Karlsruher Institut für Technologie

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

DELight

DELight: a **D**irect search **E**xperiment for **Light** dark matter with superfluid helium

Francesco Toschi for the DELight collaboration

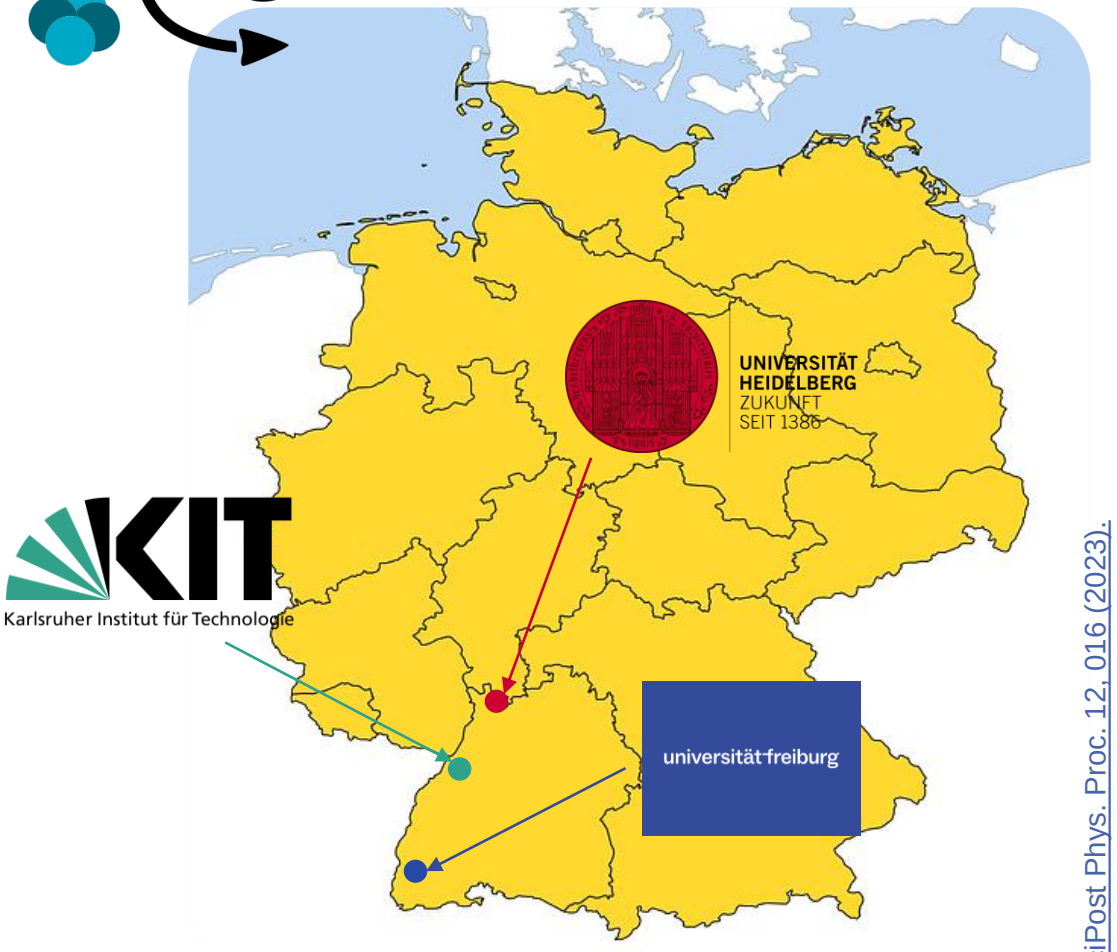
ALPS-DM 2024 – 04.04.2024, Obergurgl

The DELight collaboration

DELight

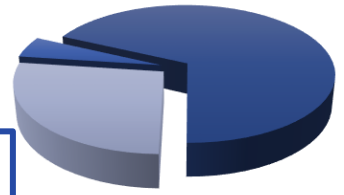
3 institutions from Baden-Württemberg

~20 scientists



SciPost Phys. Proc. 12, 016 (2023).

The hunt for Dark Matter

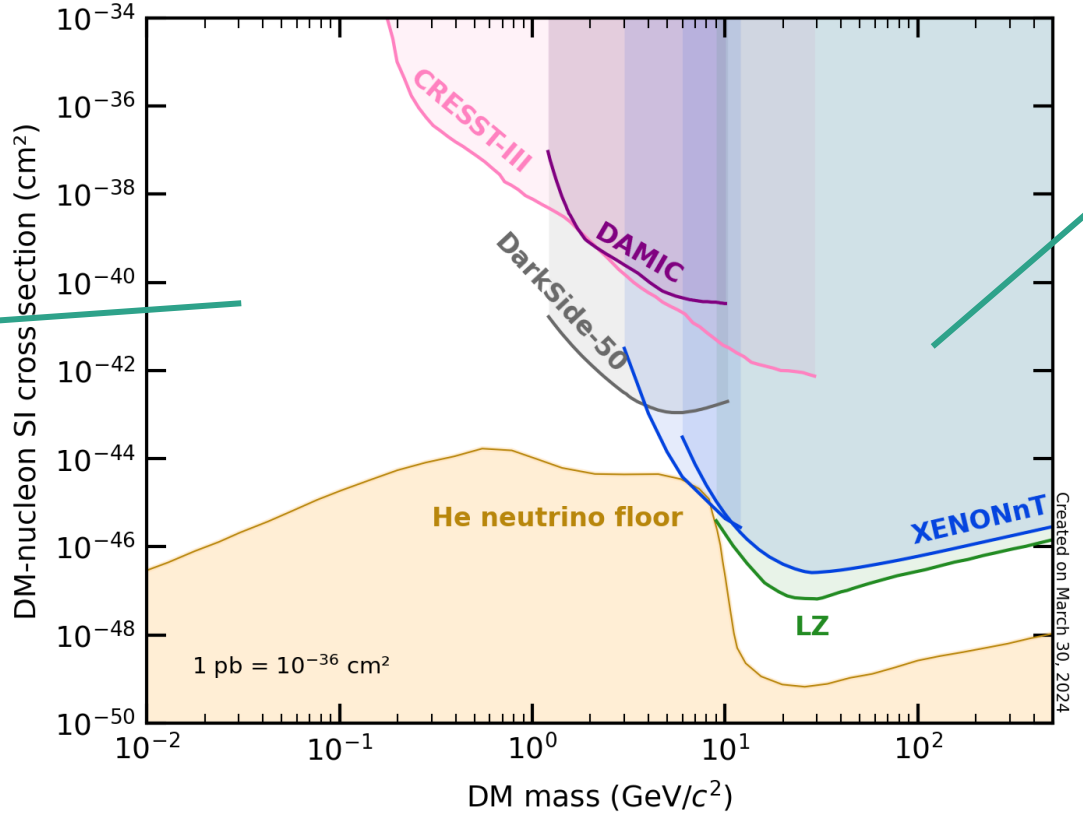


Ordinary matter
4.9%

Dark matter
26.8%

Dark energy
68.3%

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



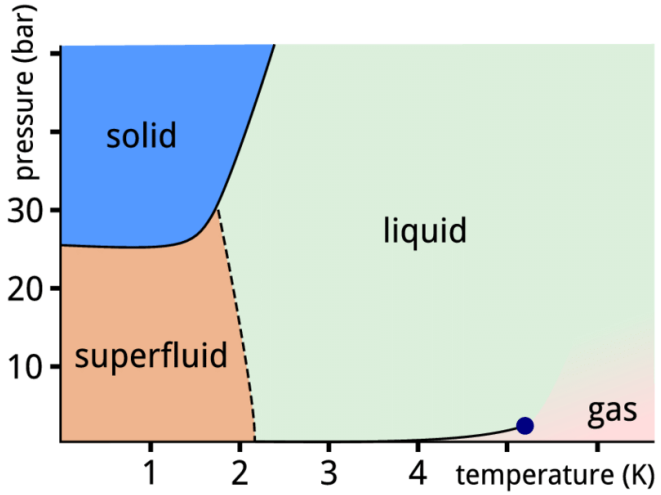
Noble liquid dual-phase TPCs constrain the phase space for large WIMP masses

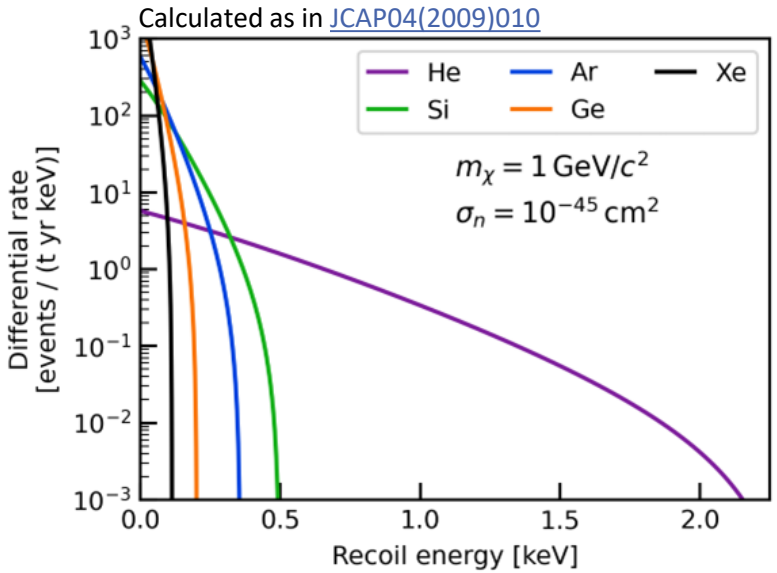
Phys. Rev. Lett. **131**, 041002 (2023)

Phys. Rev. D **107**, 063001 (2023)

Phys. Rev. Lett. **131**, 041003 (2023)

