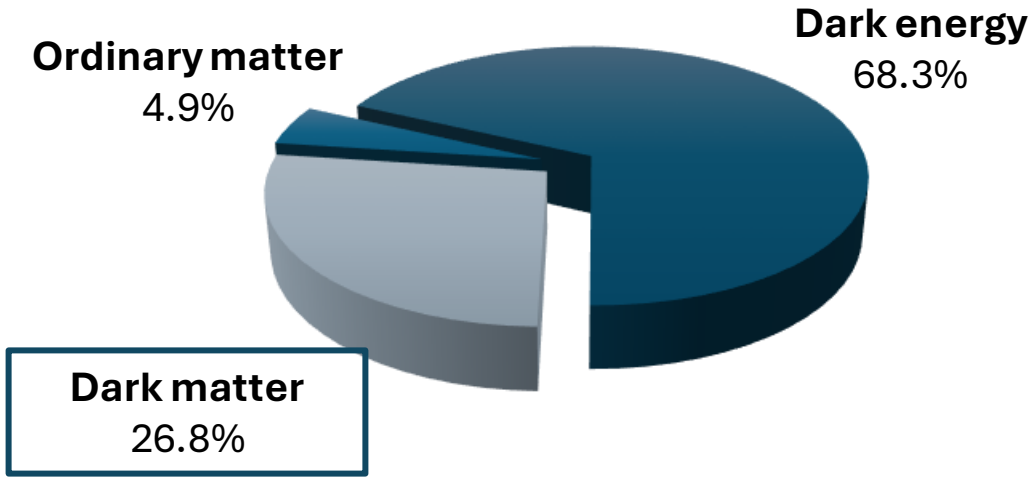


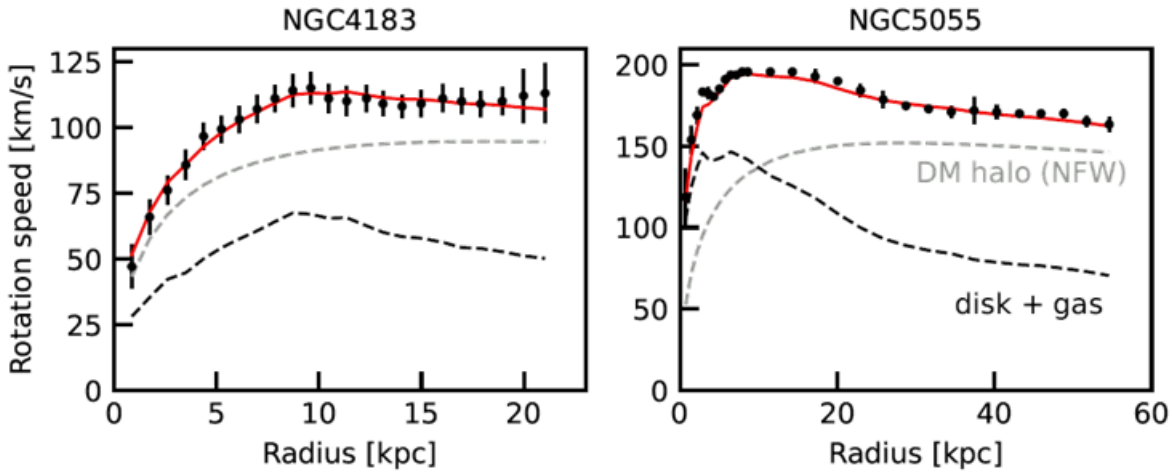
Backup slides

Dark matter

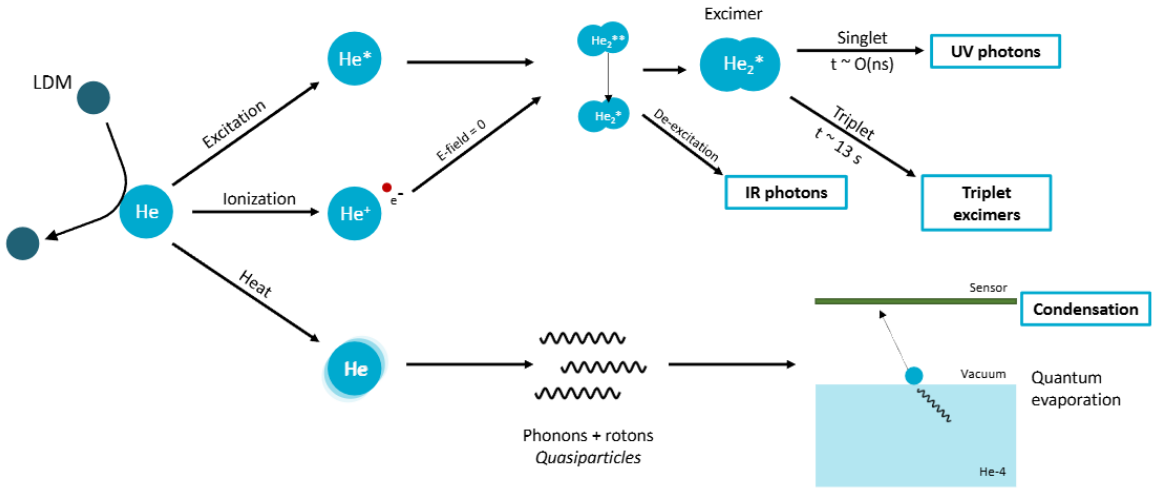
- No electromagnetic interaction → **dark**;
- Evidences of gravitational nature → **massive**;
- No particle candidate in SM → **BSM physics**;
- Direct searches for DM-nucleus scattering.







Signal in superfluid helium-4



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- Energy deposit in helium
  - Excitations, ionizations, elastic scatterings
- Response of helium
  - Excimers, photons, quasiparticles

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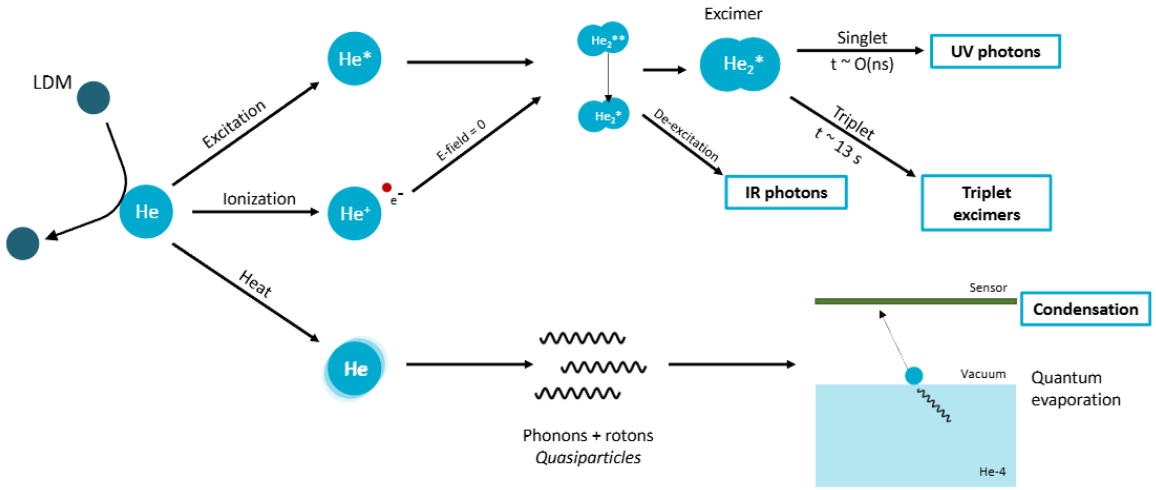

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- Known cross sections
- Microphysics assumptions
- Monte Carlo approach

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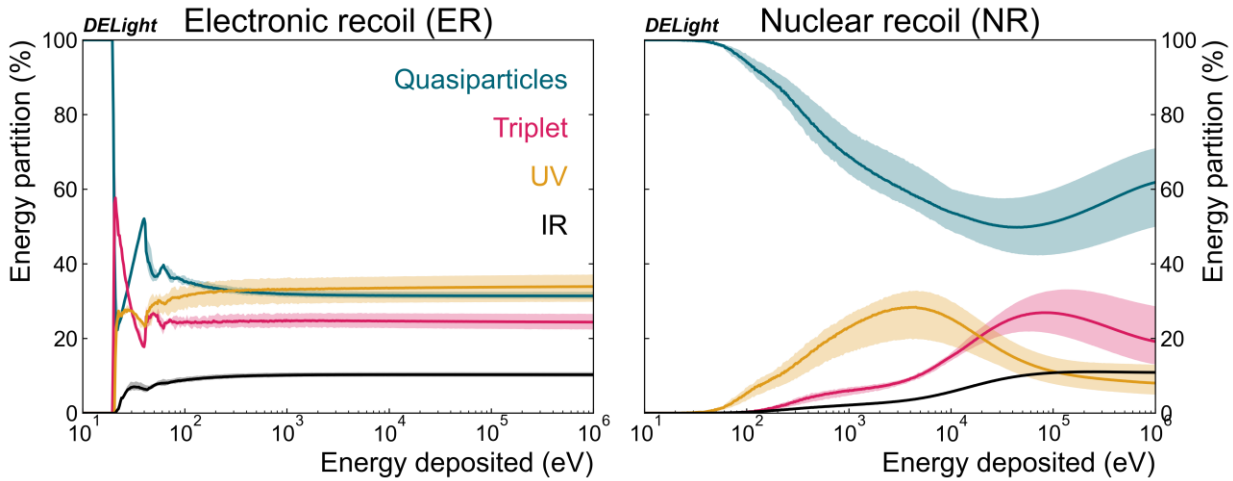

