

DELIGHT: Direct search Experiment for Light dark matter with superfluid helium

Francesco Toschi

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The DELight collaboration



DELight: a Direct search Experiment for Light dark matter with superfluid helium

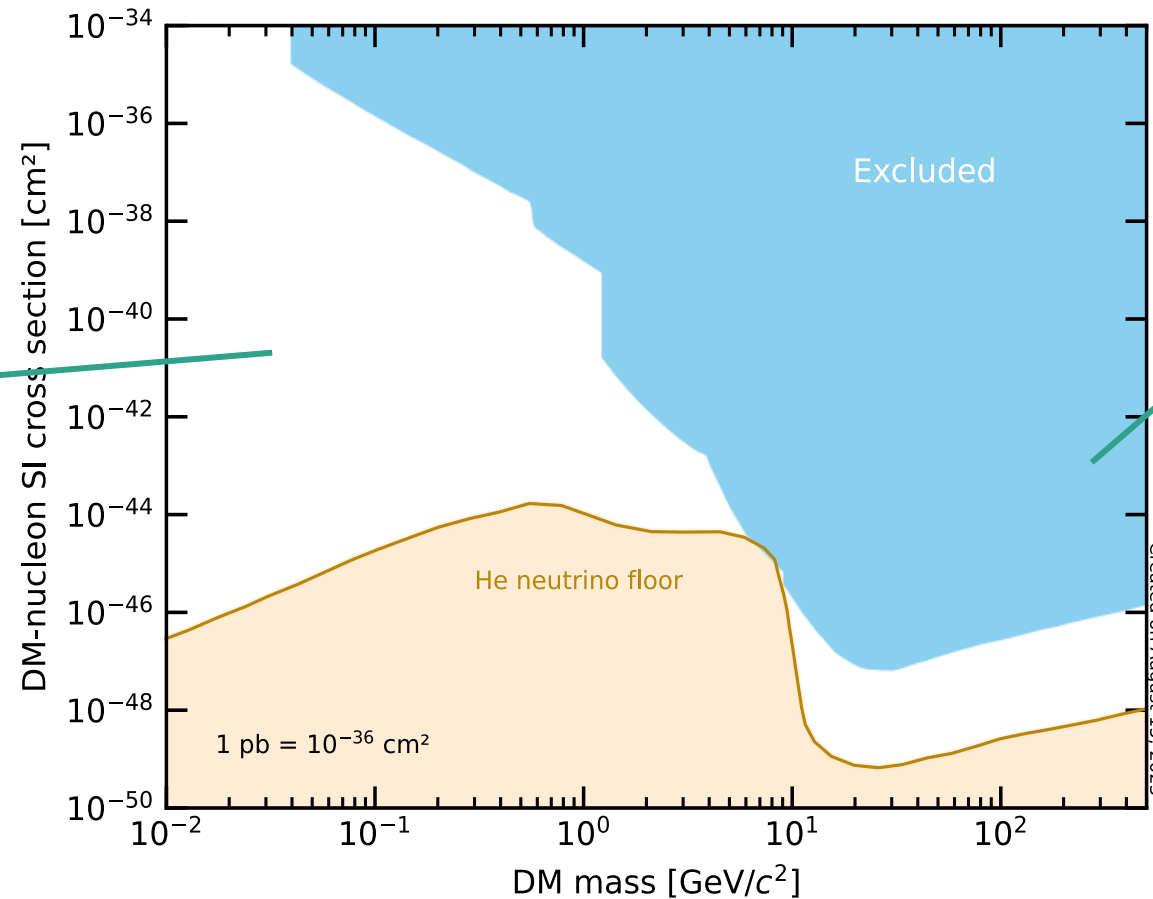
B. von Krosigk^{1*}, K. Eitel¹, C. Enss^{2,3}, T. Ferber⁴, L. Gastaldo², F. Kahlhoefer⁵, S. Kempf^{6,3},
M. Klute⁴, S. Lindemann⁷, M. Schumann⁷, F. Toschi^{1,7} and K. Valerius¹
+ K. Gerbig, G.S. Heine, B. Maier, M. Mikaya and A. Reiser



[SciPost Phys. Proc. 12, 016 \(2023\)](#)

The Dark Matter landscape today

Phase space for
Light DM (LDM) is
mostly unexplored!



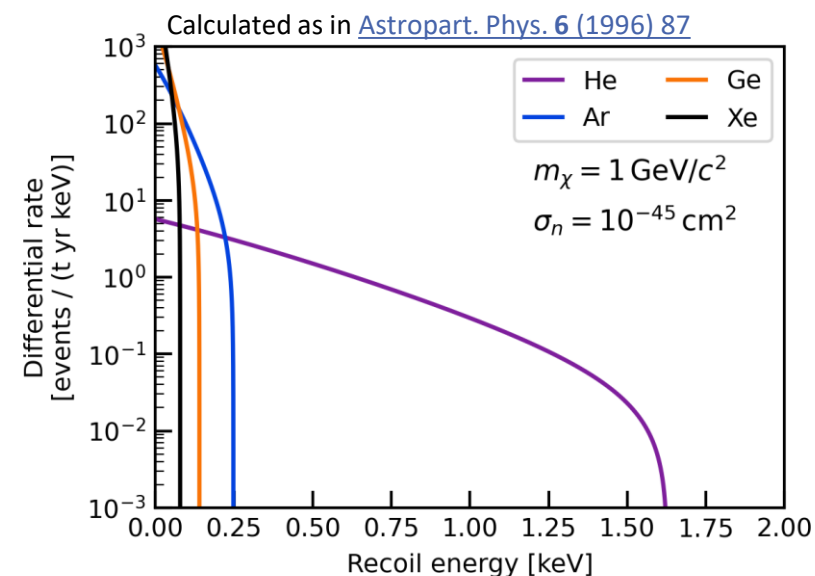
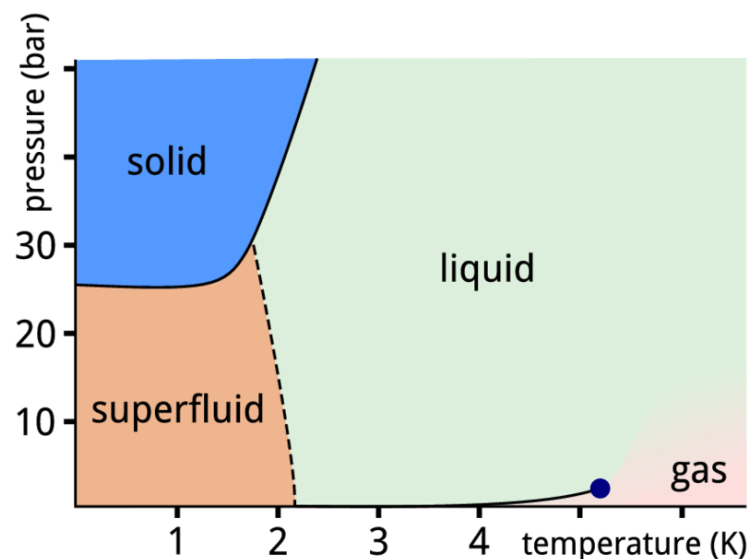
Noble liquid dual-
phase TPCs
constrain the phase
space for large
WIMP masses

[Phys. Rev. Lett. **131**, 041002 \(2023\)](#)

[Phys. Rev. D **107**, 063001 \(2023\)](#)

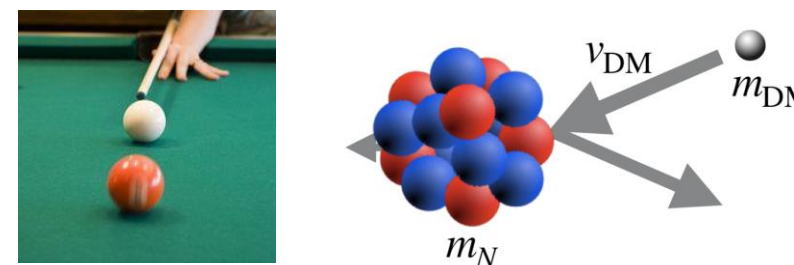
[Phys. Rev. Lett. **131**, 041003 \(2023\)](#)