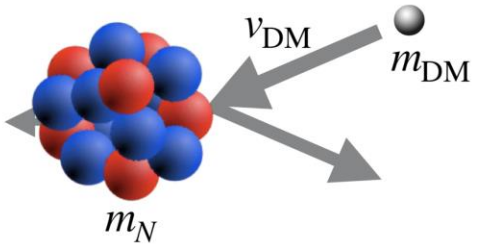
Superfluid ^{4}He as target





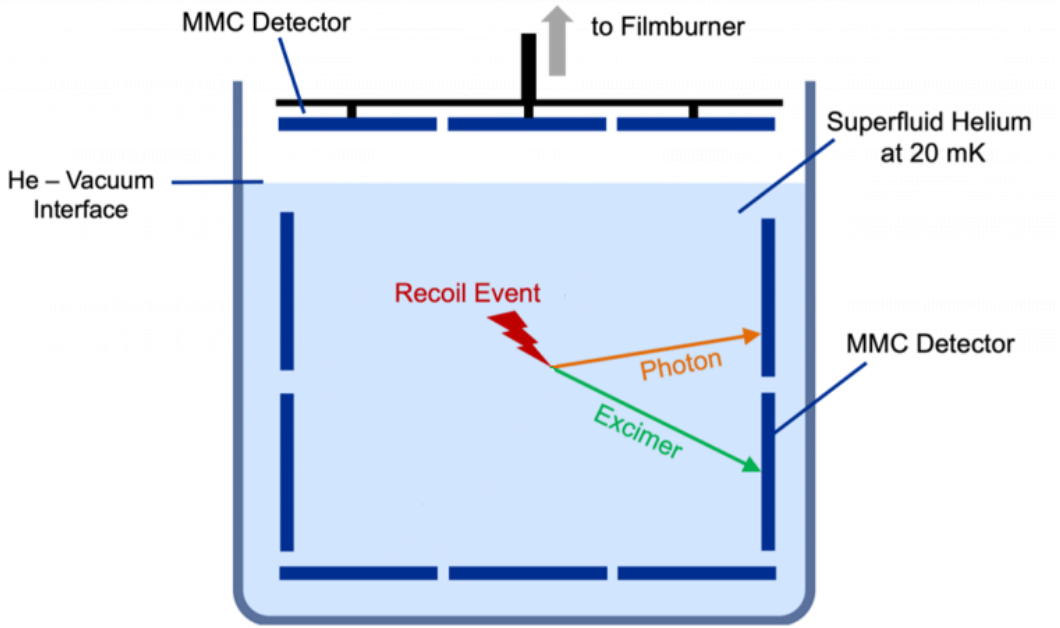
- Impurities freezing out (~20 mK)
- Multiple signal channels
  - ER/NR discrimination
  - Energy reconstruction
- Inexpensive material and scalable technology

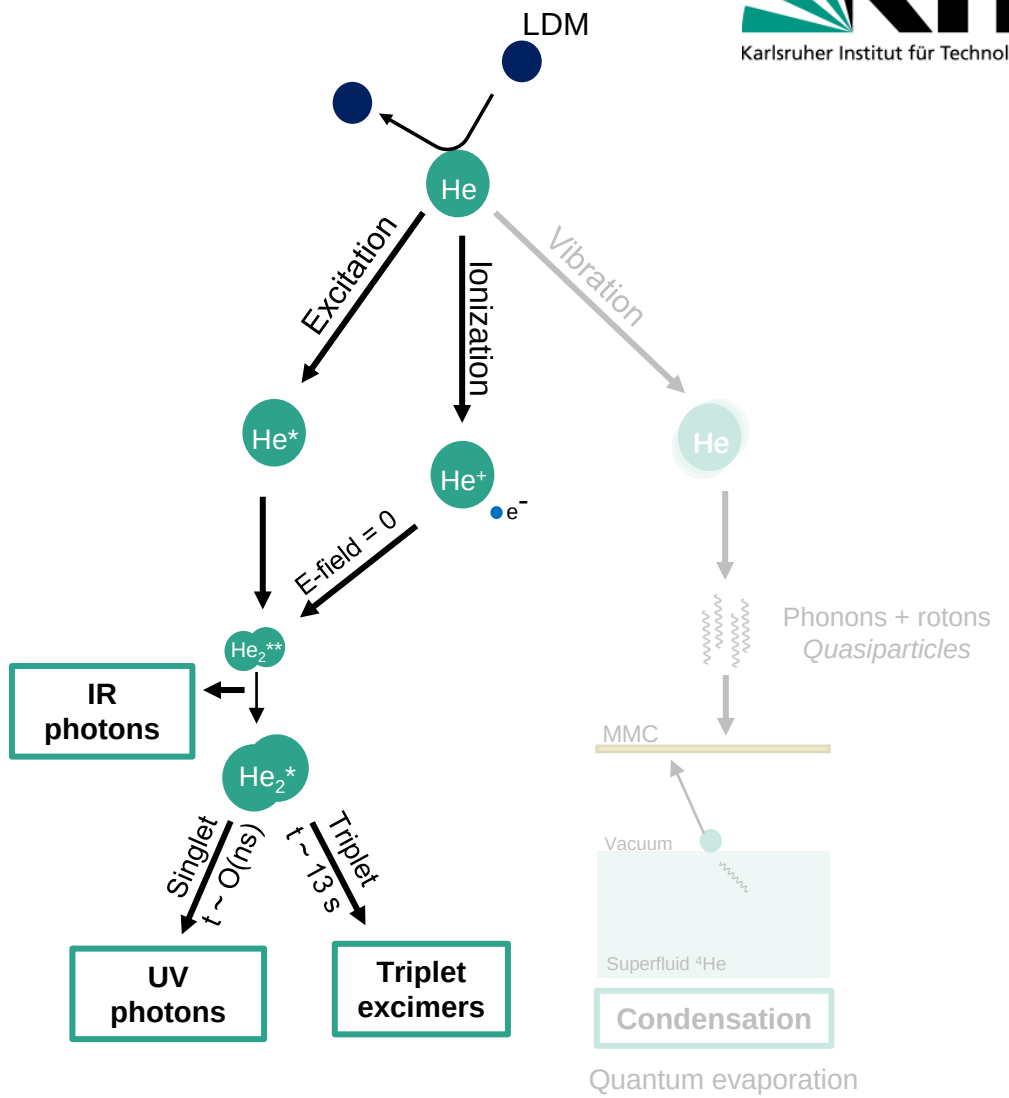
- Light nuclei maximize recoil energy for LDM



DELight detection principle

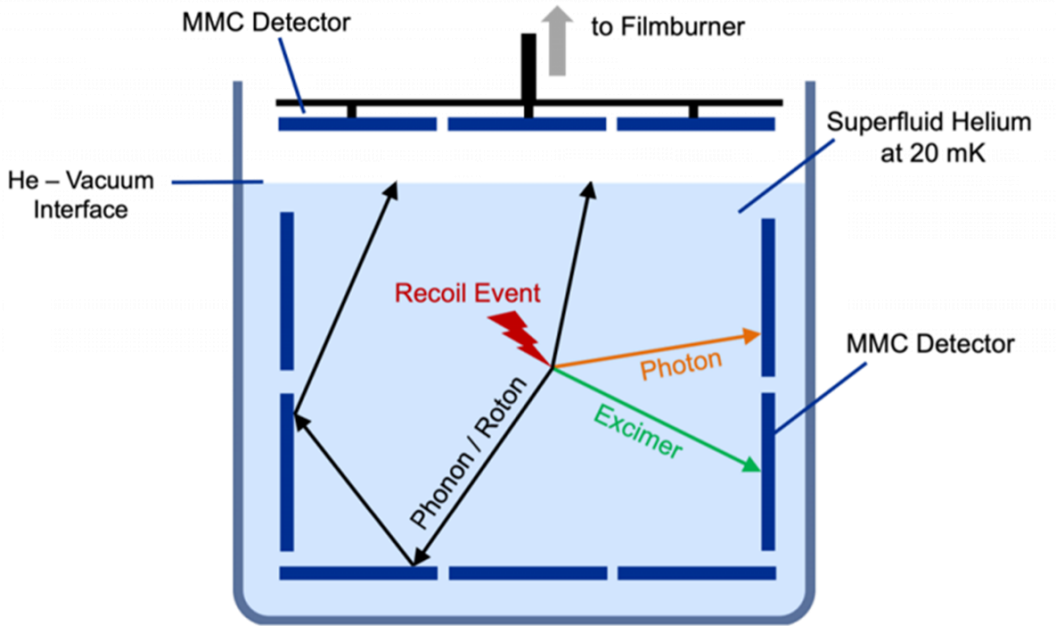
- Prompt detection of UV and IR photons
- Ballistic triplet excimer (13 s lifetime, O(m/s) speed)
  - Decay at interface with solid or vacuum