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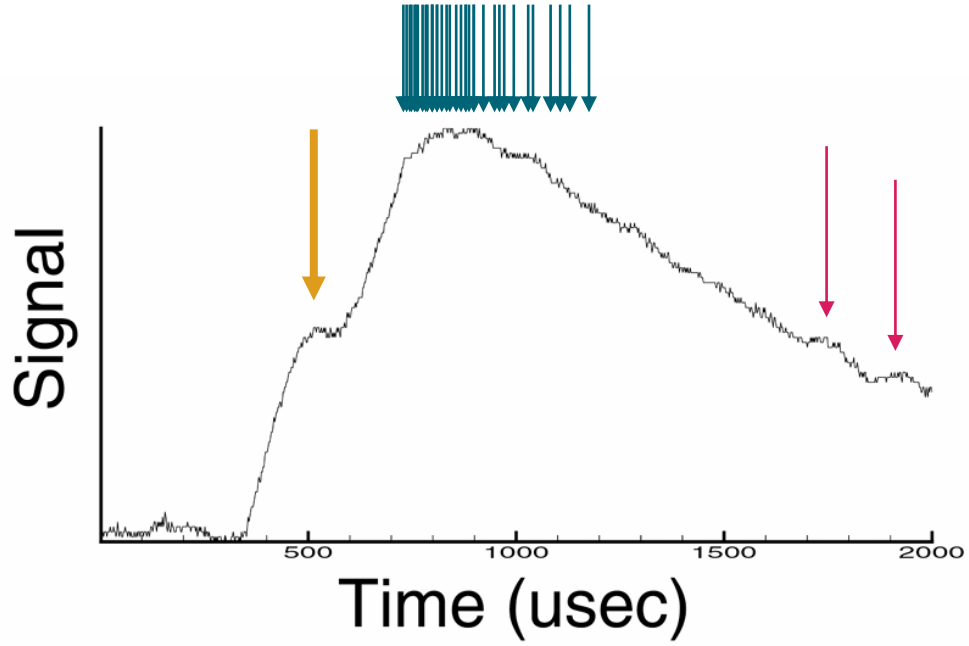
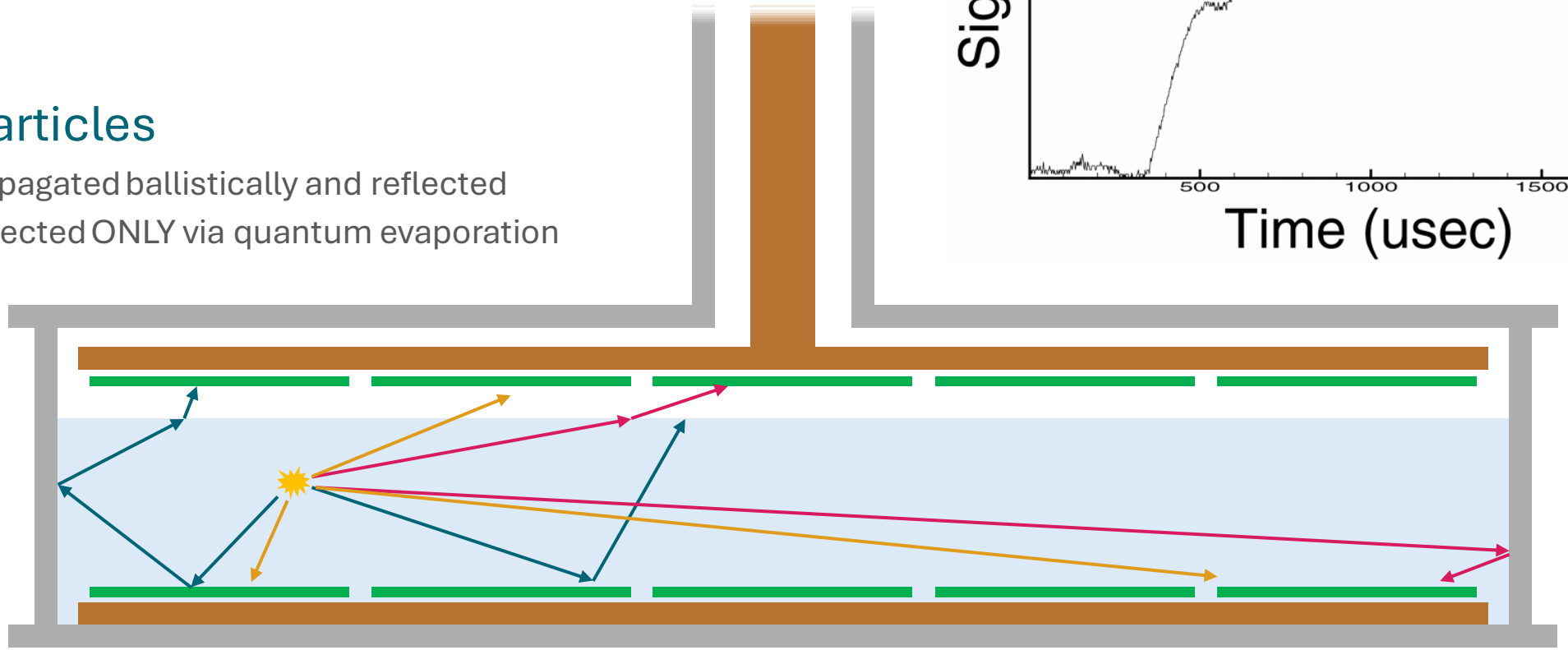
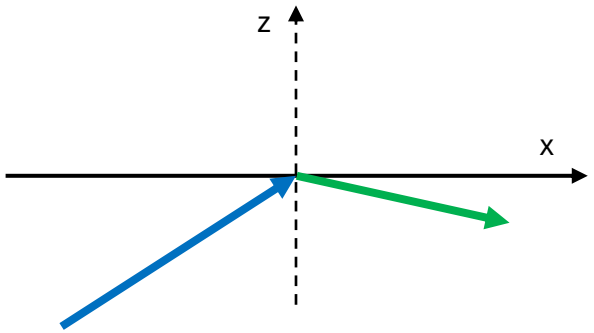


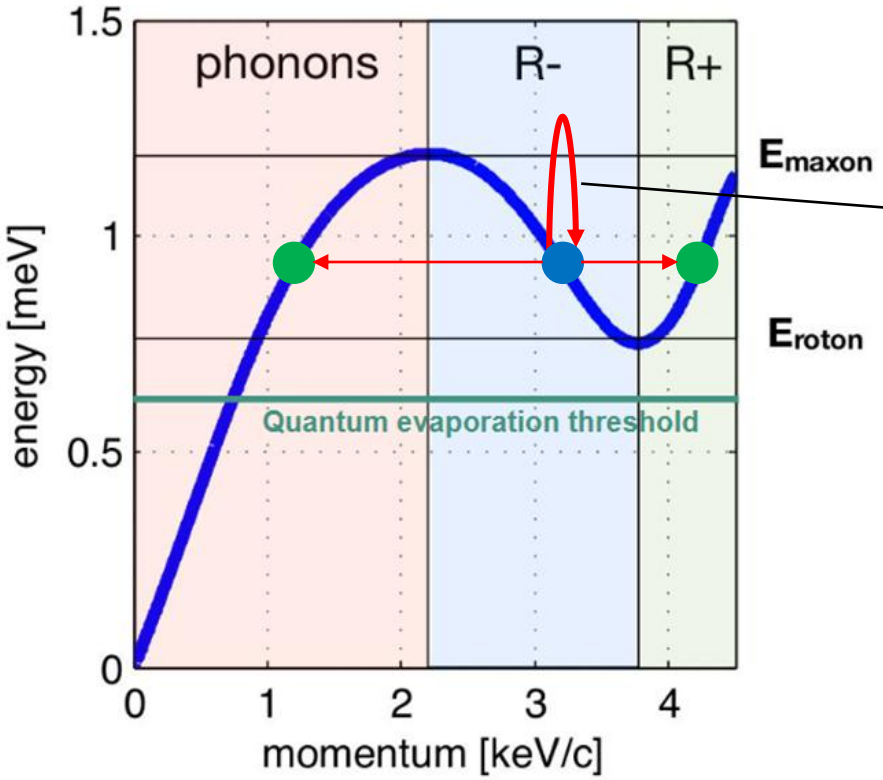


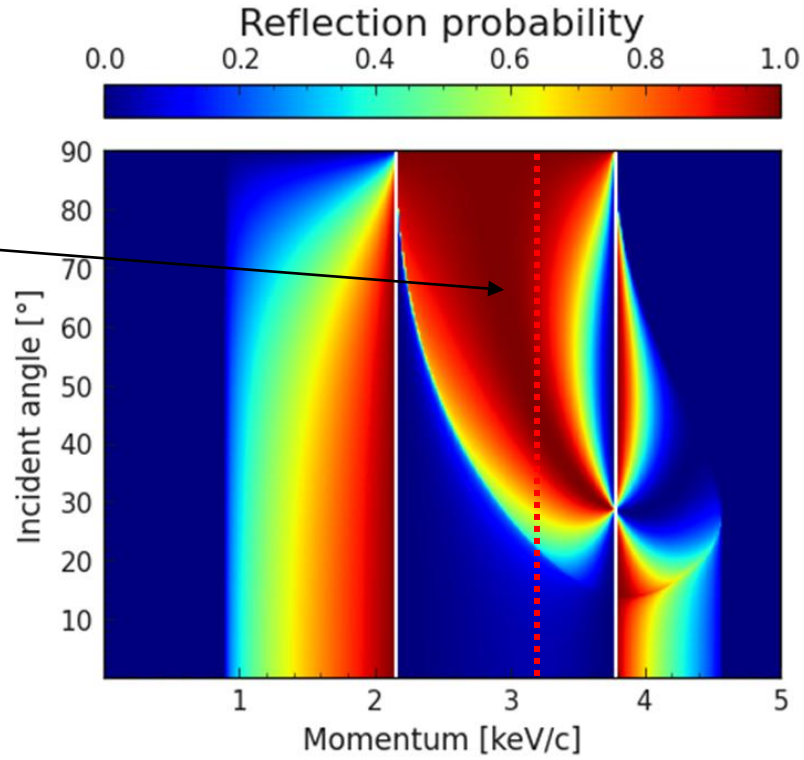
Adams et al., *J. Low Temp. Phys.* **113**, 1121 (1998)