Superfluid ^4He as target



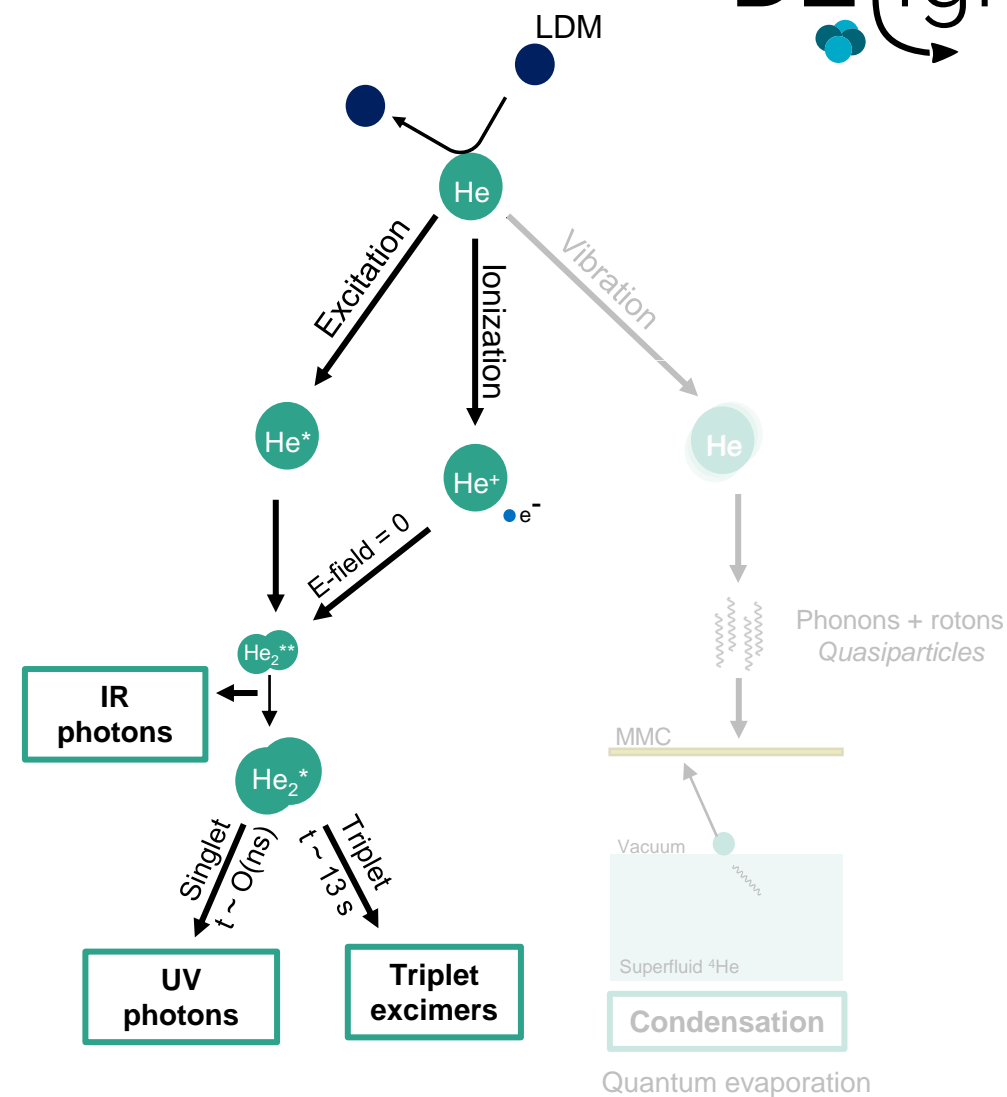
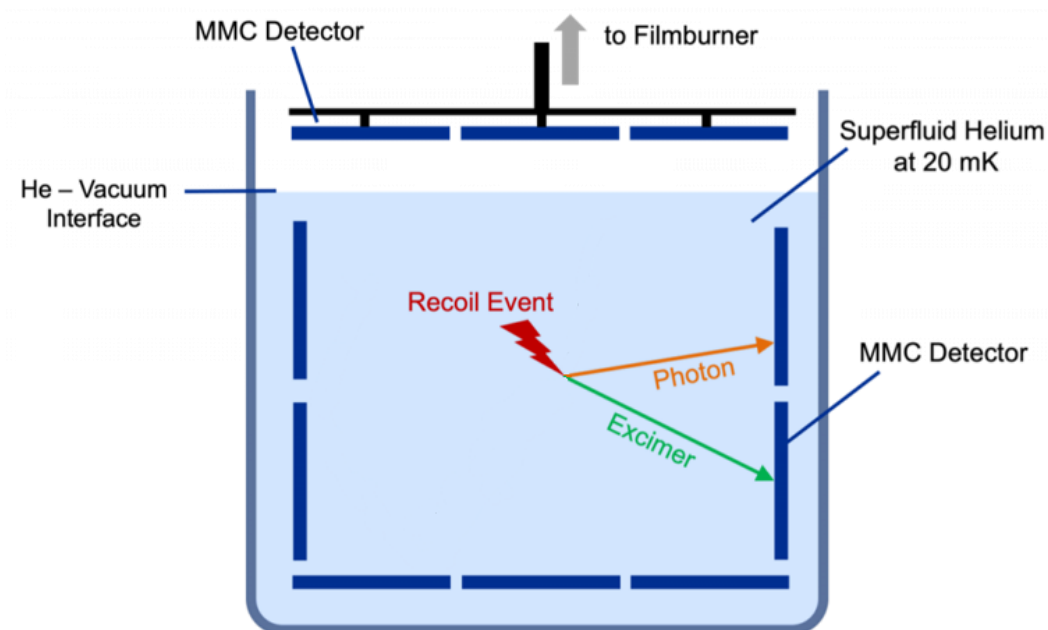
- Impurities freezing out ($\sim 20 \text{ mK}$)
- Multiple signals
- Unexpensive material and scalable technology

- Light nuclei maximize recoil energy for LDM



DELIGHT detection principle

- Prompt detection of UV and IR photons
- Ballistic triplet excimer (13 s lifetime, O(m/s) speed)
 - Detected when in contact with MMC sensor