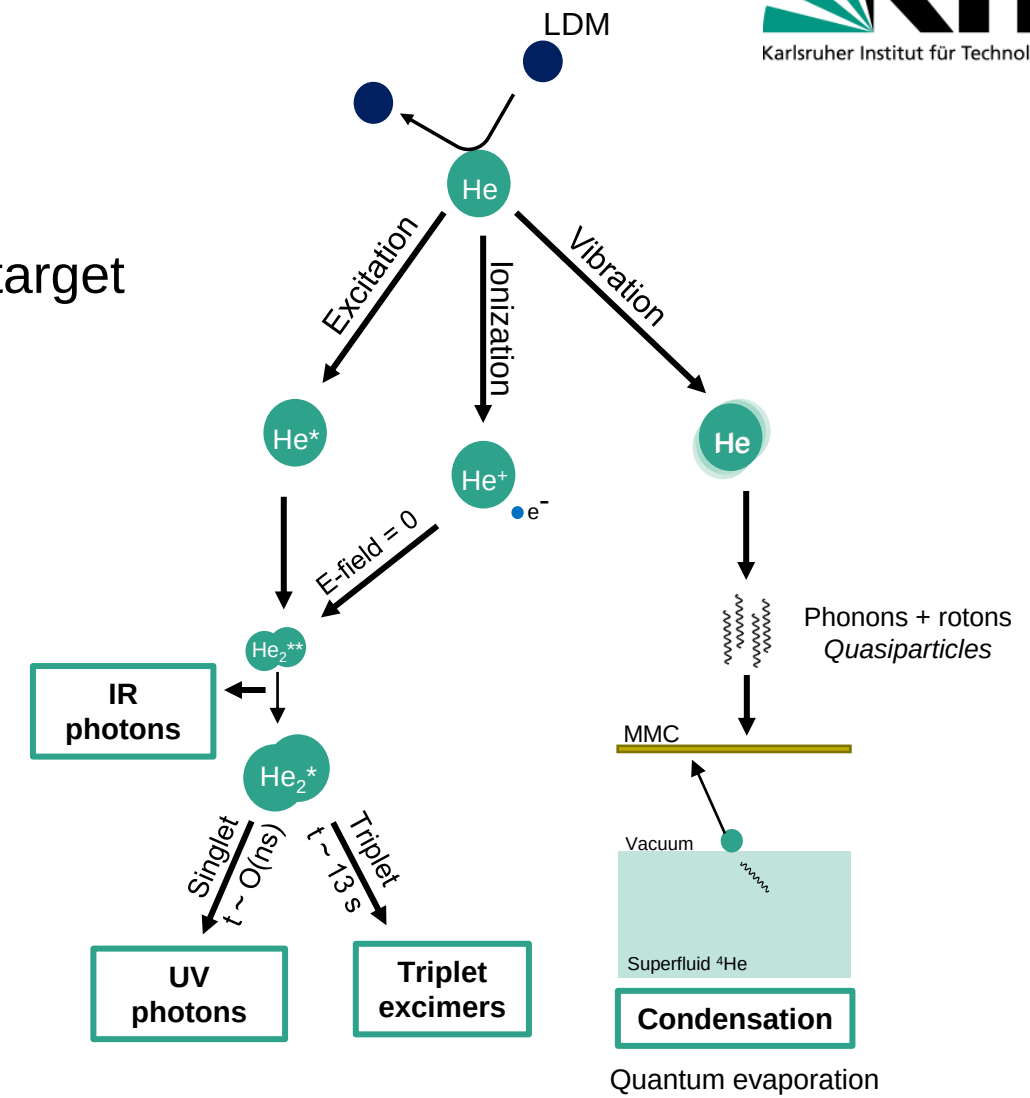




DELight detection principle

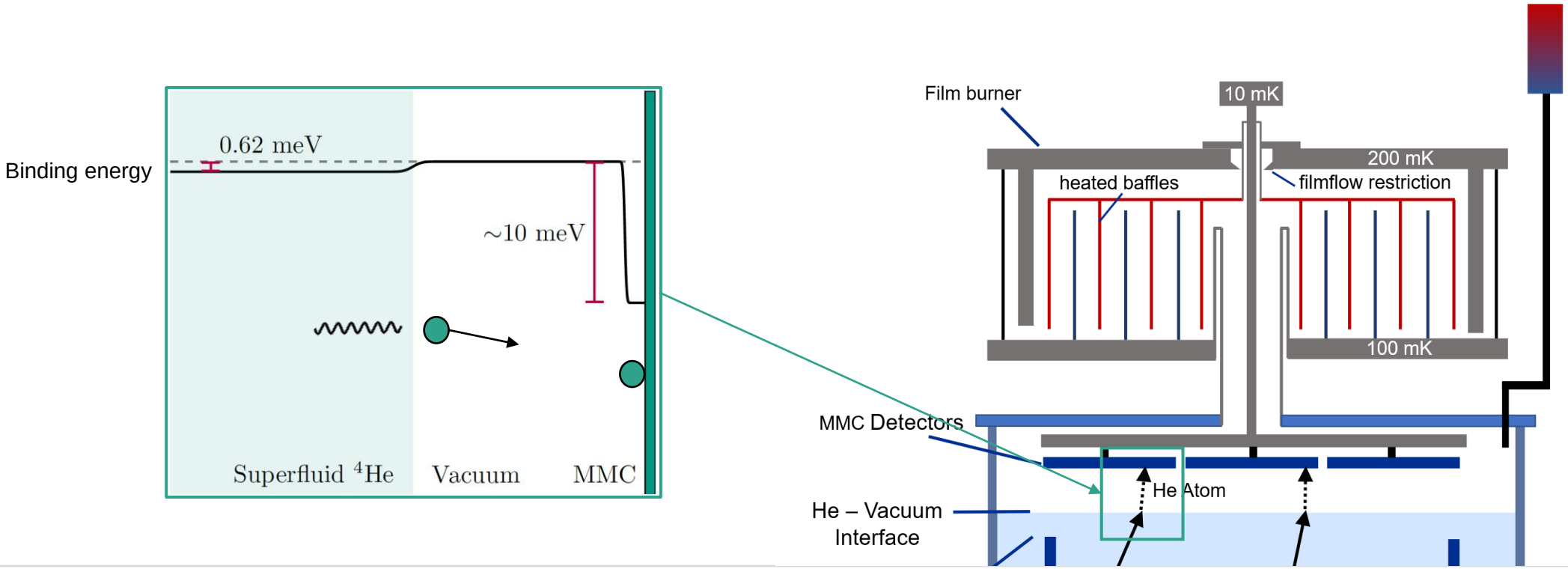
- Production of phonons and rotons
- Quasiparticles propagate ballistically within the He target
- Reflected at the interface with solid





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 ^{4}He film-free → film burner (already tested by HERON)



DELight detection principle

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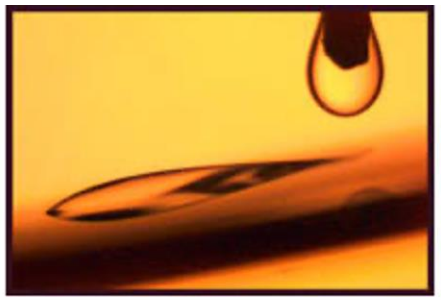
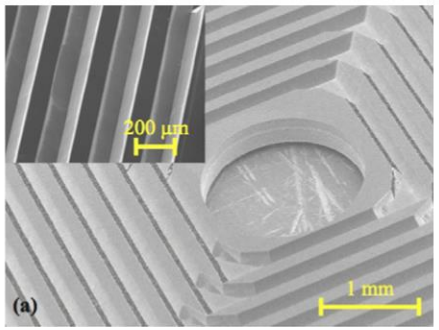
Alternatives



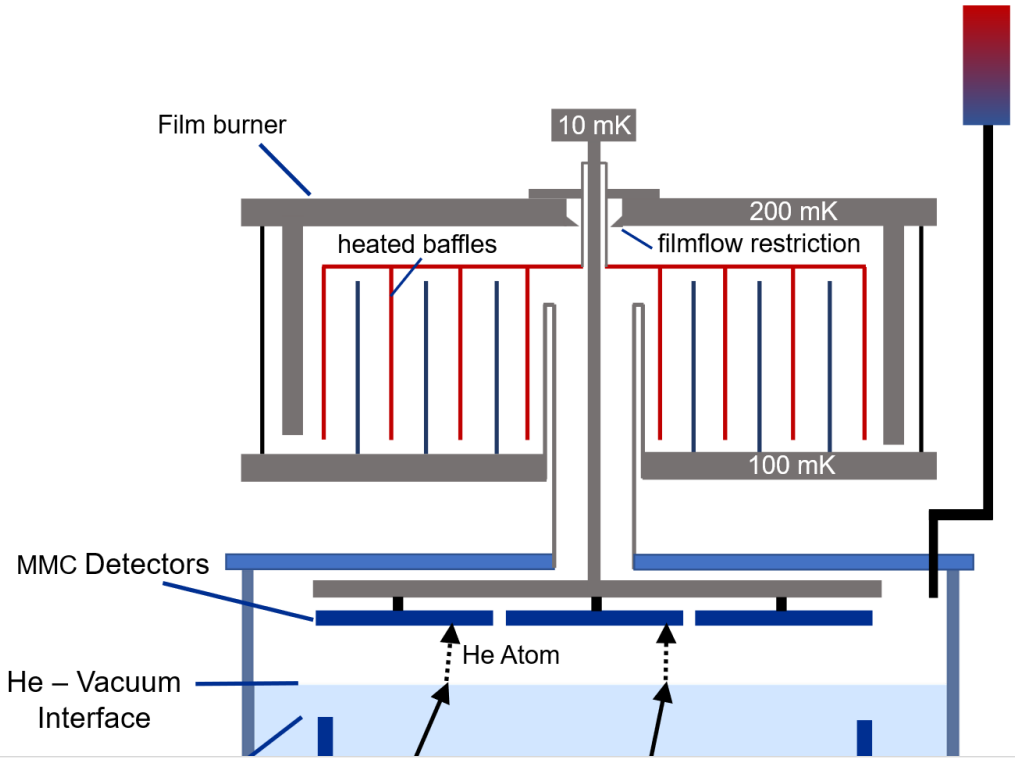
Cesium coat

successfully tested by HeRALD
arXiv:2307.11877



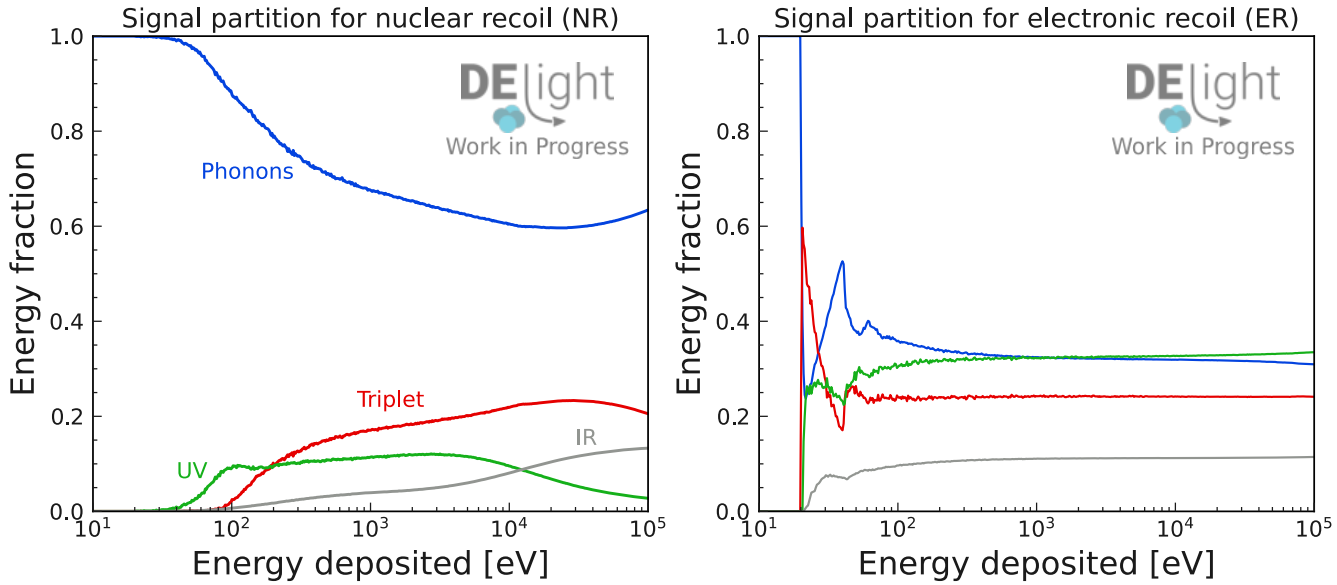
Knife-edge

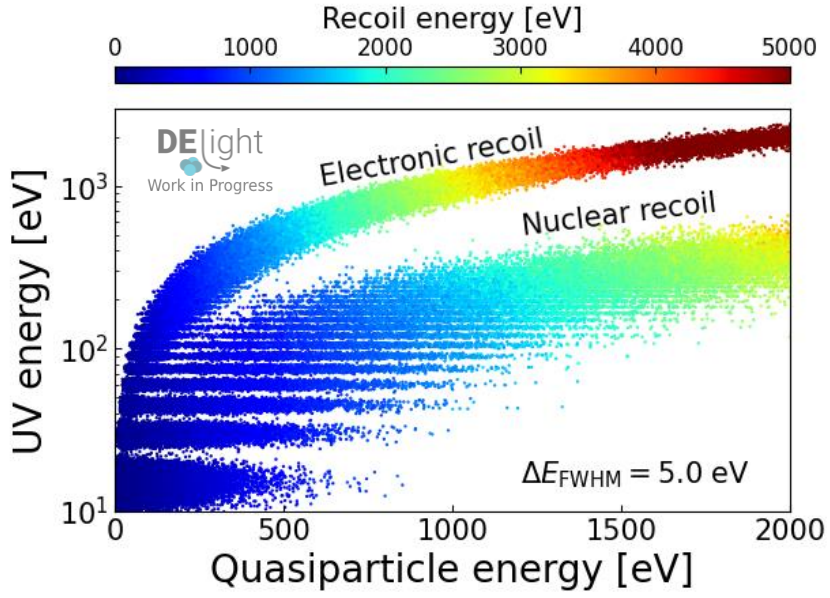
film-flow reduction of 30% (NASA)
J. Astr. Tel. Inst. Syst. 4(1), 011203