Signal propagation – quasiparticles



$$\begin{cases} E^i = E^f \\ \vec{p}_{\parallel}^{\,i} = \vec{p}_{\parallel}^{\,f} \end{cases}$$

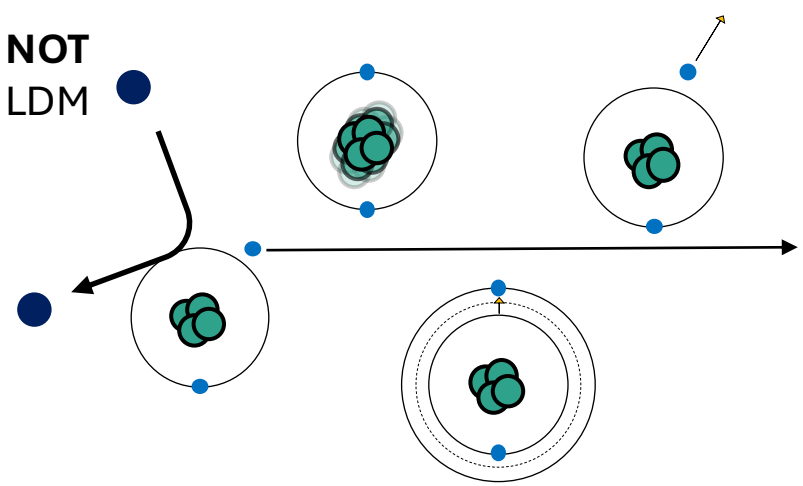


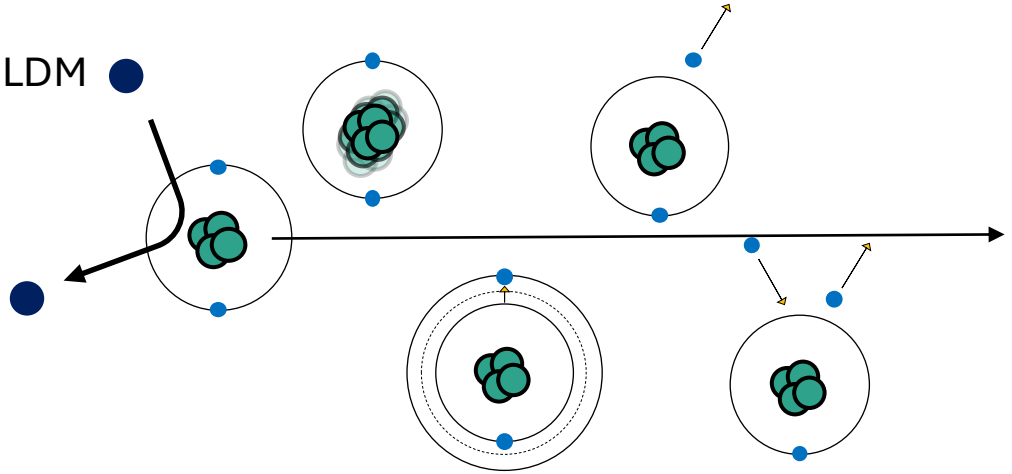


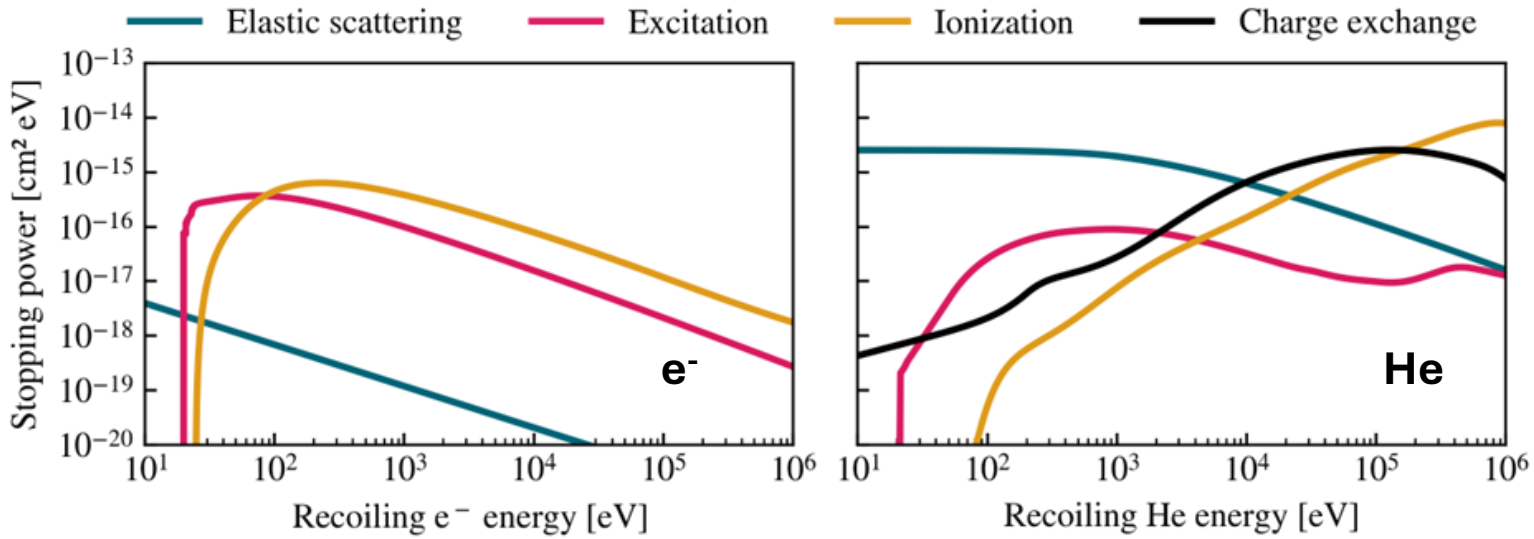
Reflection on copper

Phys. Rev. B 77, 174510

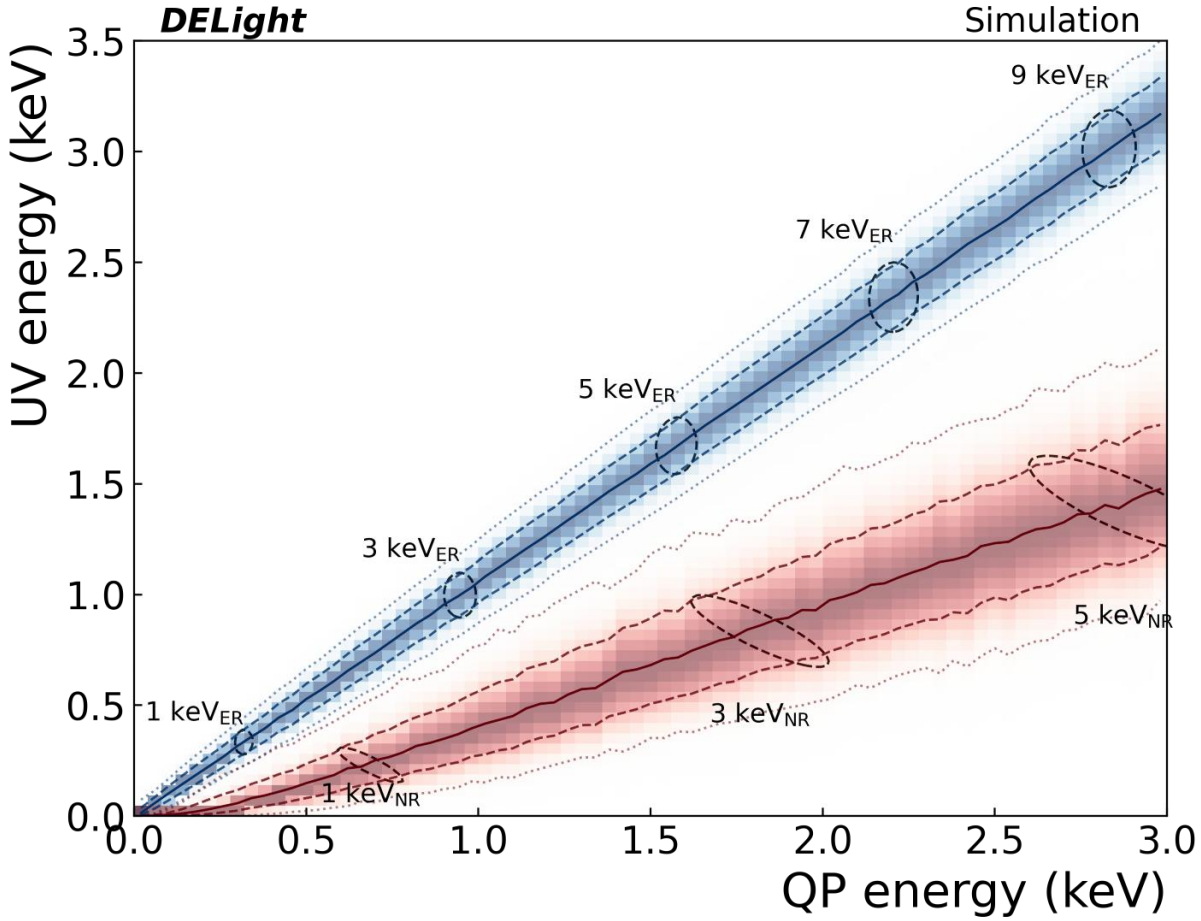
Recoil of electrons (ER) vs. He ions (NR)