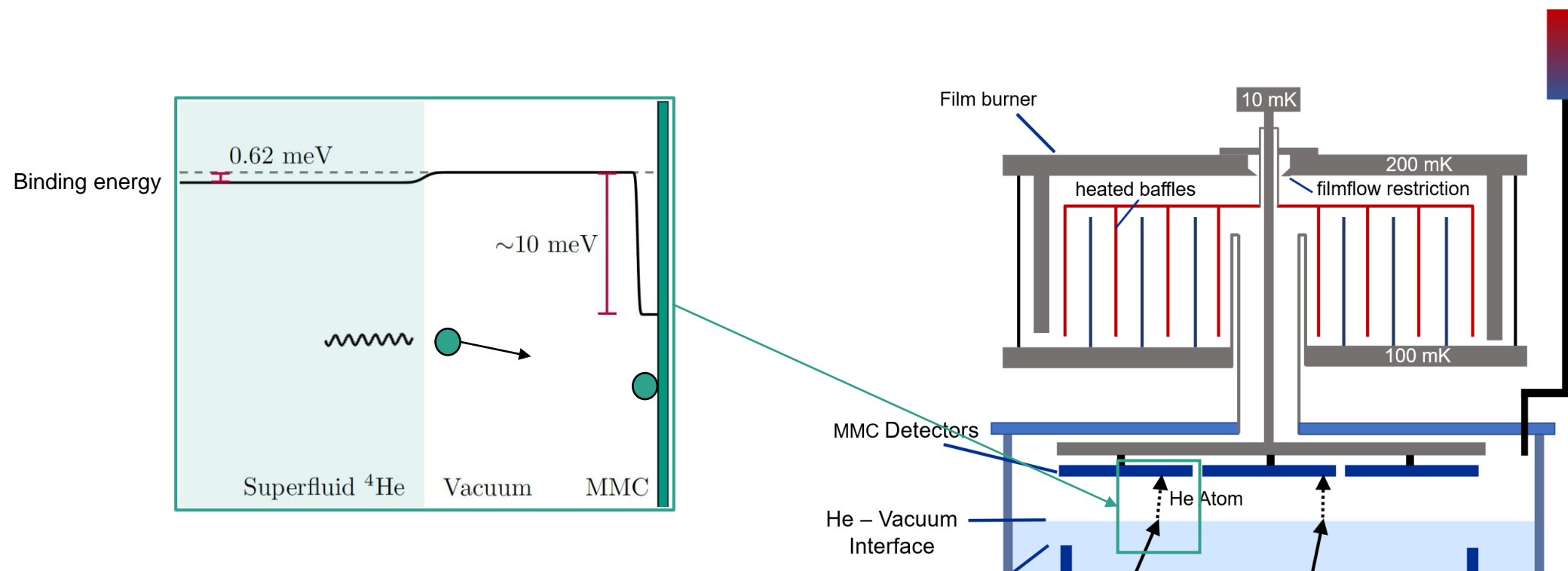


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- The diagram illustrates the experimental setup for measuring the recoil of a single atom. A central region of superfluid helium at 20 mK is contained within a chamber. The top and bottom boundaries are marked as the He-Vacuum Interface. Two MMC Detectors are positioned on the top and bottom surfaces. A vertical tube leads from the top detector to a film burner. A recoil event is shown as a red lightning bolt. From the event, three paths emerge: a black arrow labeled 'Photon / Roton' pointing towards the bottom detector, an orange arrow labeled 'Photon' pointing towards the right MMC Detector, and a green arrow labeled 'Excimer' pointing towards the bottom right. A grey arrow points upwards from the top detector towards the film burner.



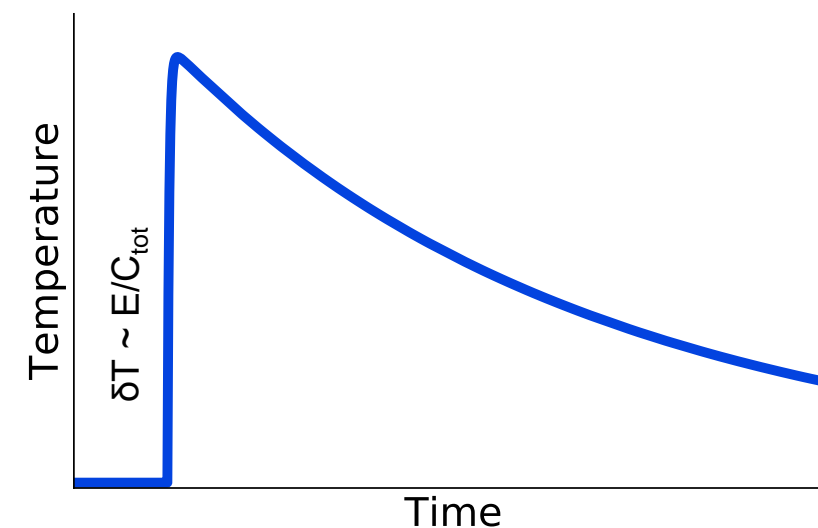
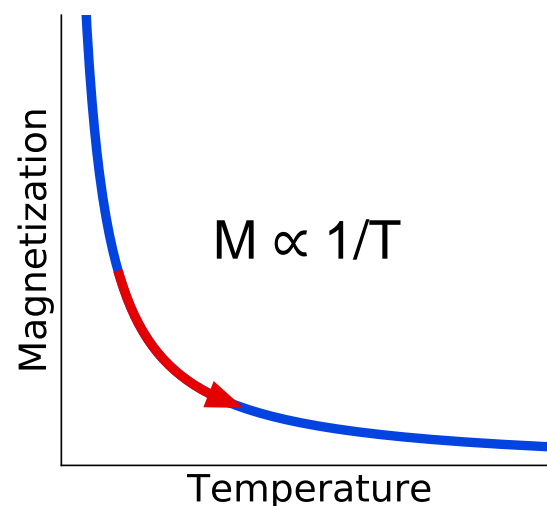
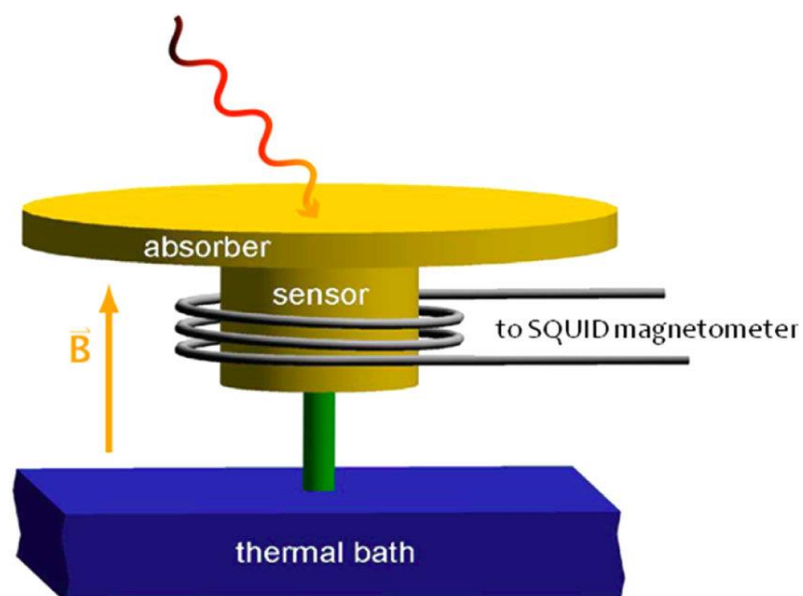
DELIGHT detection principle

- Noise-free gain ≥ 10 in the MMC as binding energy He-He is smaller than He-absorber
- MMCs in vacuum need to be ^4He film-free \rightarrow film burner



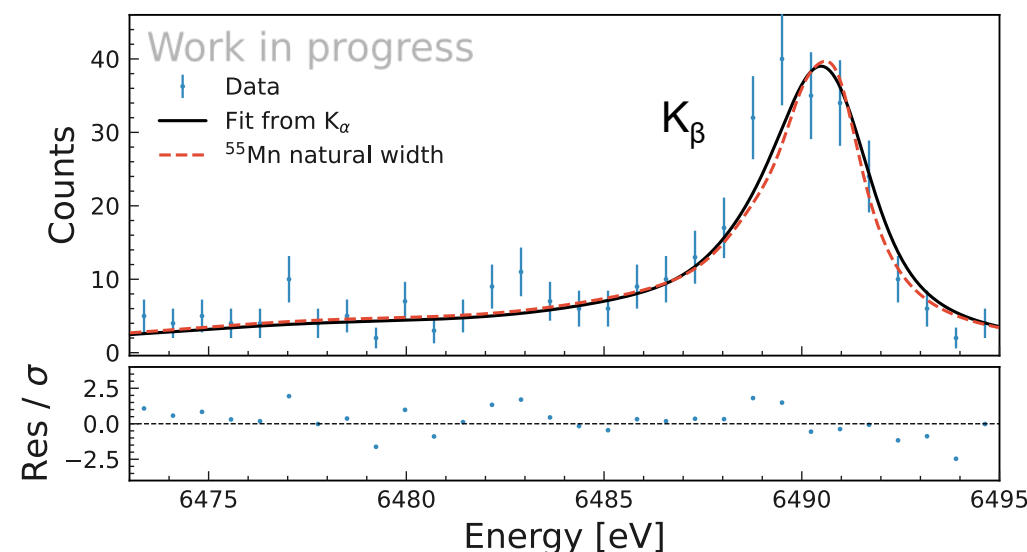
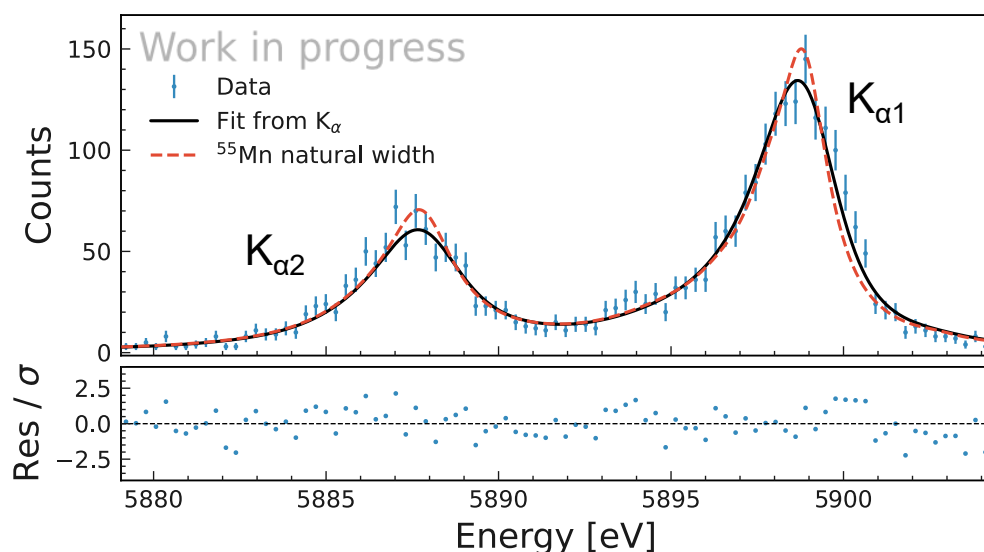
Magnetic Micro-Calorimeters (MMCs)