Signal partitioning in superfluid ^{4}He

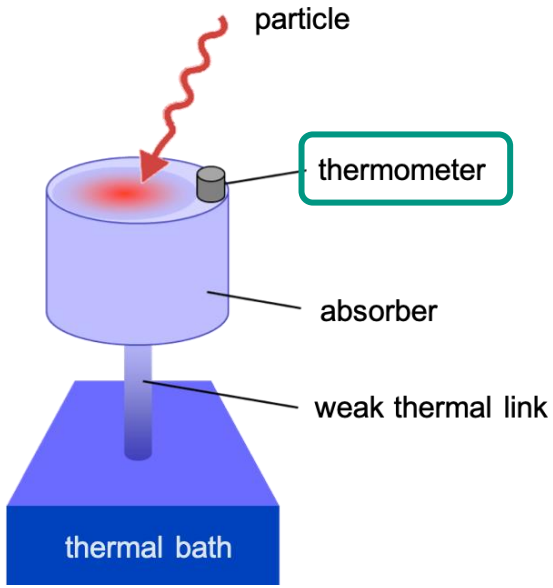
- „Interaction-by-interaction“ estimate of energy partition into different channels using measured and calculated cross sections
- Very promising discrimination between electronic (background) and nuclear (signal) recoil

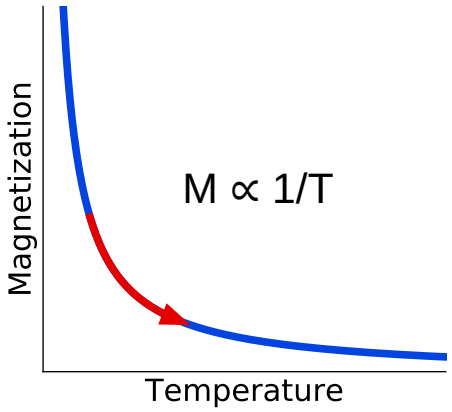


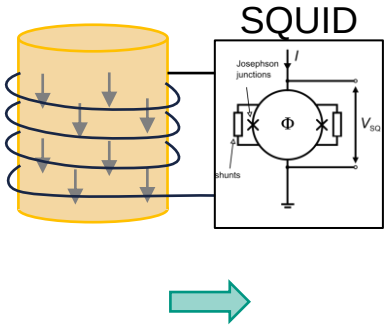


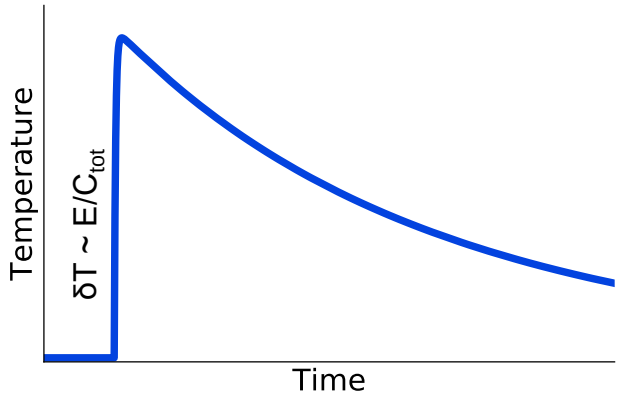
Magnetic microcalorimeters (MMC)

- Energy deposit in an *absorber* converted to a temperature increase δT, changing the magnetization of the *paramagnetic sensor* **δM ∝ δT**
- Change in magnetization measured by a coupled SQUID as change in current **δI ∝ δM**





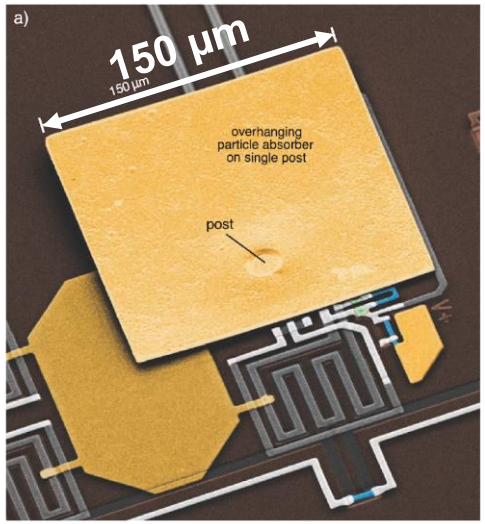


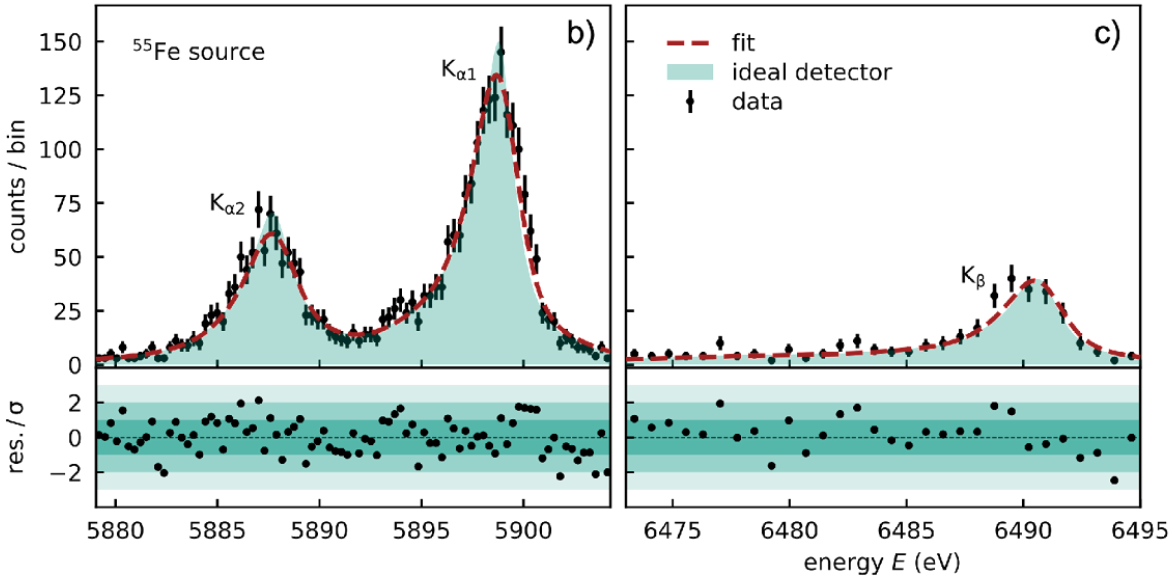


Magnetic microcalorimeters (MMC)

- Previous best MMC resolution: $\Delta E_{FWHM} = 1.58$ eV @ 5.9 keV (x-rays from ^{55}Fe) (1)
- Achieved best resolution to date with optimum-filter based analysis(2,3):
  - $\Delta E_{FWHM} =$ **1.25(18) eV** @ 5.9 keV;
  - amplitude fit to K_α data, validation reconstruction K_β.

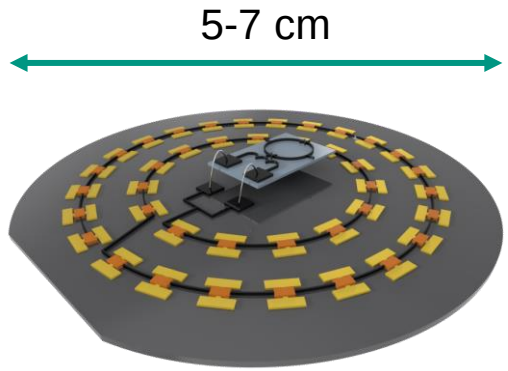
X-rays MMC

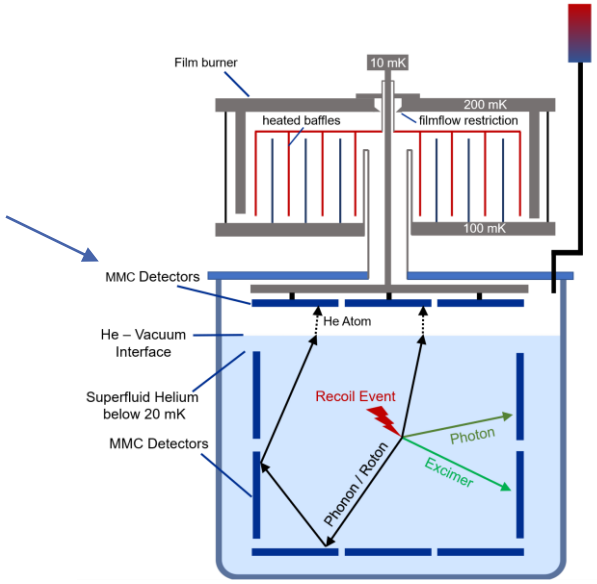




1 J. Low Temp. Phys. 193, 365-379 (2018)
2 Phys. Rev. D 109, 043035 (2024)
3 Appl. Phys. Lett. 124, 032601 (2024)

MMCs in DELight

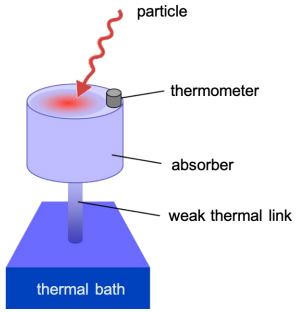




First phase

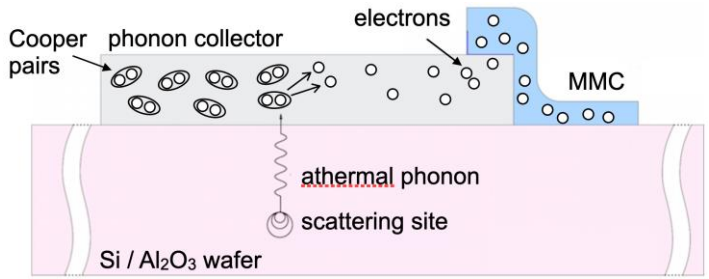
- ~50 MMC-based wafer calorimeters
- 5-6 eV resolution ⇒ ~20 eV threshold
- Sapphire or silicon substrate wafer
- Athermal phonon detection (R&D)

Thermal phonon detector

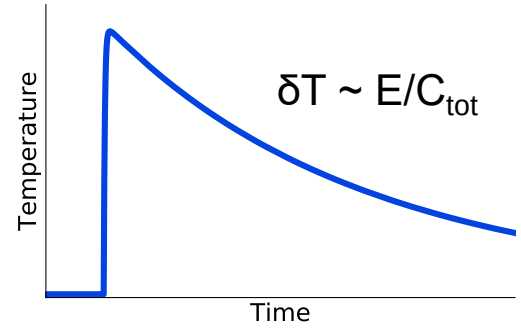


$$C_{\mathrm{tot}} = C_{\mathrm{sens}} + C_{\mathrm{abs}}$$

Athermal phonon detector



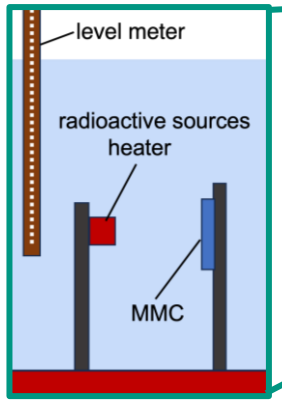
$$C_{\mathrm{tot}} = C_{\mathrm{sens}}$$