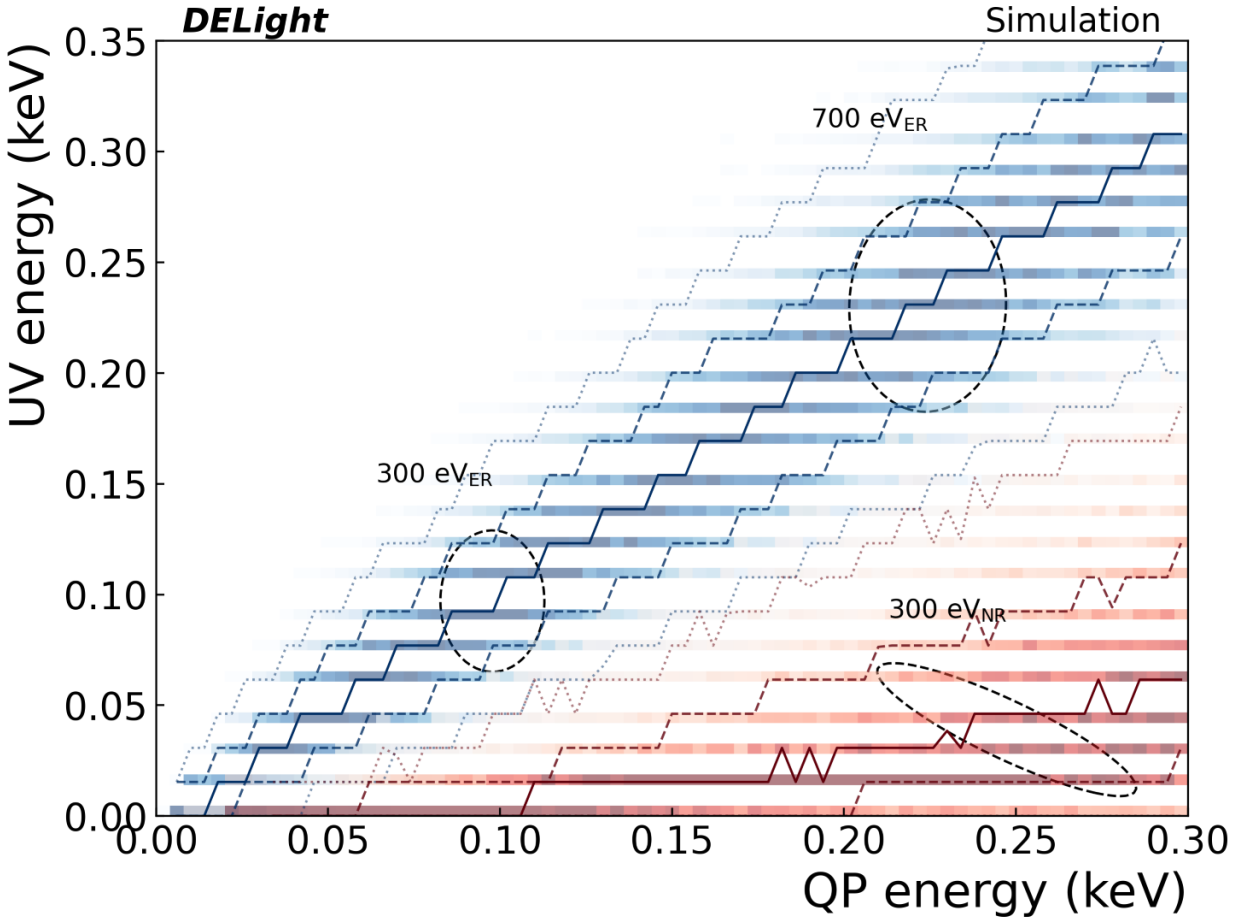




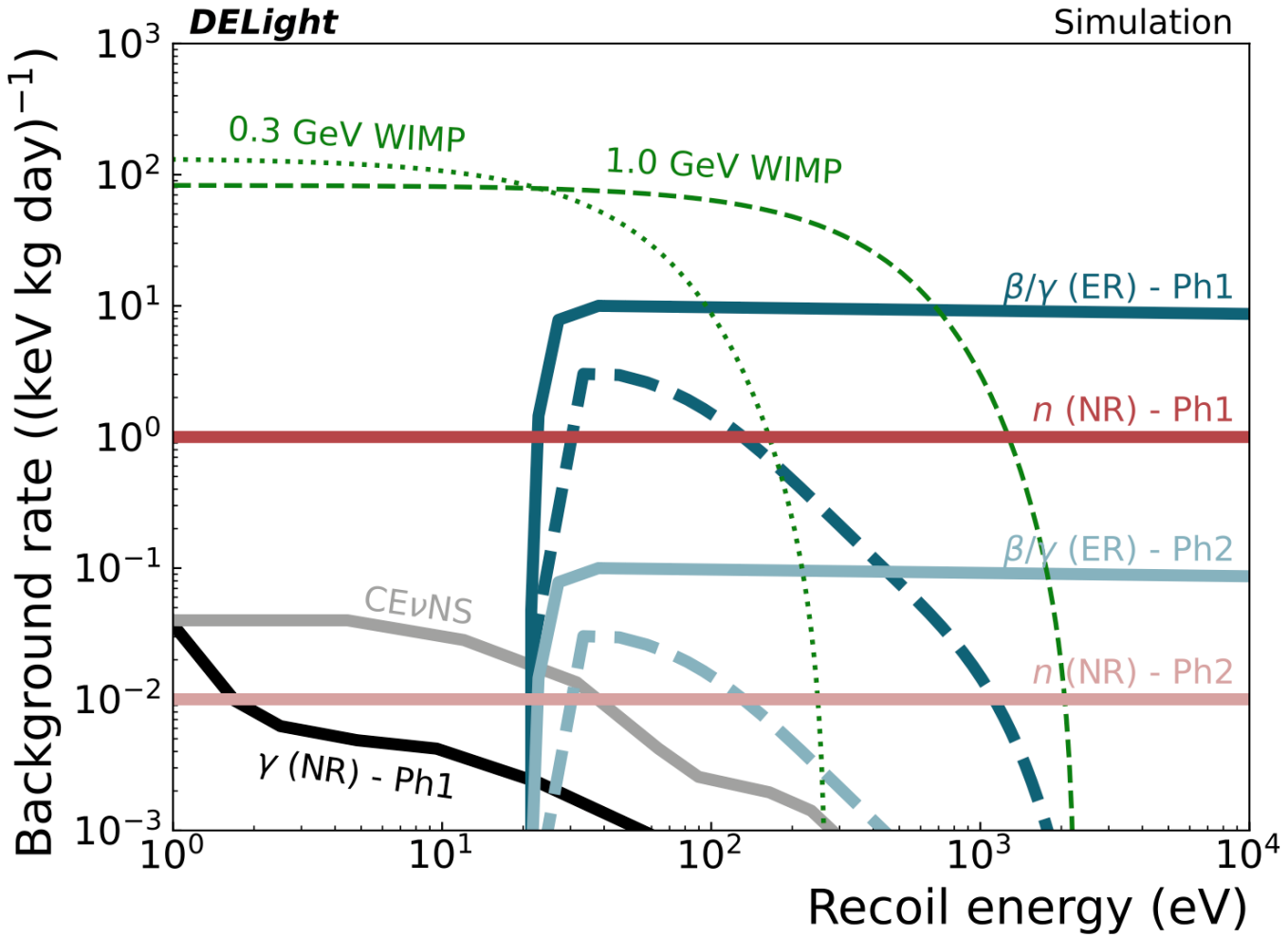


ER vs. NR bands

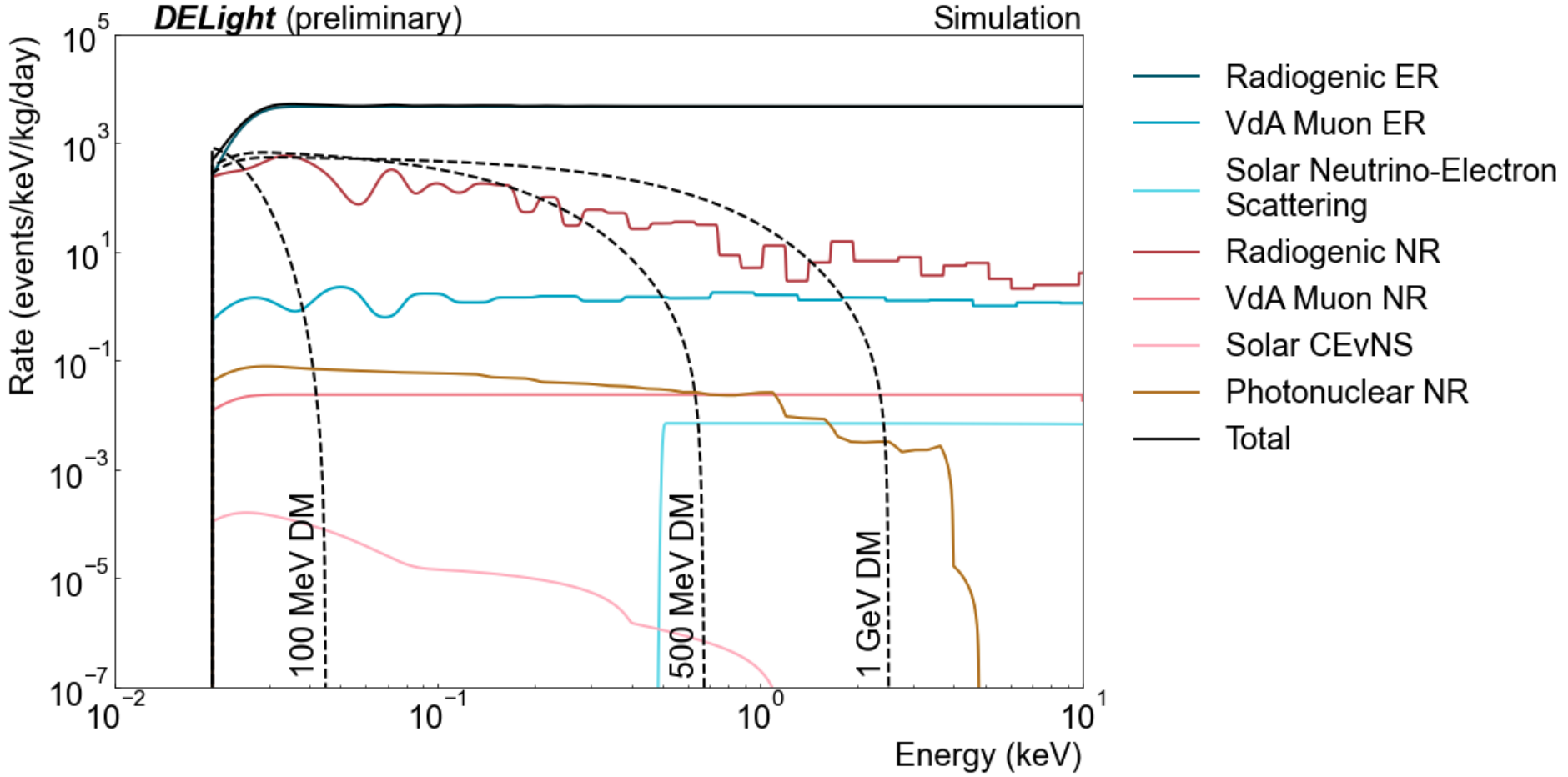




Goal background

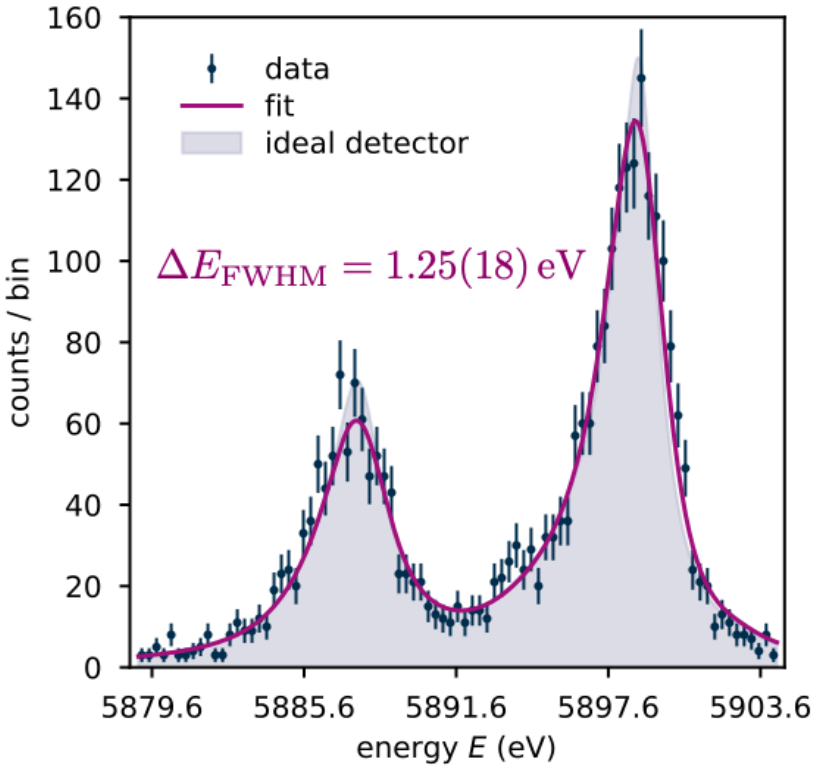


Background expectation vs. WIMP spectrum