- Energy deposit in an *absorber* leads to a temperature increase δT changing the magnetization of the *paramagnetic* sensor $\delta M \propto \delta T$
- Change in magnetization measured by a coupled SQUID as change in current $\delta I \propto \delta M$



R&D: energy resolution of MMCs

- Best achieved so far: $\Delta E_{\text{FWHM}} = 1.58 \text{ eV}$ @ 5.9 keV (x-rays from ^{55}Fe) [1]
- Improvement of the analysis in [2]:
 - amplitude from optimum filter, fit to K_{α} data via chi-square minimization and check with K_{β}
 - resolution down to **$\Delta E_{\text{FWHM}} = 1.25 \text{ eV}$** @ 5.9 keV (best to date!)
 - potential sub-eV resolution limited by μK temperature fluctuations

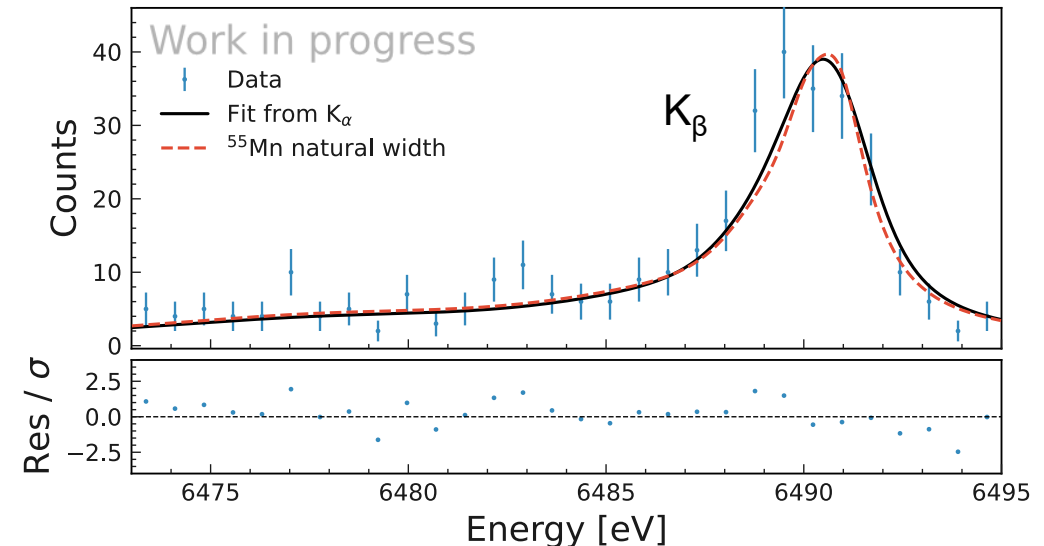
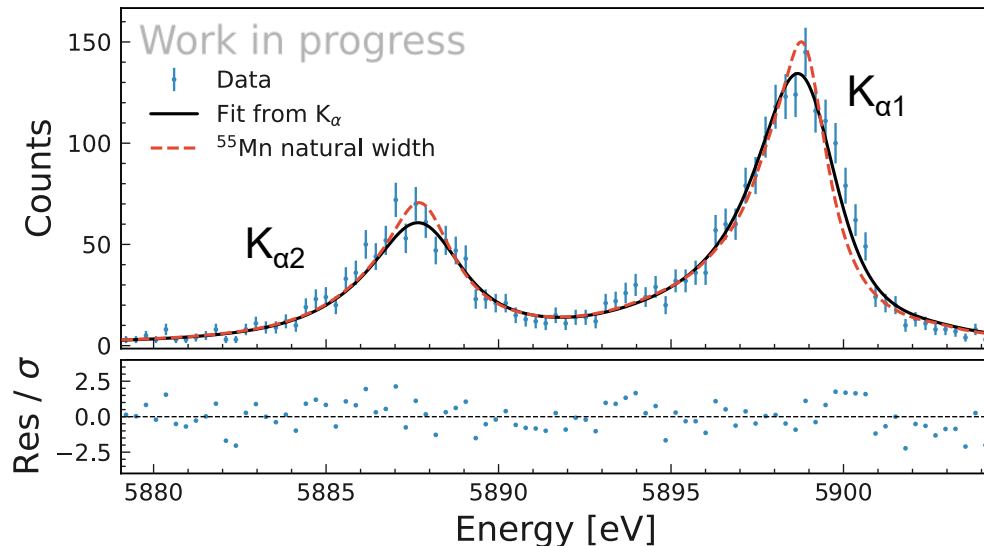


[1] J. Low Temp. Phys. 193, 365-379 (2018)
 [2] M. Krantz, PhD thesis, Heidelberg (2020)

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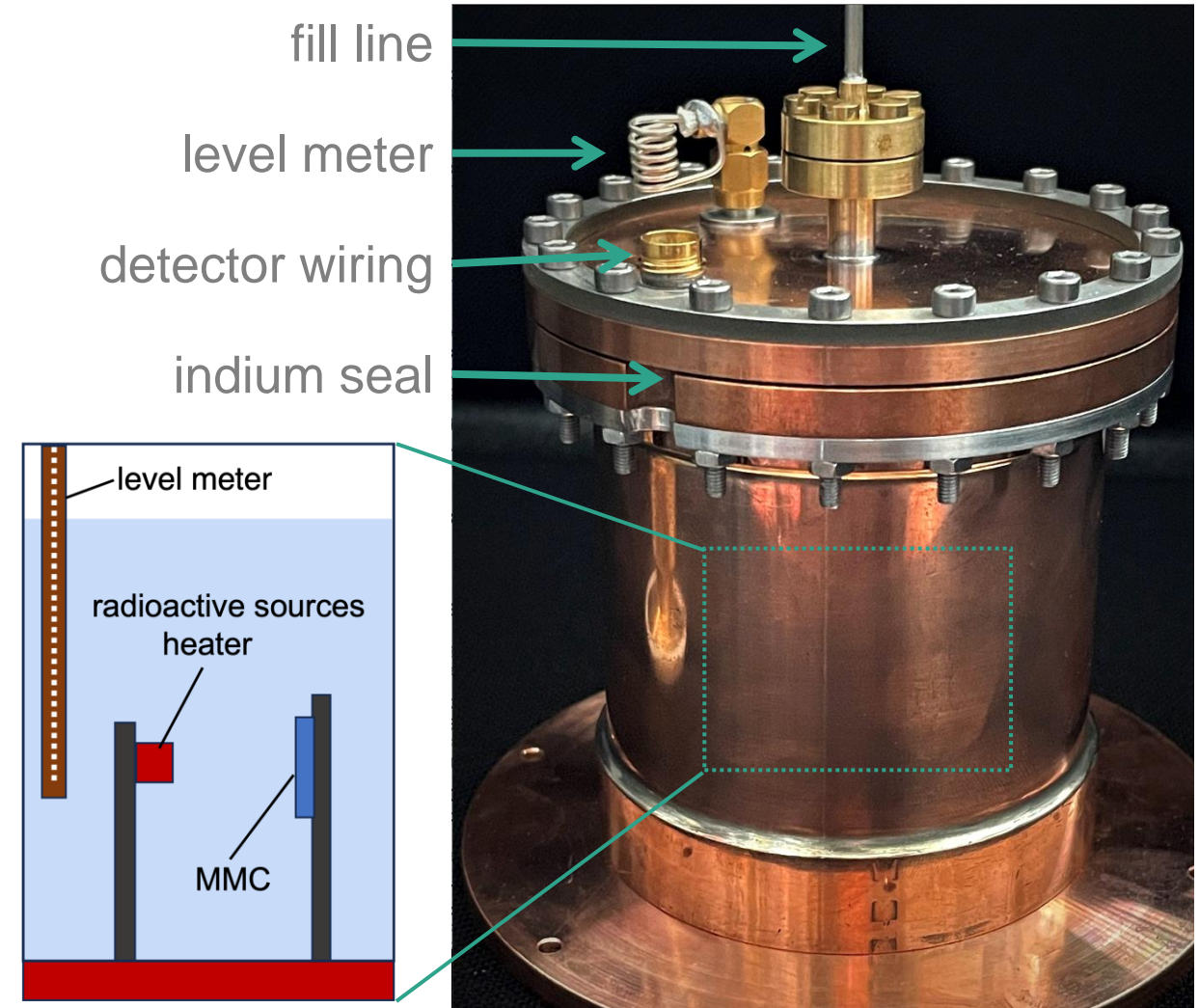