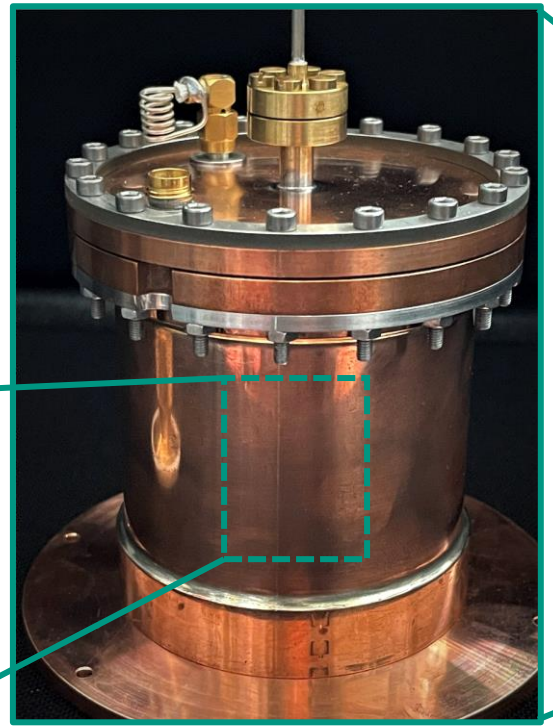


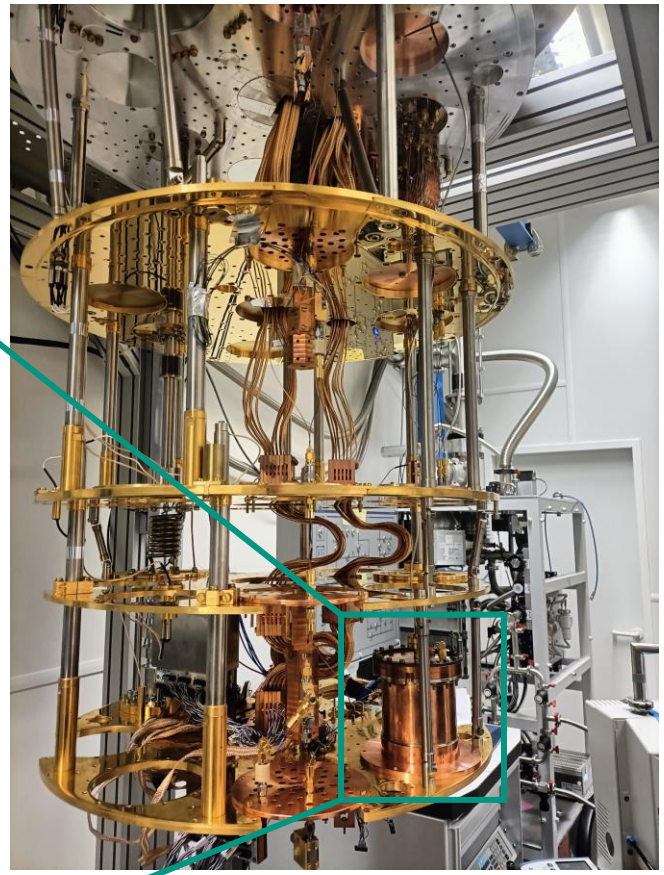
Helium cell @ Heidelberg University

- 280 mL test cell with capacitance level meter
- Operating in the ECHo experiment cryostat

- Planned/ongoing tests:
  - operation of MMC in superfluid helium,
  - direct quasiparticle measurement,
  - detection of UV photons and triplets,
  - and much more!

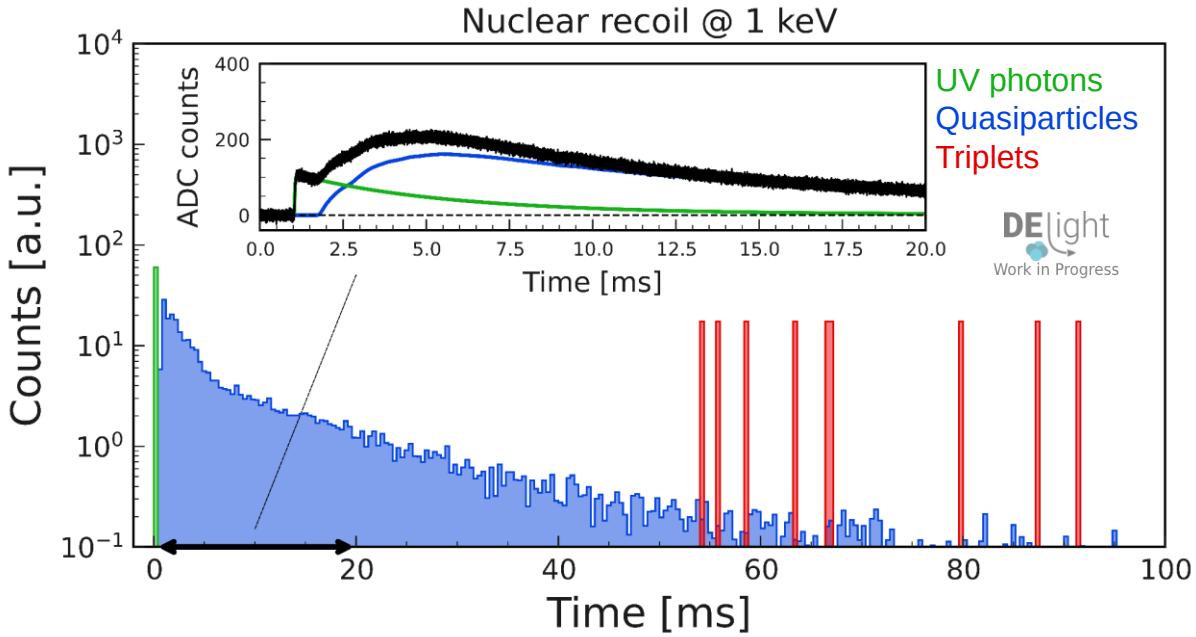


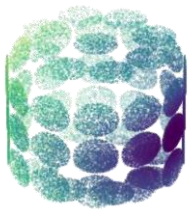


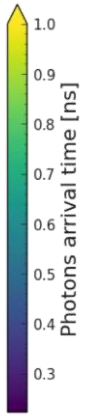


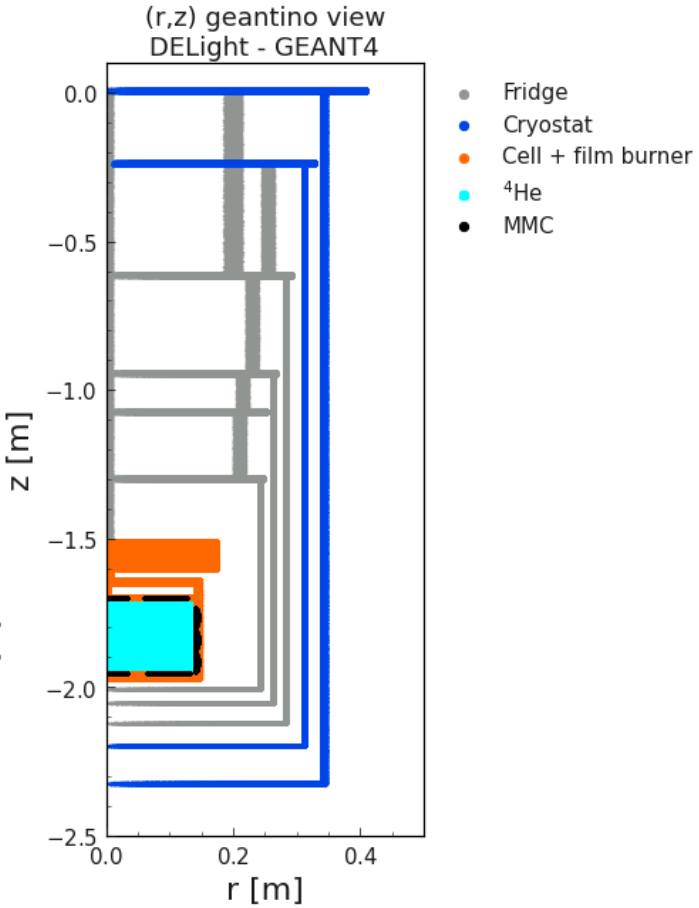
Simulations

- GEANT4 model of preliminary detector geometry
- Quasiparticle physics and propagation implemented
- First simulations of possible waveforms
- Backgrounds and discrimination studies ongoing