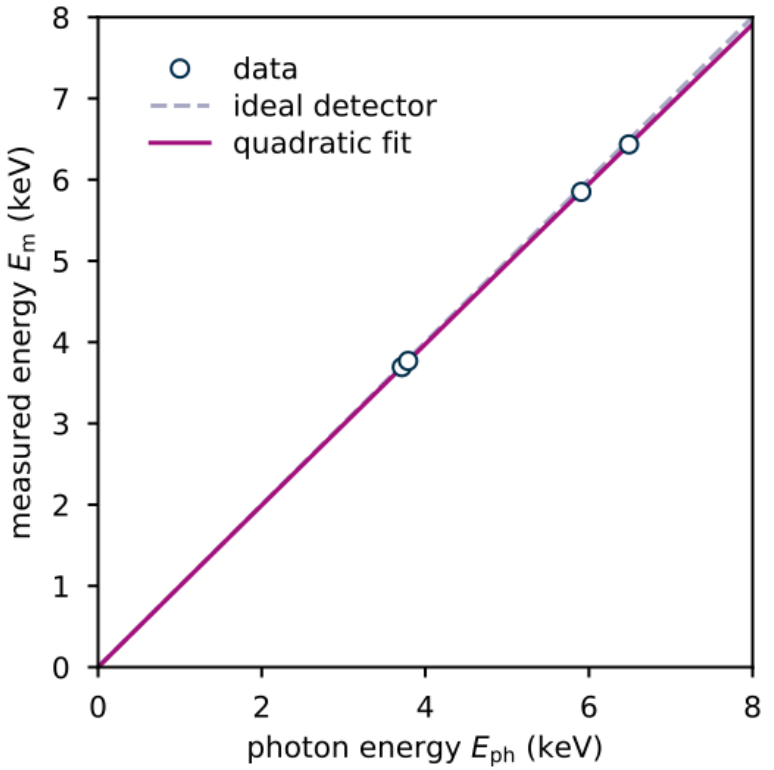


Magnetic MicroCalorimeter

world-leading energy resolution

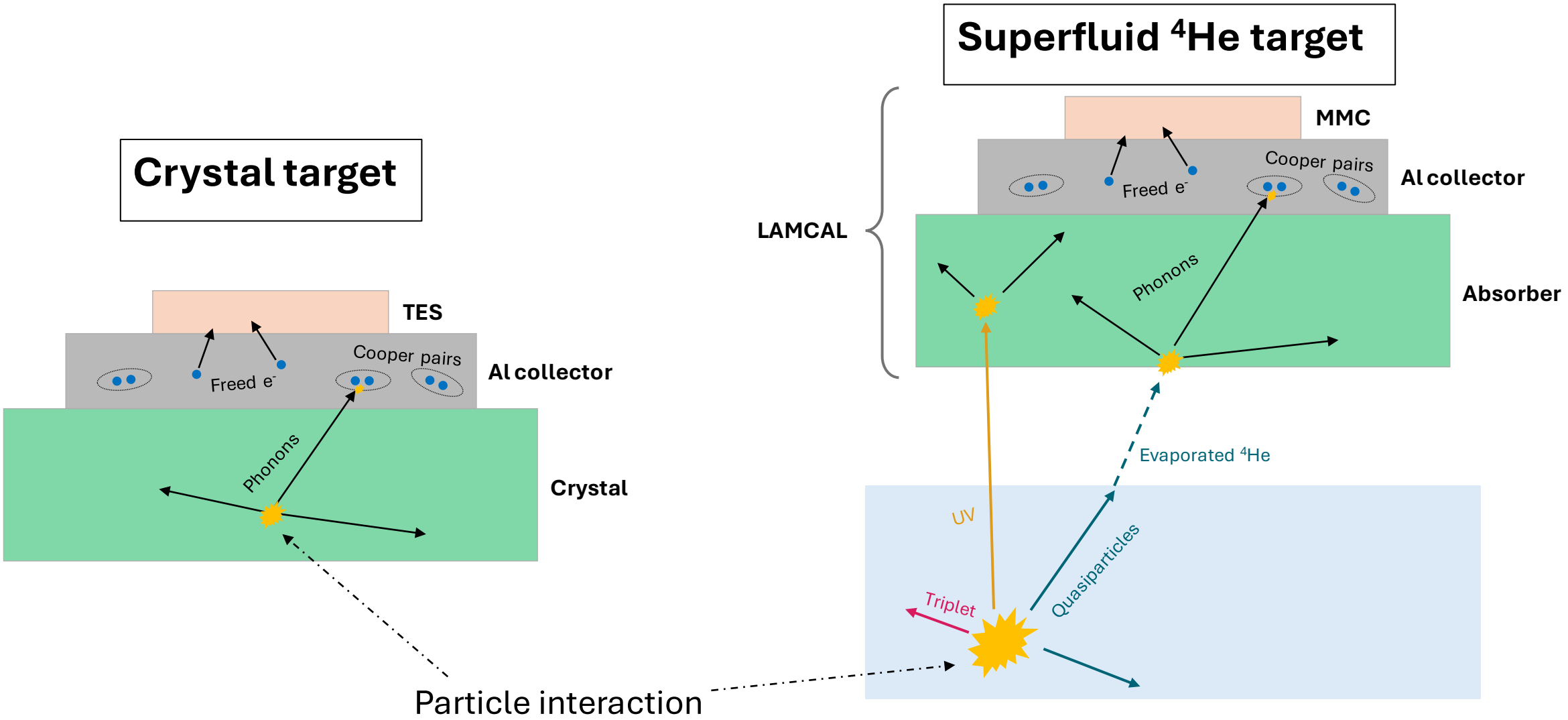


close-to-ideal detector response



Phys. Rev. D 109, 043035 (2024)
Appl. Phys. Lett. 124, 032601 (2024)