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R&D: DELight 0 – mini cell

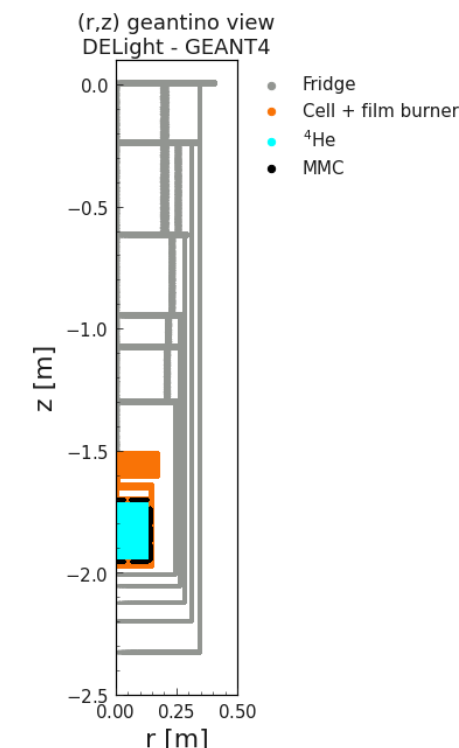
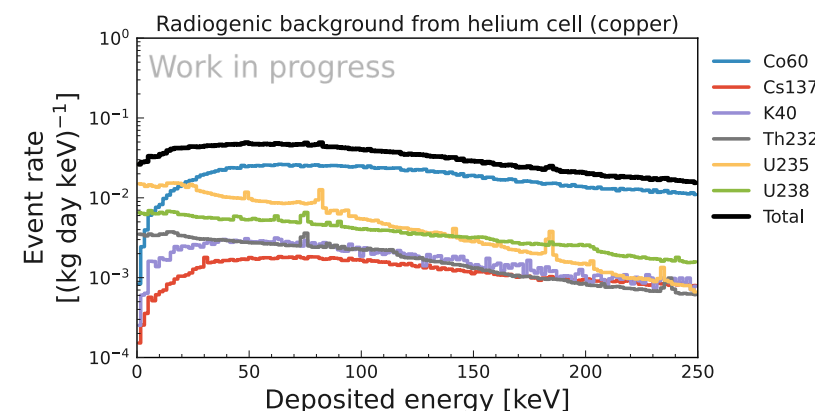
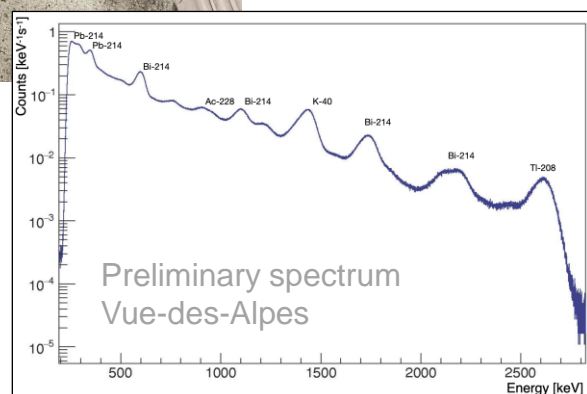
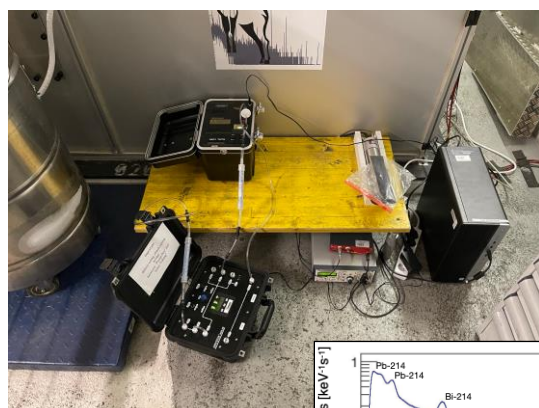
Testbed for DELight:

- Studies of MMCs in liquid:
 - first test of MMC in liquid ^4He
 - search for quasiparticle signals within liquid
- Test of new level meter
- Testing purification and filling systems
- Detection of UV and triplets



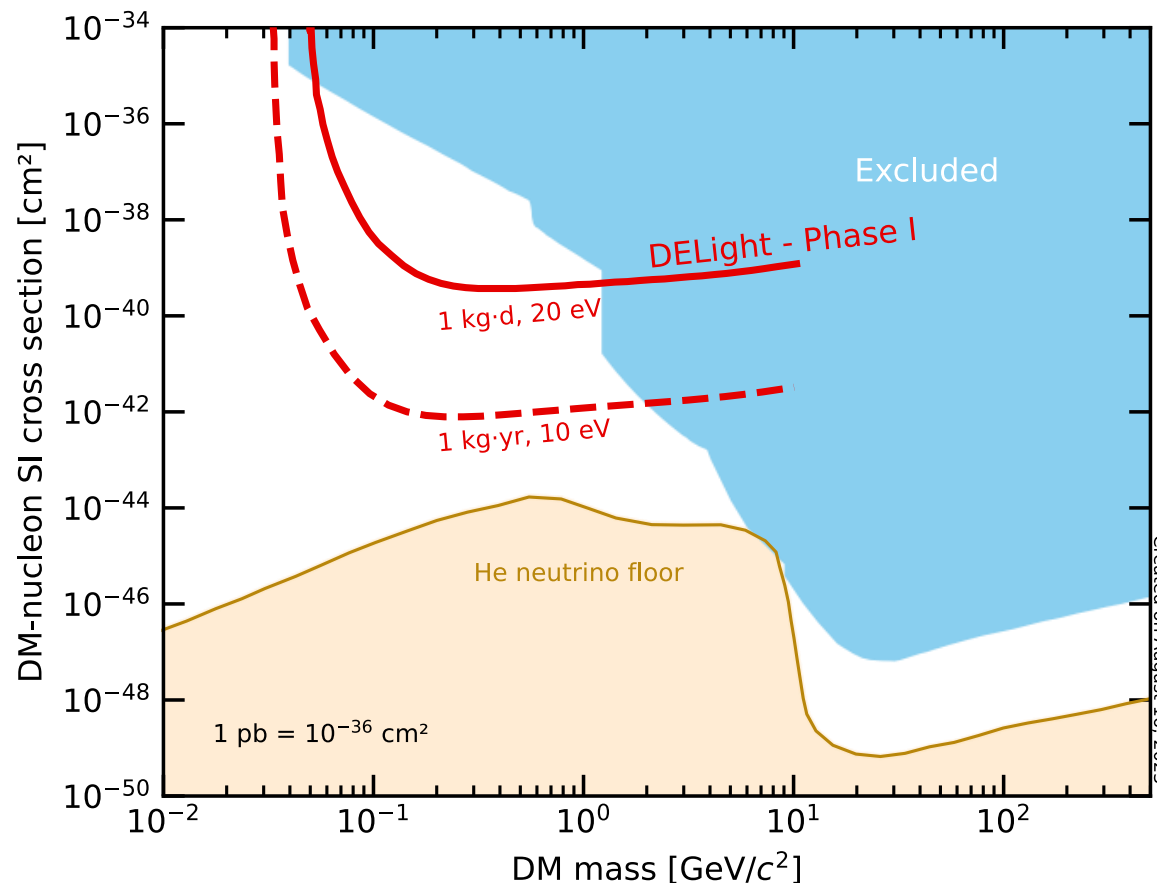
R&D: background and simulations

- GEANT4 model of first geometry already set up
- Ongoing measurements of gamma background of Vue-des-Alpes underground laboratory (possible location for initial phases)