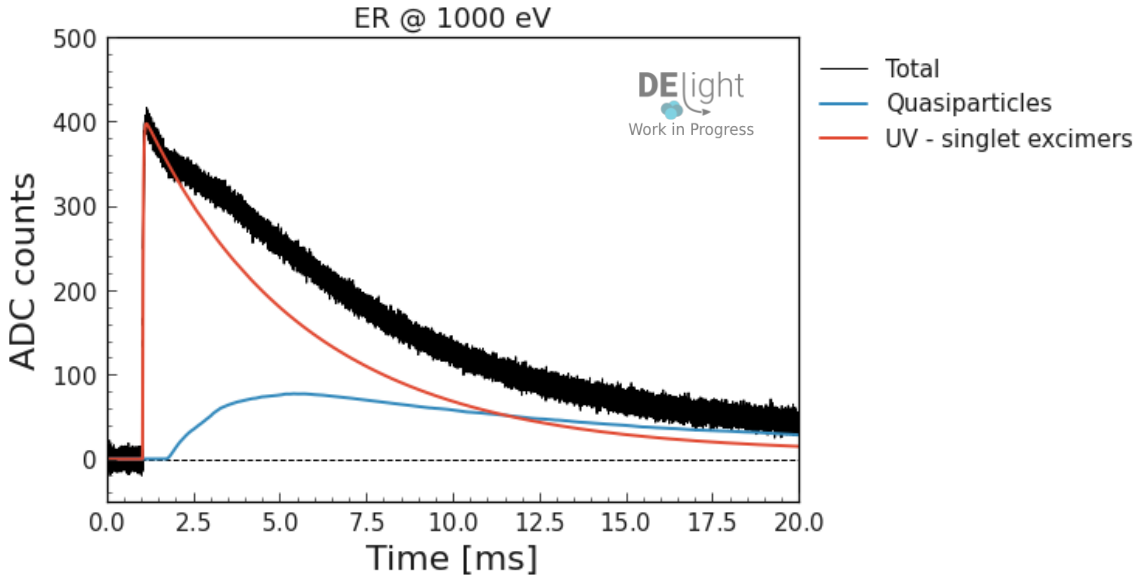


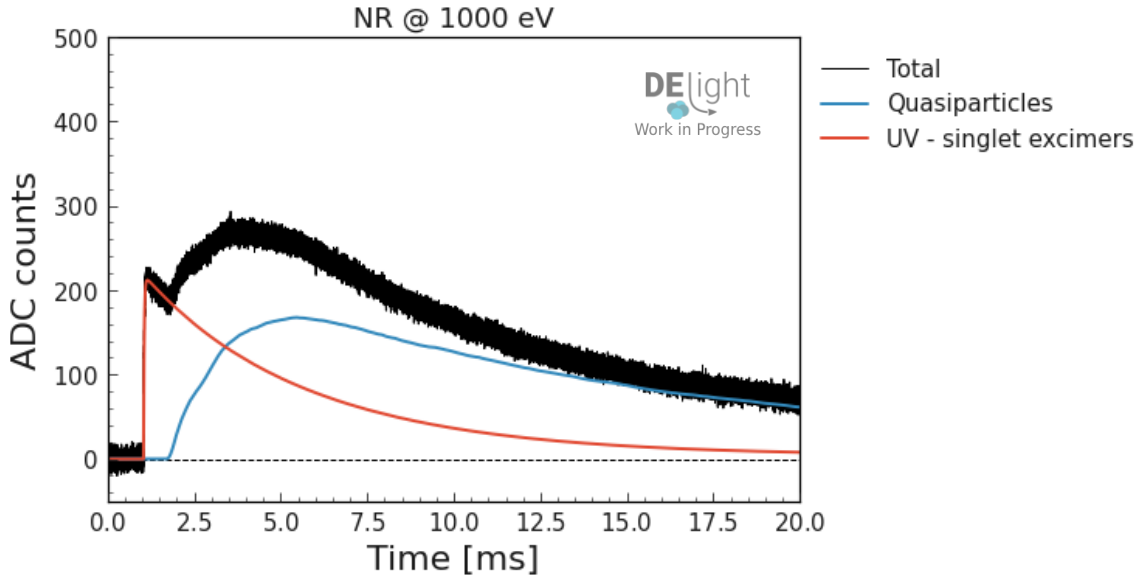




First waveform expectations

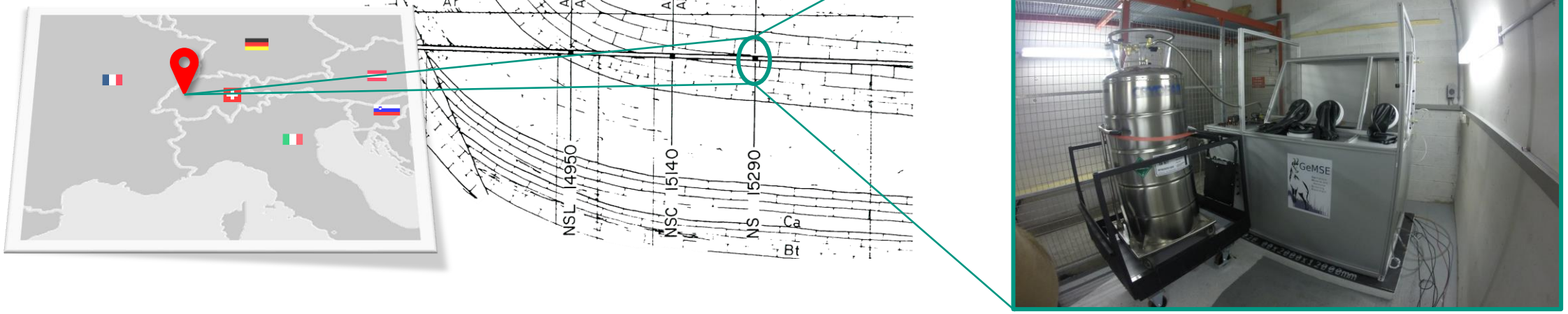
- First preliminary expectations using (x-ray) MMC response
  - MMC-based wafer calorimeters might likely have different time response





Vue-des-Alpes underground laboratory

- Shallow underground lab close to Neuchâtel, Switzerland
- Rock overburden of 620 m.w.e. ⇒ muon flux reduced by 1/2000
- Gamma and radon background measurements
- Operated by University of Freiburg (hosting GeMSE gamma spectrometer)



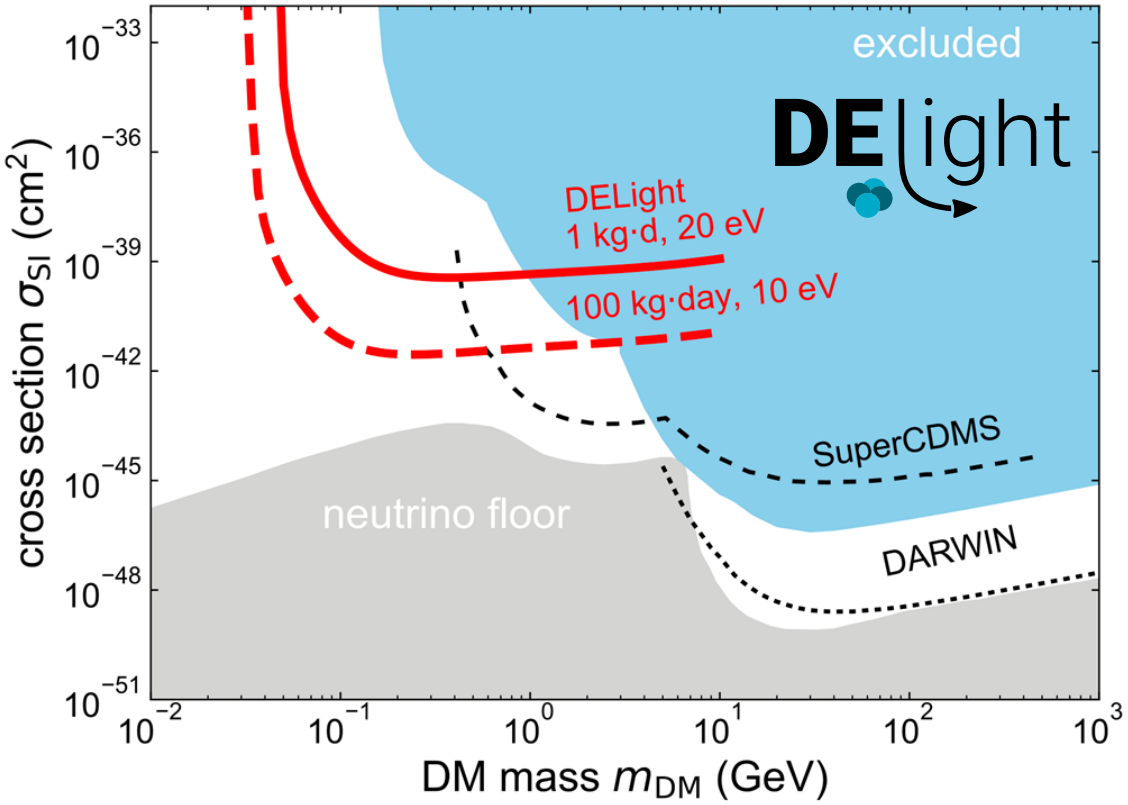
The future of DELight

First phase

- Above ground and/or shallow lab (e.g., VdA)
- 10 L target volume (≳1 kg)
- Threshold of 20 eV
- Probing new physics with exposure of 1 kg·d

and beyond

- Underground lab
- Larger cell + long exposure
- Threshold <10 eV



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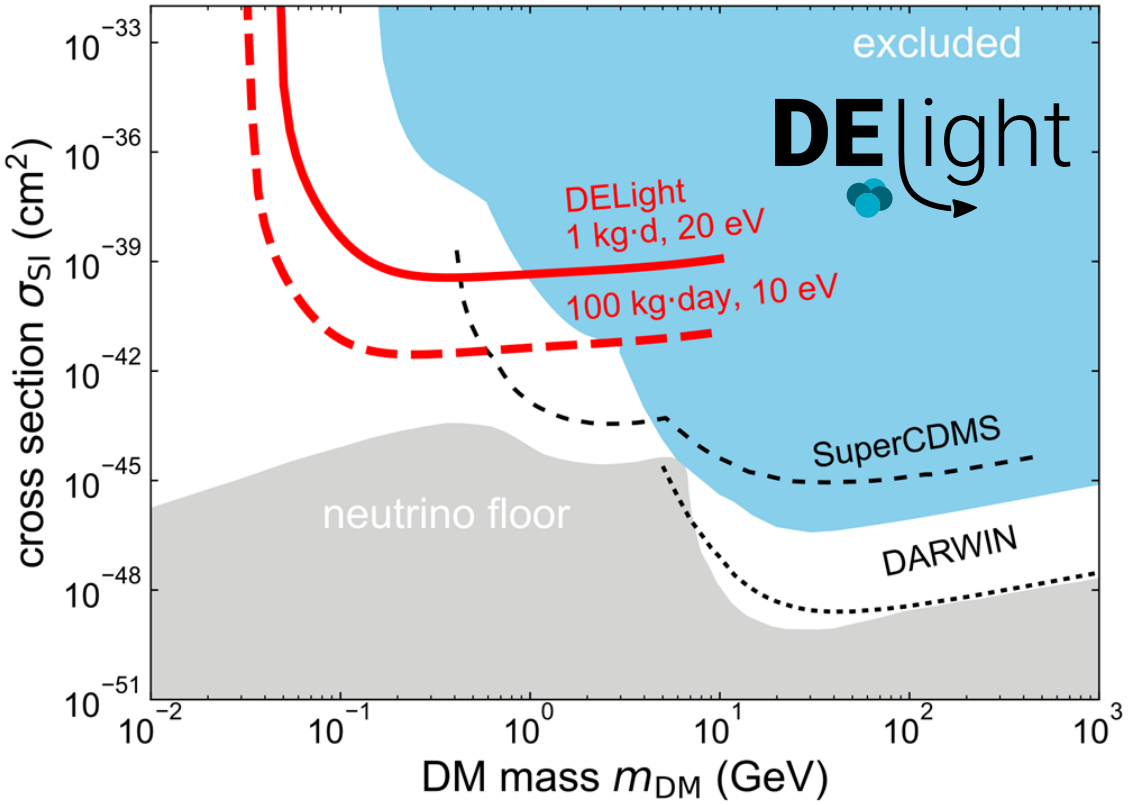
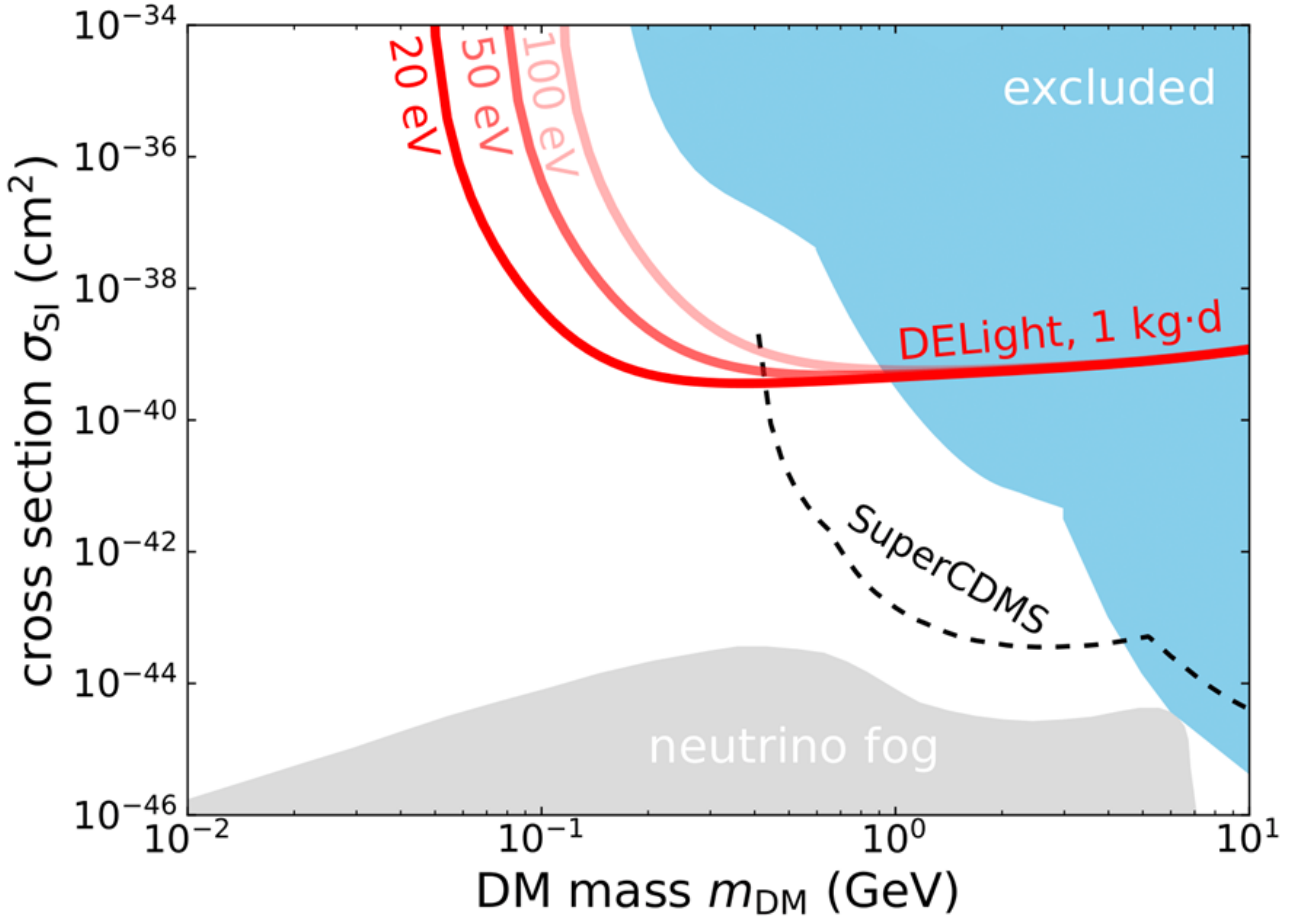
Find out more and stay tuned!