From detector to sensor



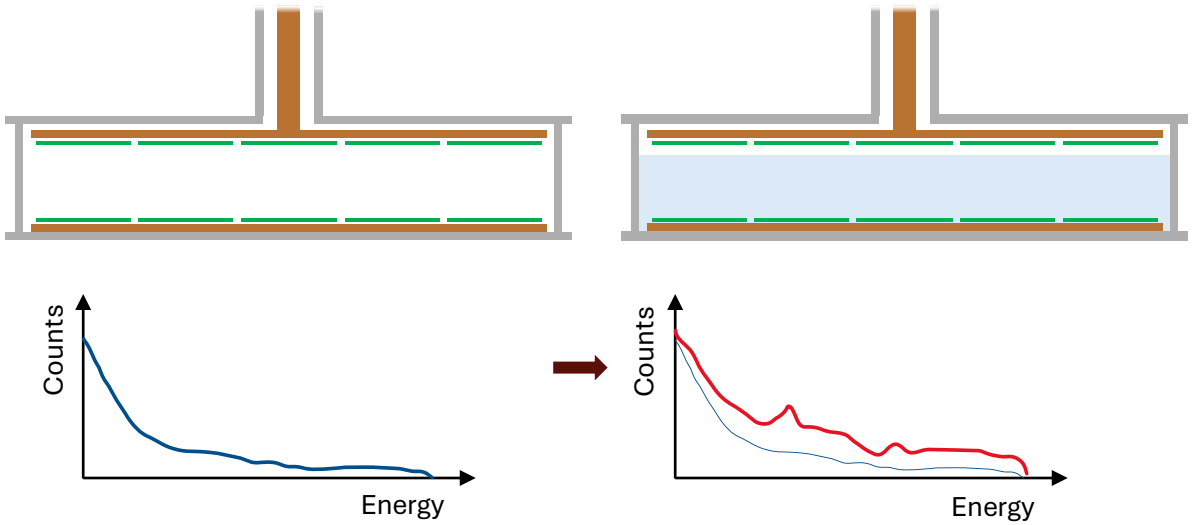
Low Energy Excess in DELight

We **DO NOT** expect any LEE from the helium target

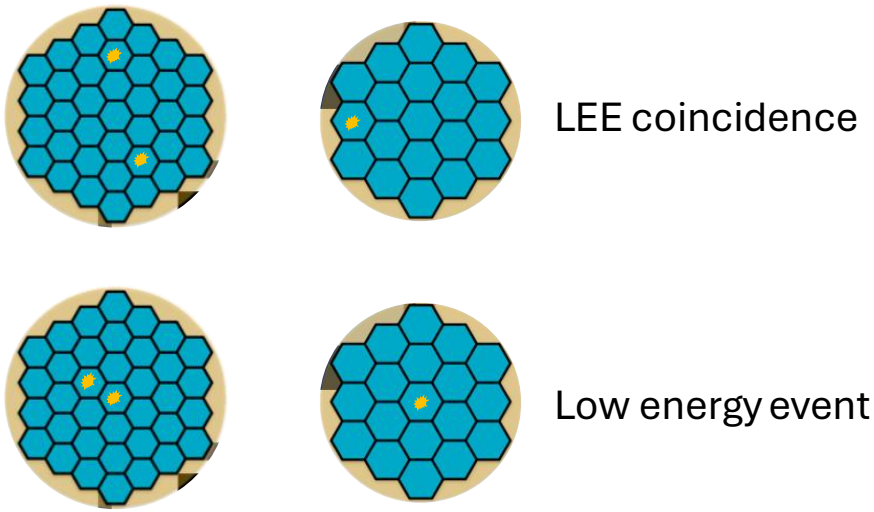
We **DO** expect LEE from LAMCALs

Some ways to handle it:

Full – empty background



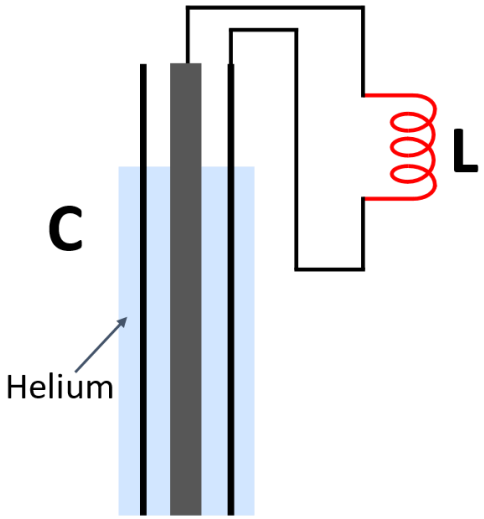
Multi-LAMCAL hits

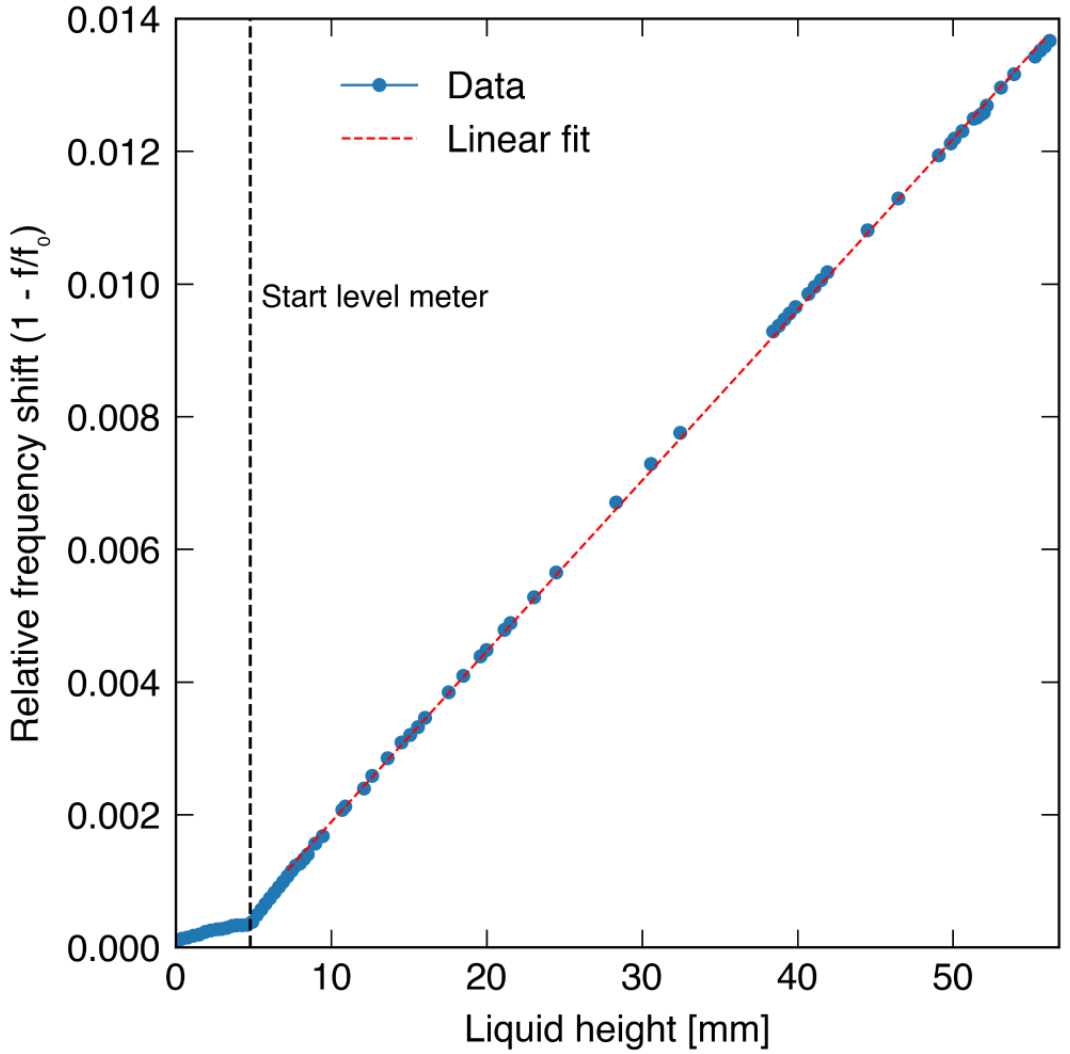


LEE coincidence

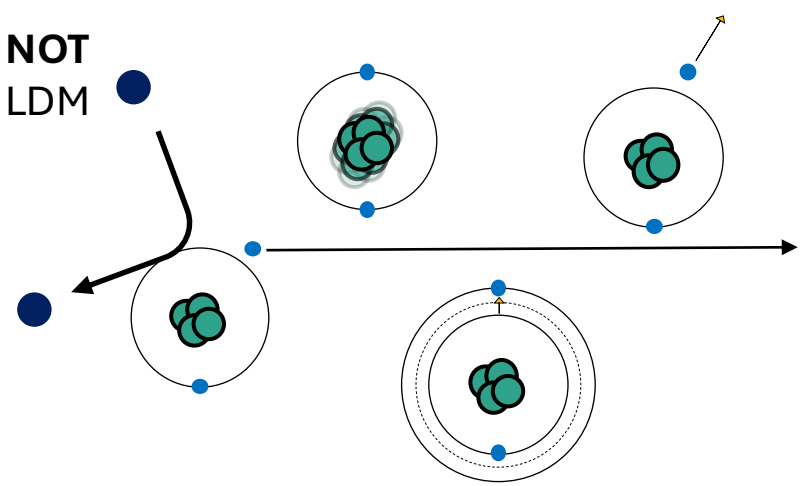
Low energy event

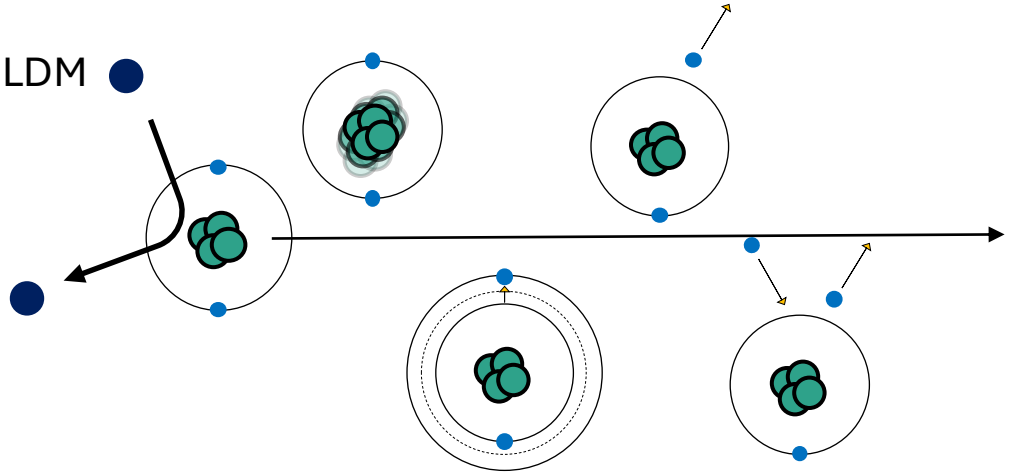
Levelmeter

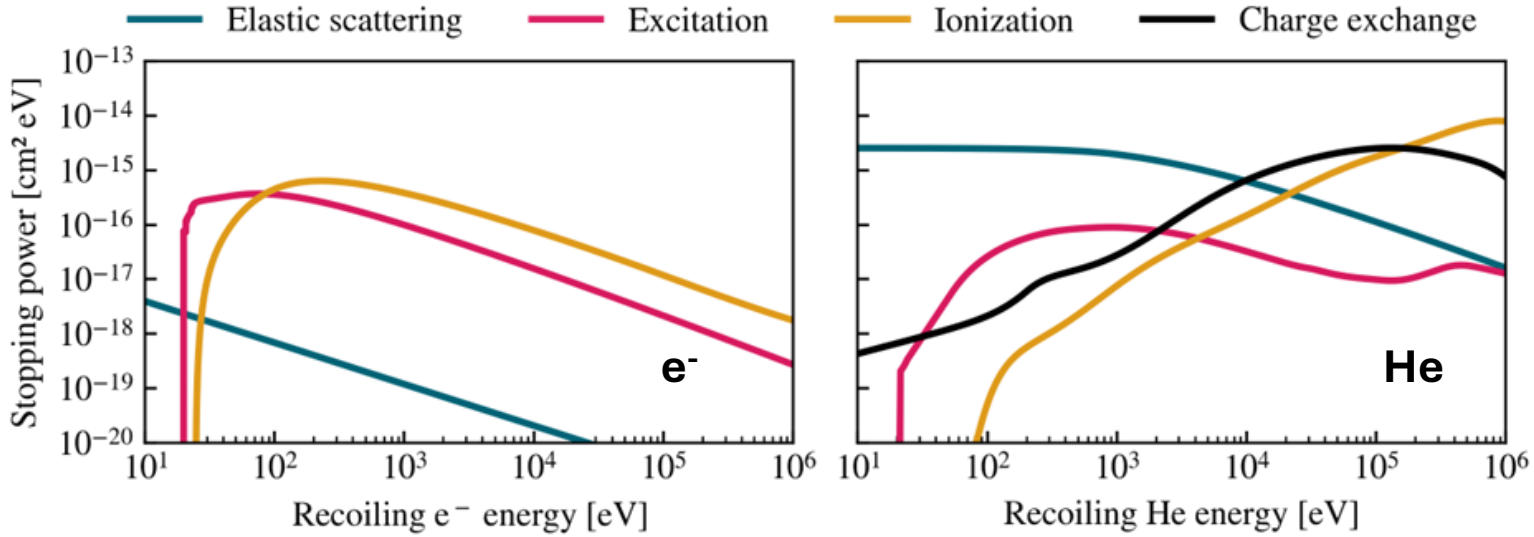

C
L
Helium


Data
Linear fit
Start level meter
Relative frequency shift (1 - f/f0)
Liquid height [mm]
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0
10
20
30
40
50

Recoil of electrons (ER) vs. He ions (NR)

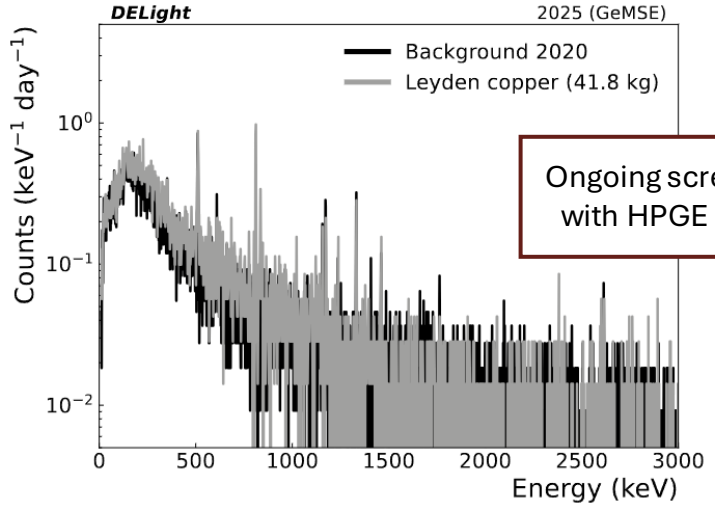




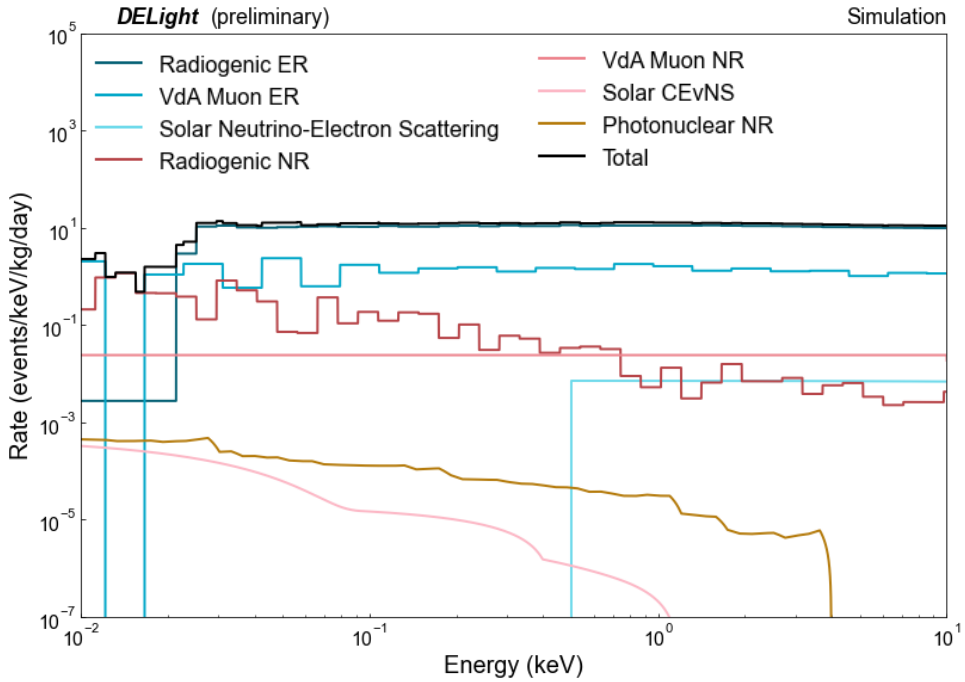


Background model

- Baseline geometry (0.15 kg helium)
- Included:
  - radiogenic material contamination
  - cosmics for medium-depth lab
  - neutrinos (negligible)
  - photonuclear NRs (negligible)
- Detector response model applied
  - Signal partitioning
  - Energy smearing
  - Trigger efficiency