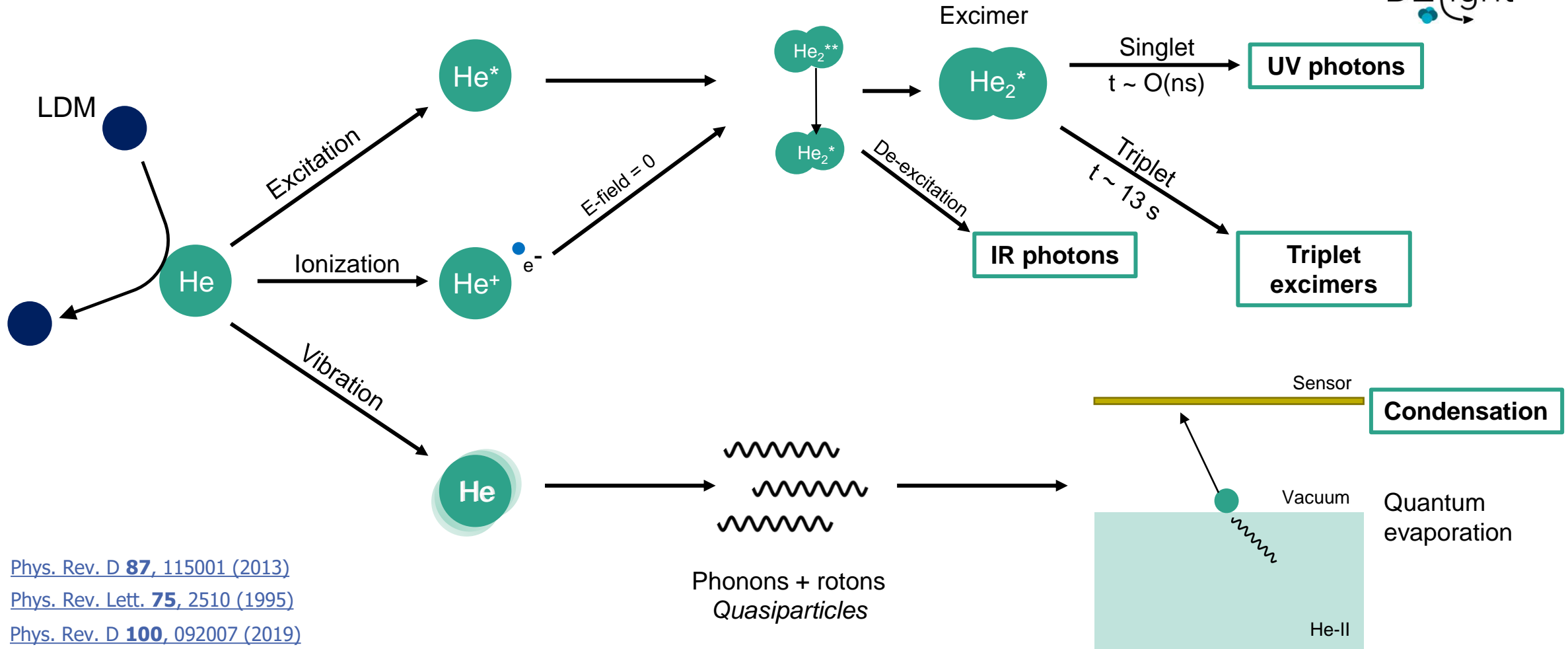
The future of DELight

- First phase can already probe new parameter space with limited exposure:
 - 10 liters (~1 kg)
 - O(kg·d) exposure
 - 20 eV threshold
- Long term plan:
 - Up to 200 liters in UG lab
 - O(kg·yr) exposure
 - <10 eV threshold



Back-up slides

Superfluid Helium as target



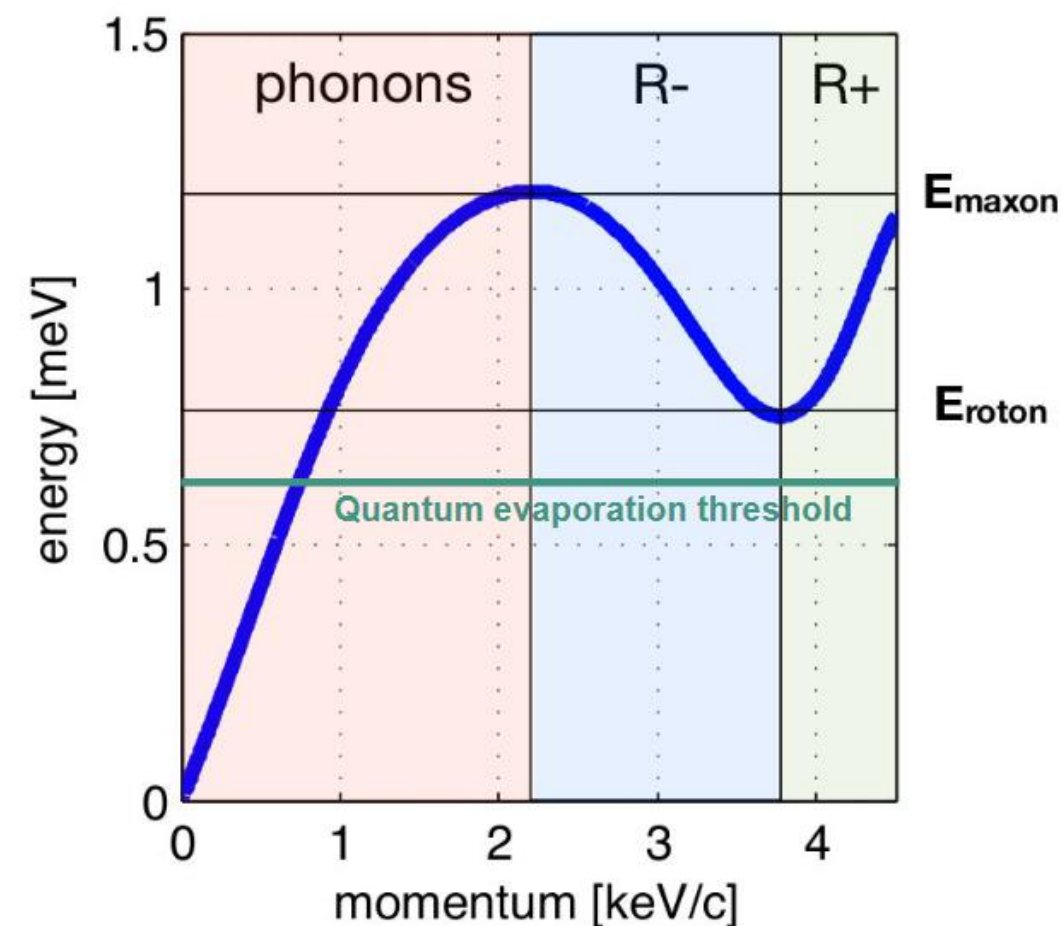
[Phys. Rev. D **87**, 115001 \(2013\)](#)