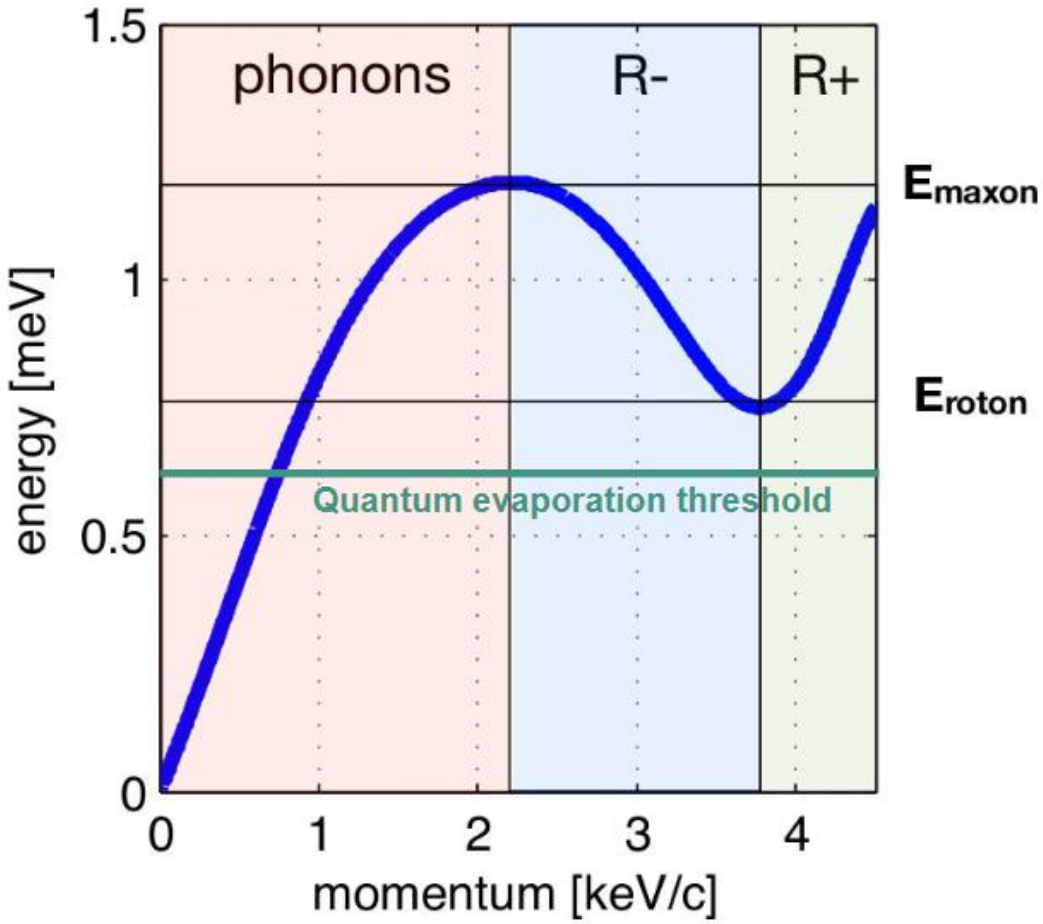
Backup slides

DELight phase-I: threshold impact



Quasiparticle in superfluid ^{4}He

- Non-monotonic dispersion relation
- No anharmonic decay below ~1 keV/c
- As scattering off surfaces, quasiparticles can change their nature