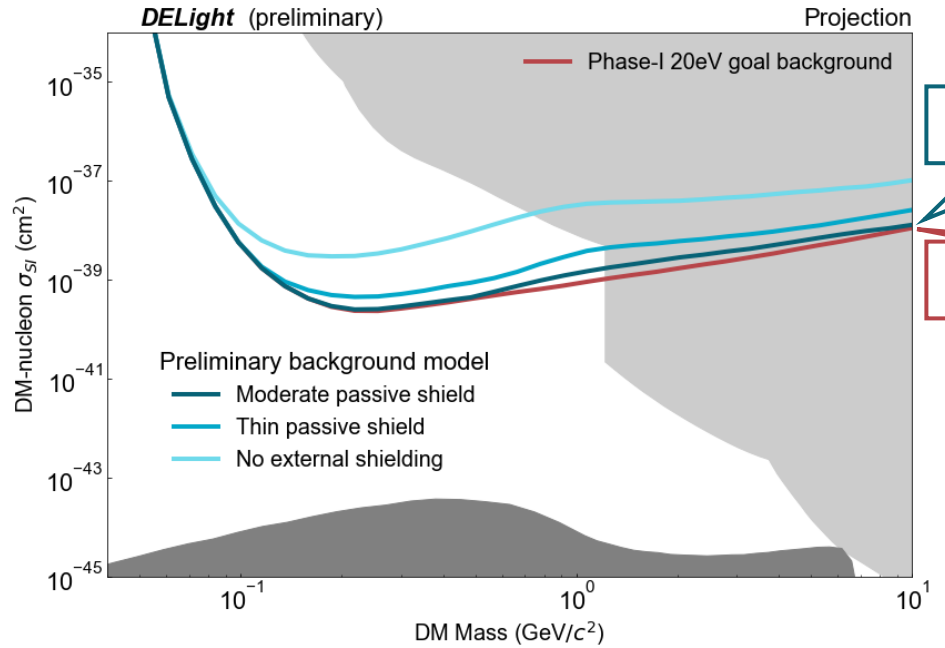


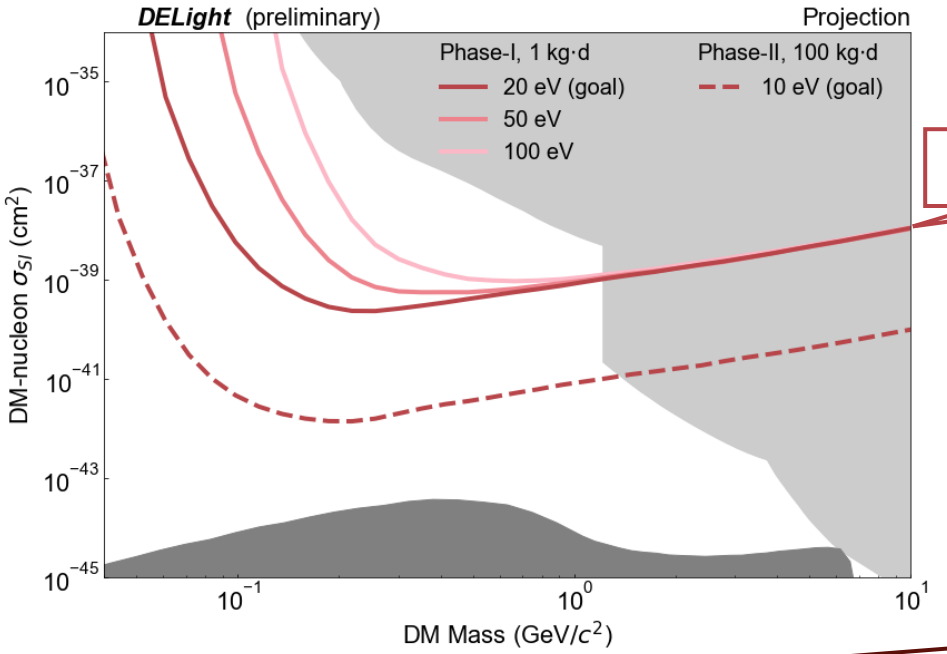
Ongoing screening campaign with HPGE (GeMSE @ VdA)



Sensitivity projections

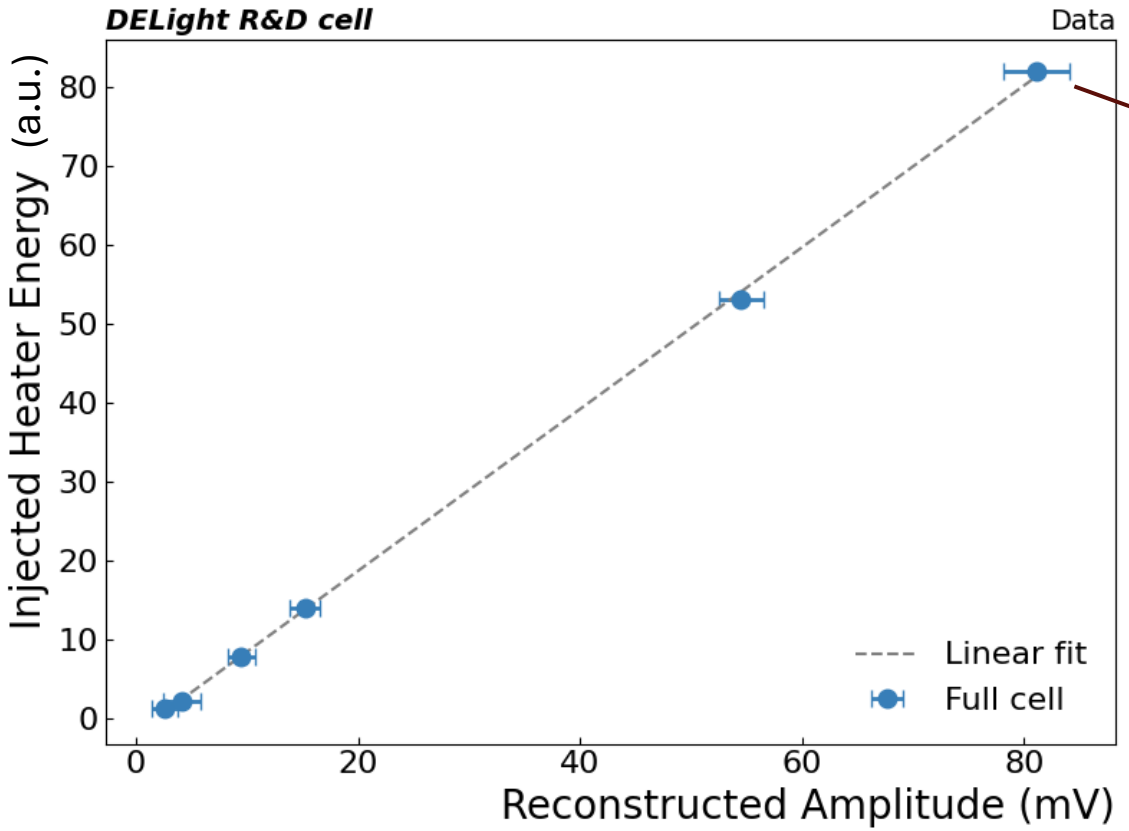
- Sensitivity via PLR method
  - Different external shields
  - Different energy thresholds
- Leading results for just **1 kg·d** exposure
  - Approximately 1 week of data taking
- No ER/NR discrimination included

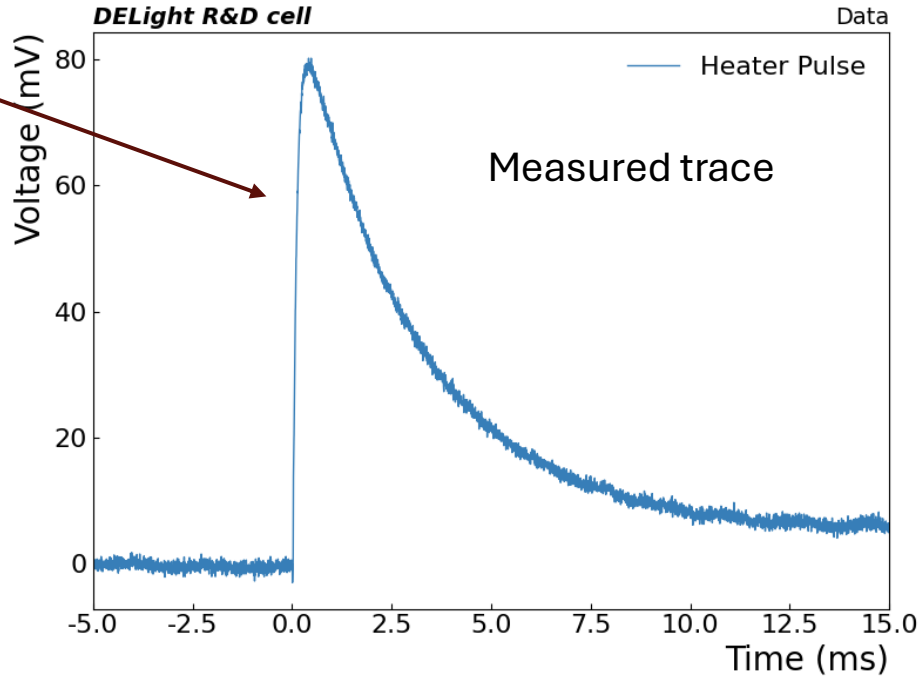




Resistive heater measurements

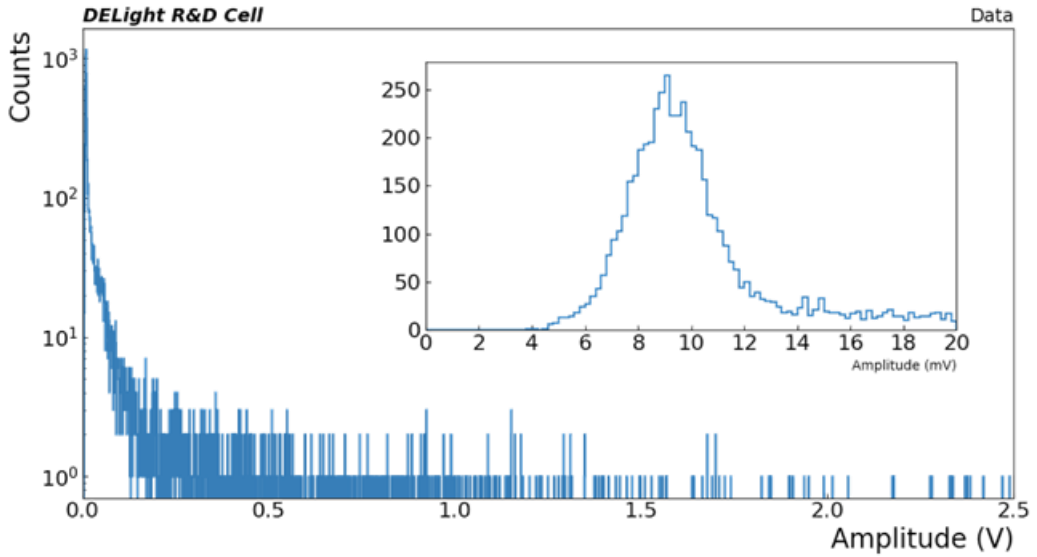
Indication of quasiparticle signal coming from heater for high energy heater pulses





First measurements

- Muon spectrum with peak expected at *O*(100 keV)
- Ongoing simulations to understand collection efficiencies



- Heater positioned in front of MMC inside helium
- Observed heater pulse with helium
- Indication of quasiparticle signal detection within helium