[Phys. Rev. Lett. **75**, 2510 \(1995\)](#)

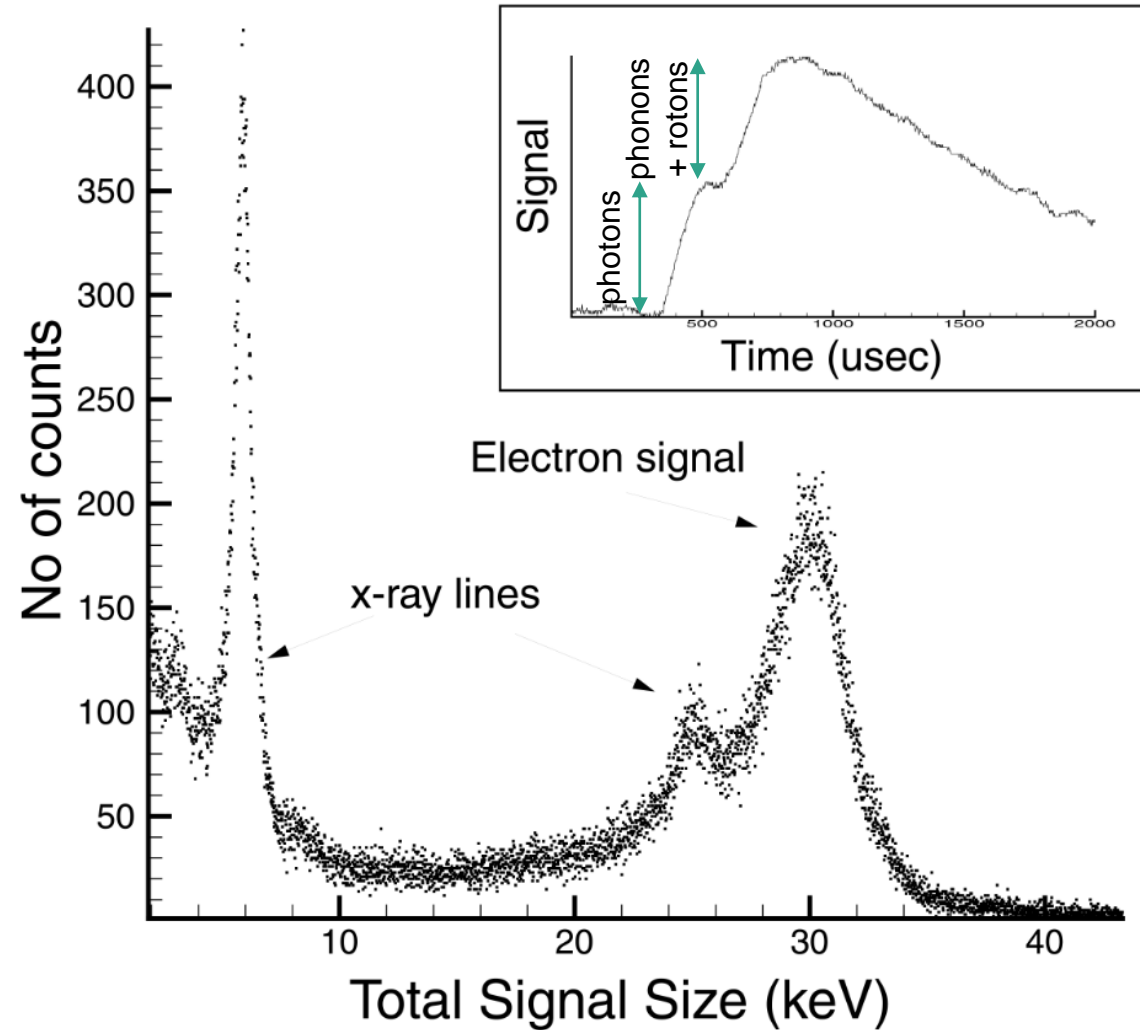
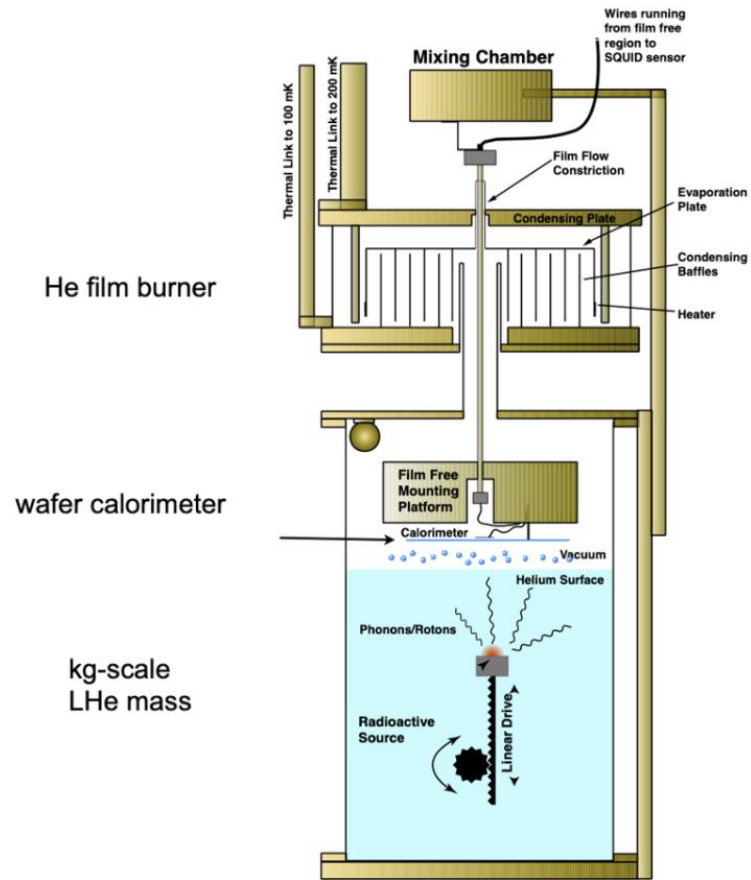
[Phys. Rev. D **100**, 092007 \(2019\)](#)