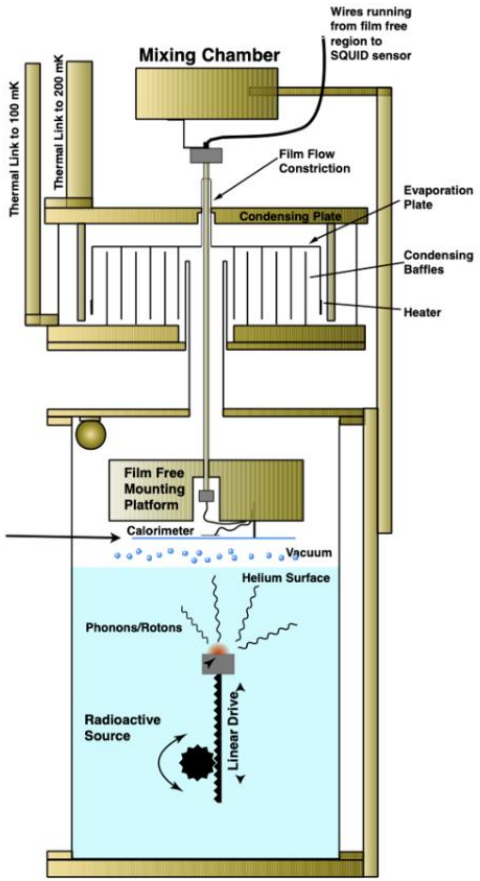


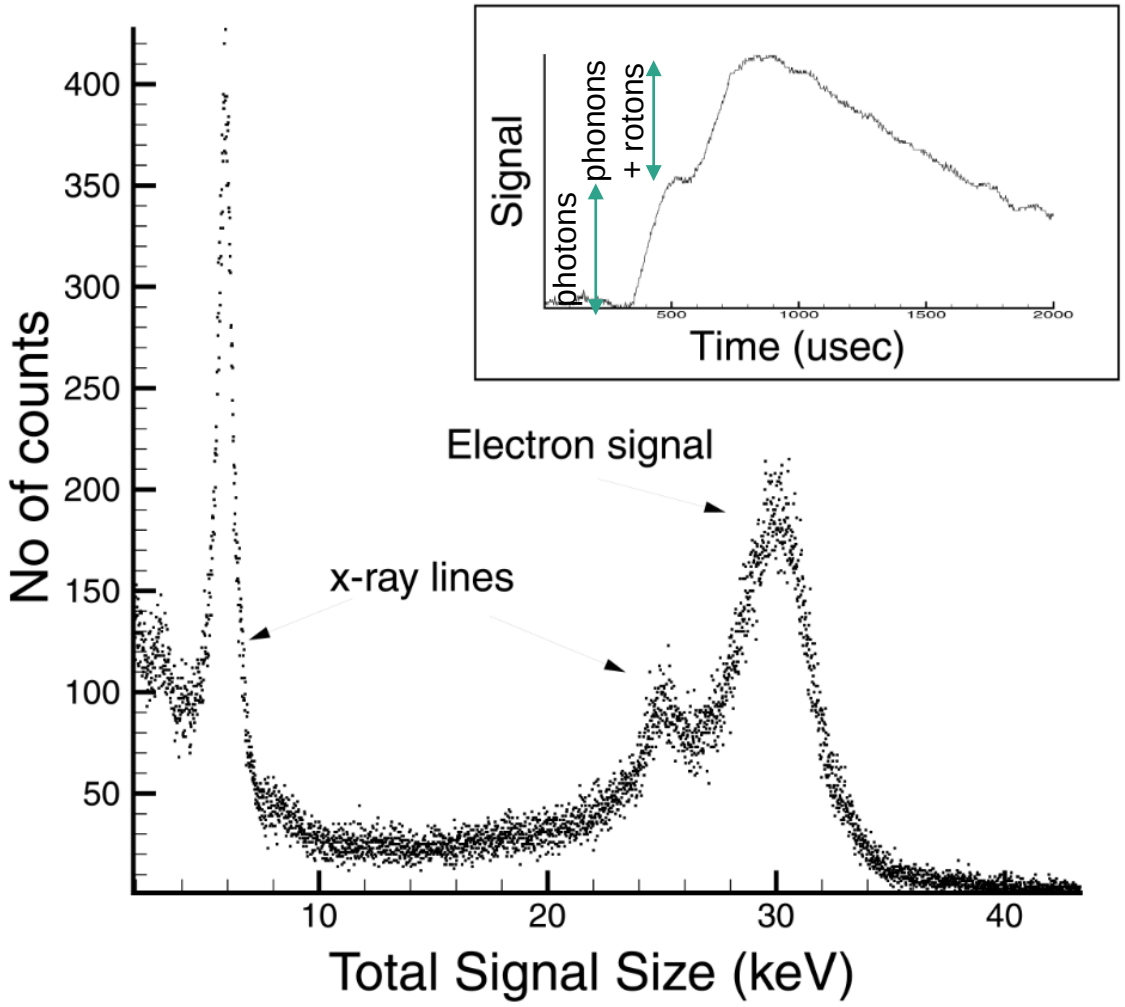
HERON

He film burner

wafer calorimeter

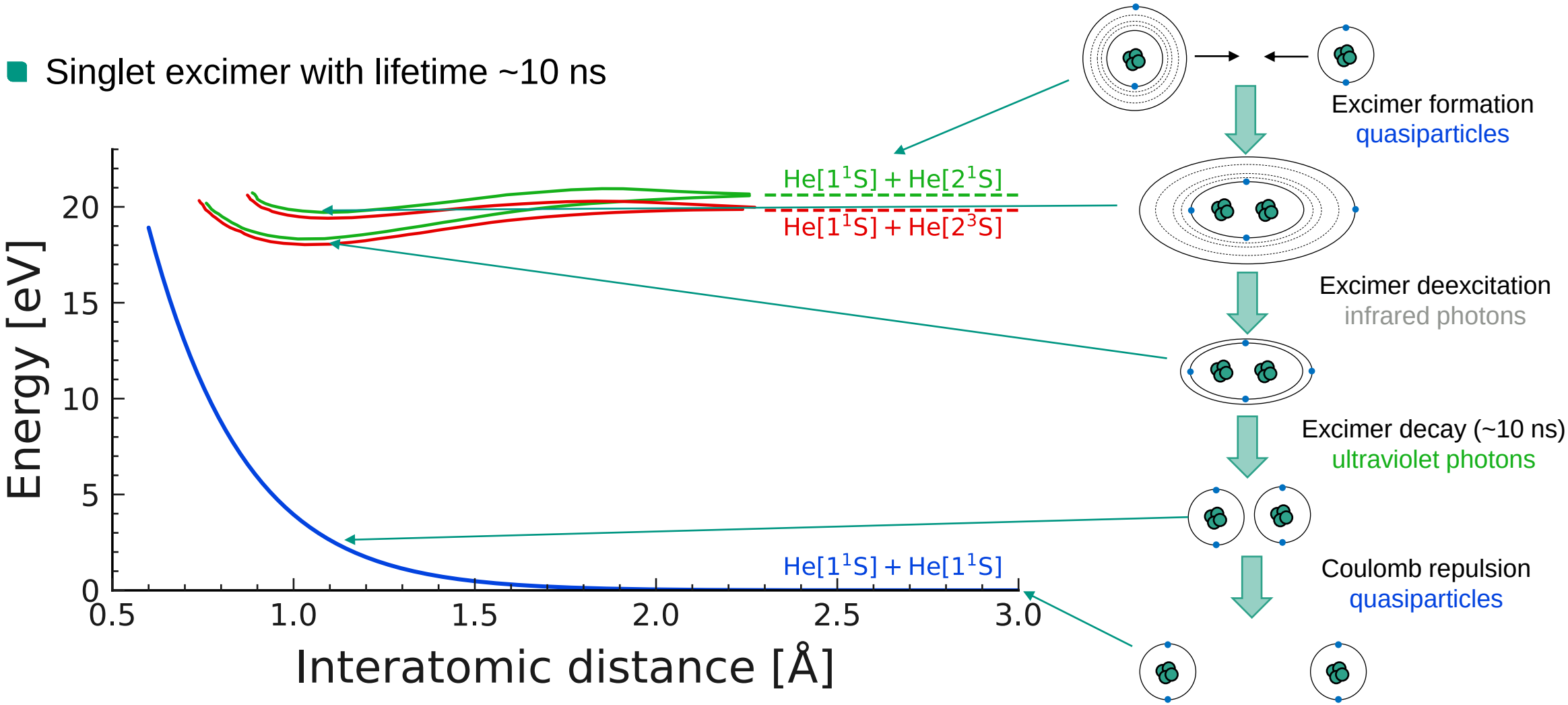
kg-scale
LHe mass





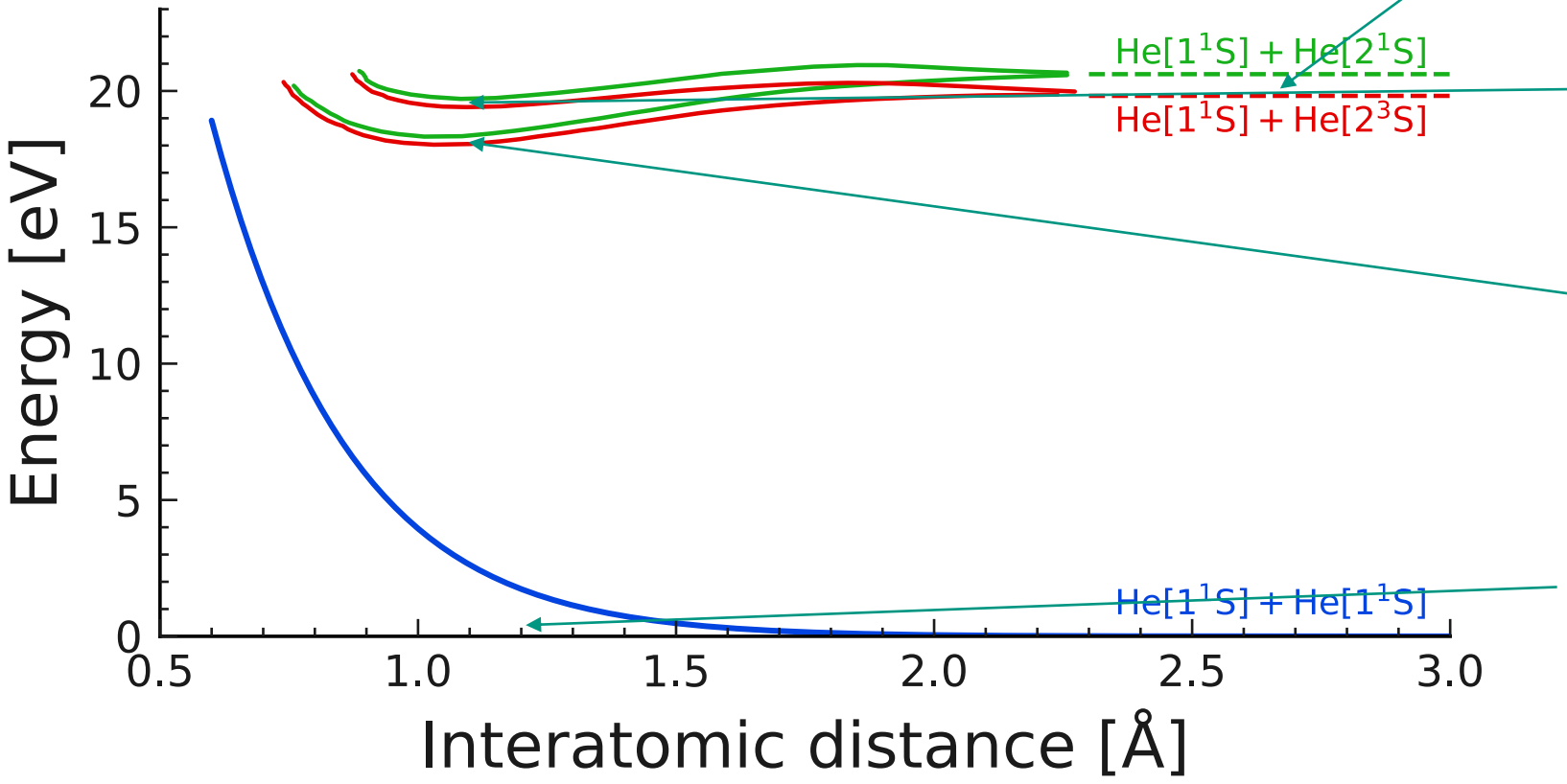
UV signal

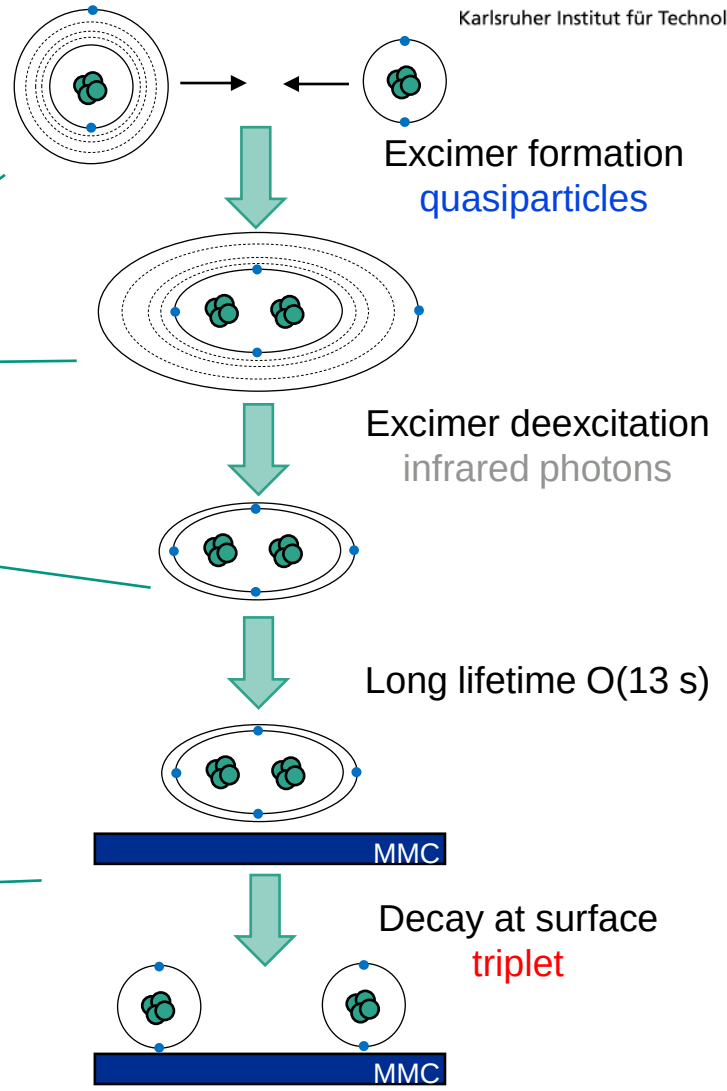
- Singlet excimer with lifetime ~10 ns



Triplet signal

- Triplet excimer with lifetime ~13 s





ER leakage (PRELIMINARY)

- Gaussian fit of the ER band in slices of quasiparticle energy
- Leakage as fraction of ER below the NR median