Phonon in superfluid Helium

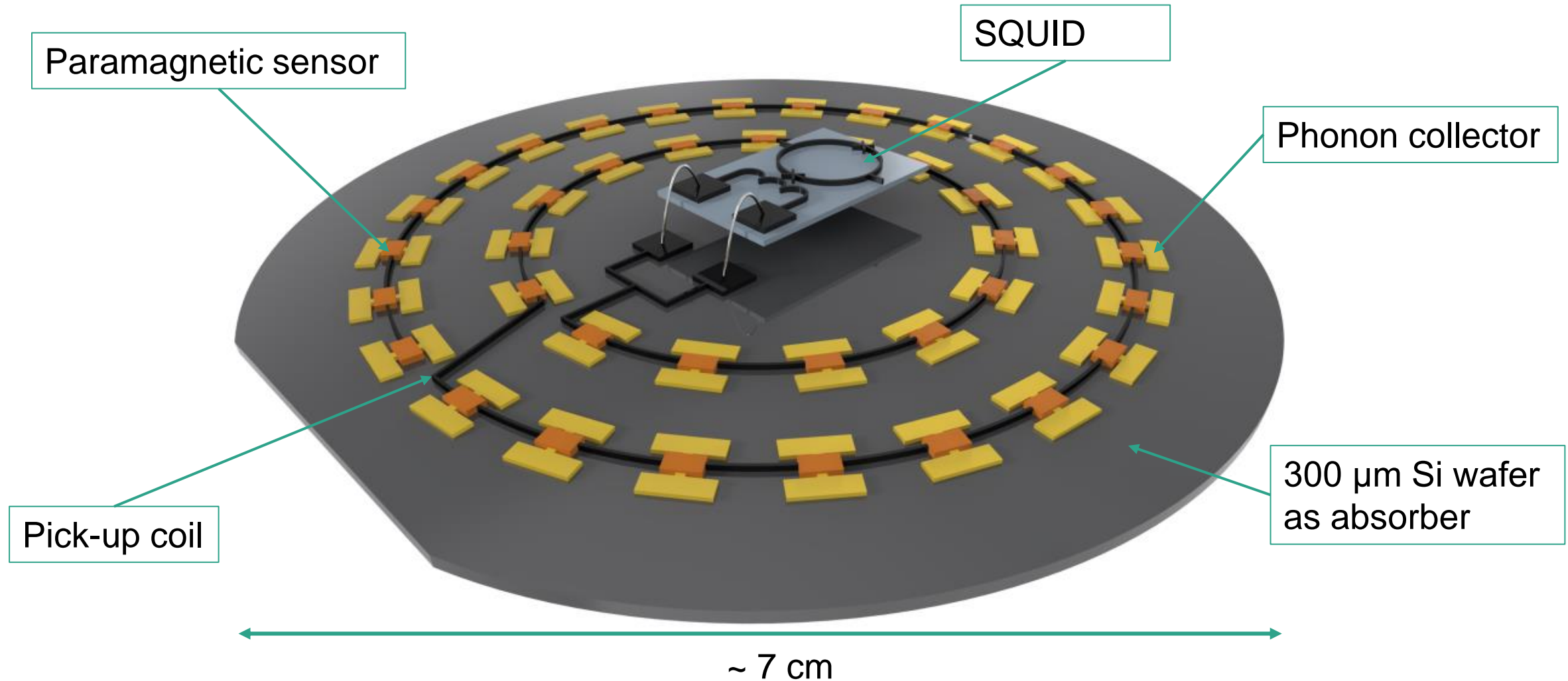
- Rotons \simeq high momentum phonons



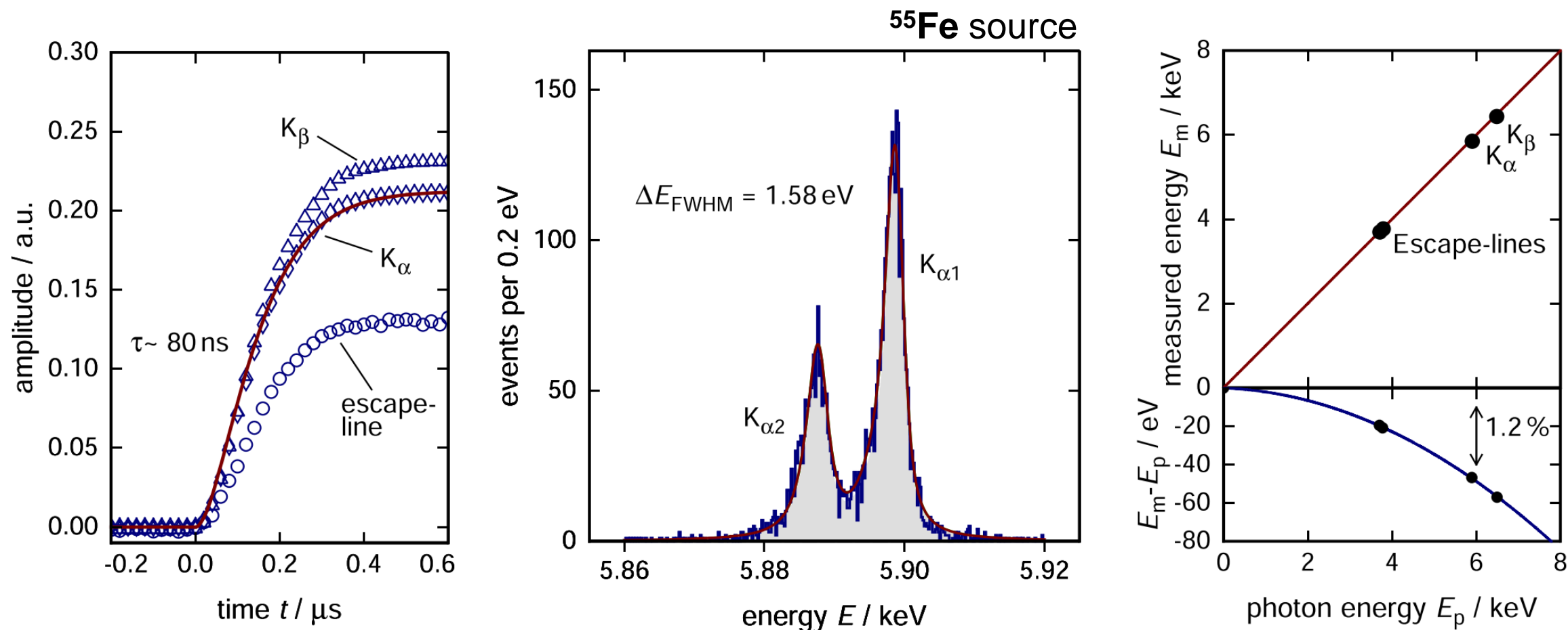
HERON



DELIGHT MMCs

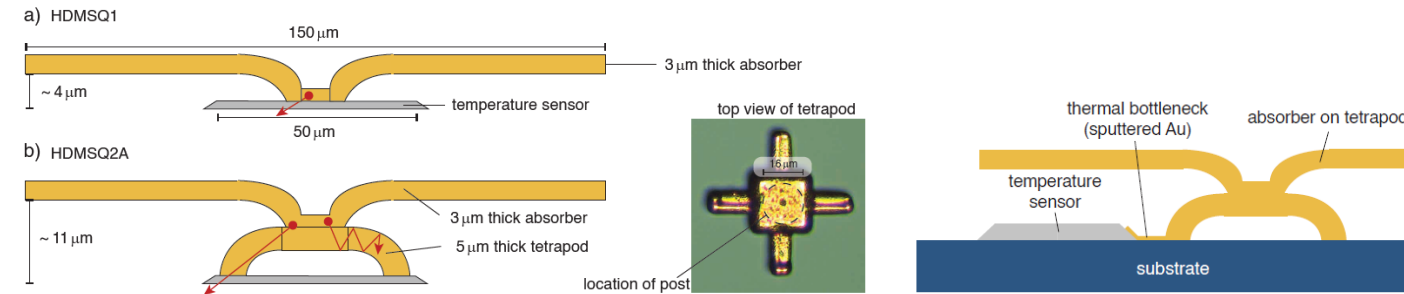


MMCs performance: maXs-20 detector

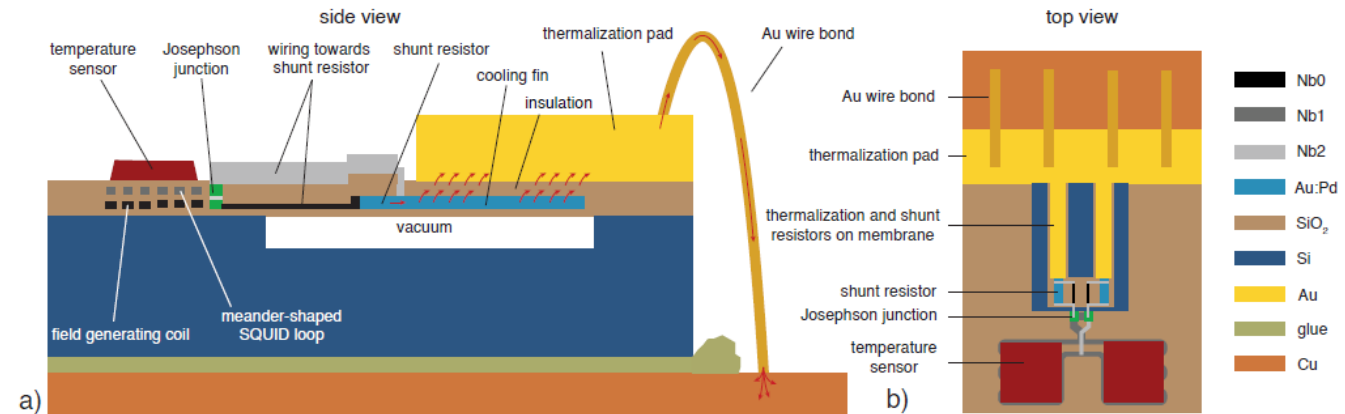


MMC improvements

Tetrapod absorber geometry



Shunt resistor on SiO₂ membrane



MMC resolution analysis

