The Direct Search Experiment for Light Dark Matter (DELight): Overview and Perspectives

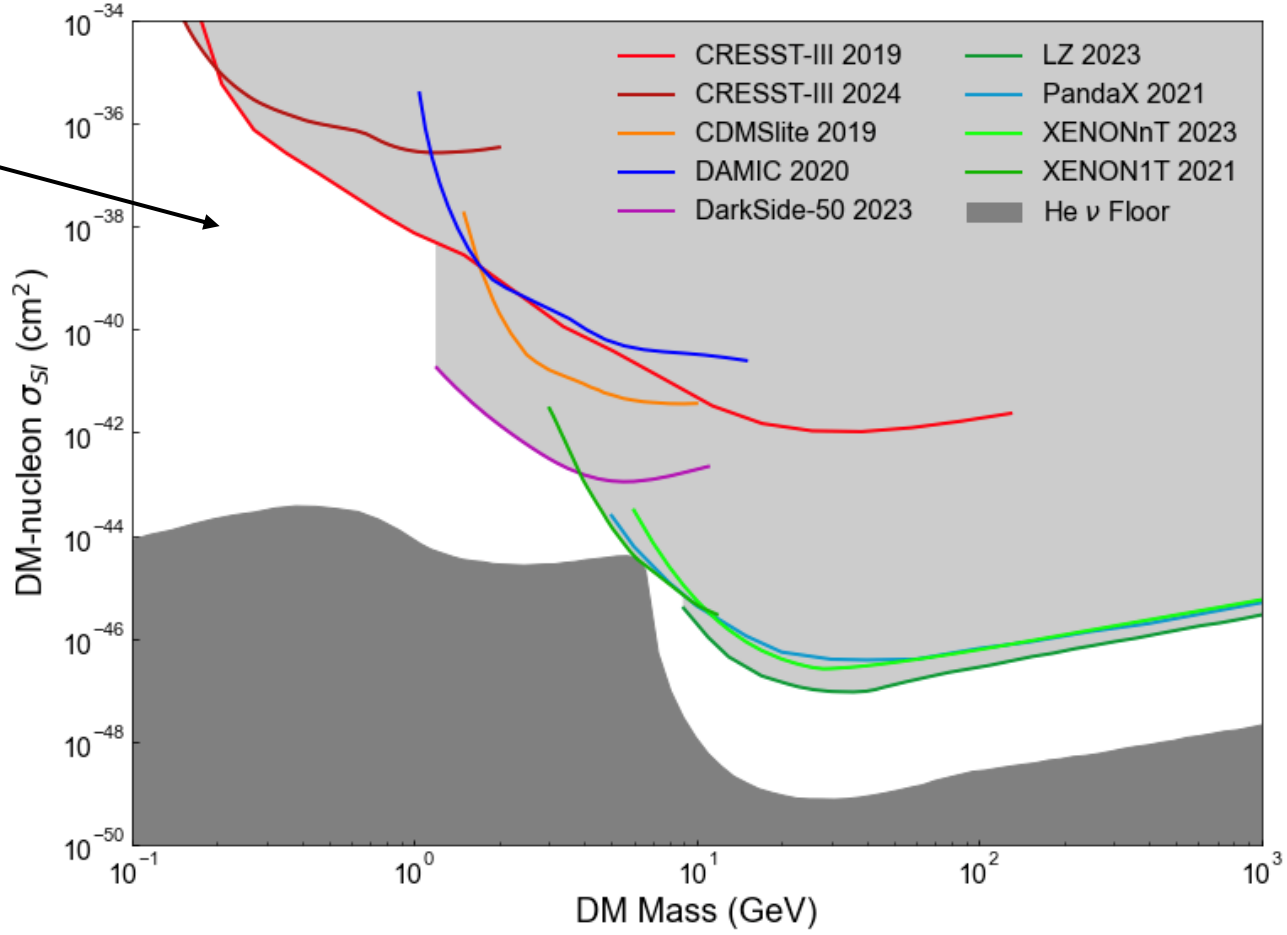
Credits foreground image: Matthew Herbst
Credits background image: NASA, ESA, E. Jullo, P. Natarajan, J.-P. Kneib

Melih Solmaz
on behalf of the DELight Collaboration

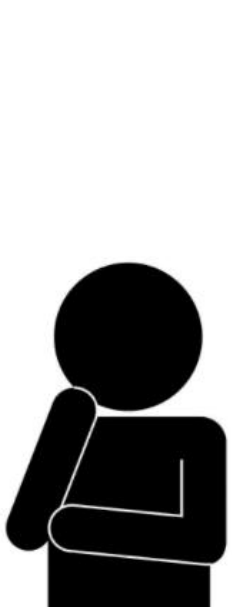
TAUP 2025, Xichang, 26.08.2025

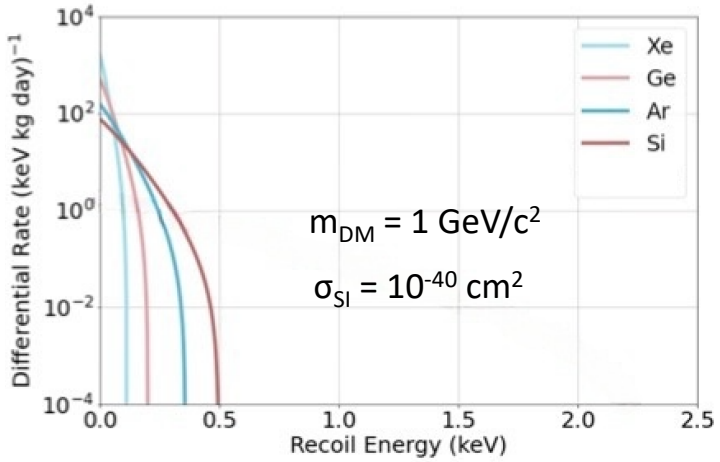
In Search for Light Dark Matter

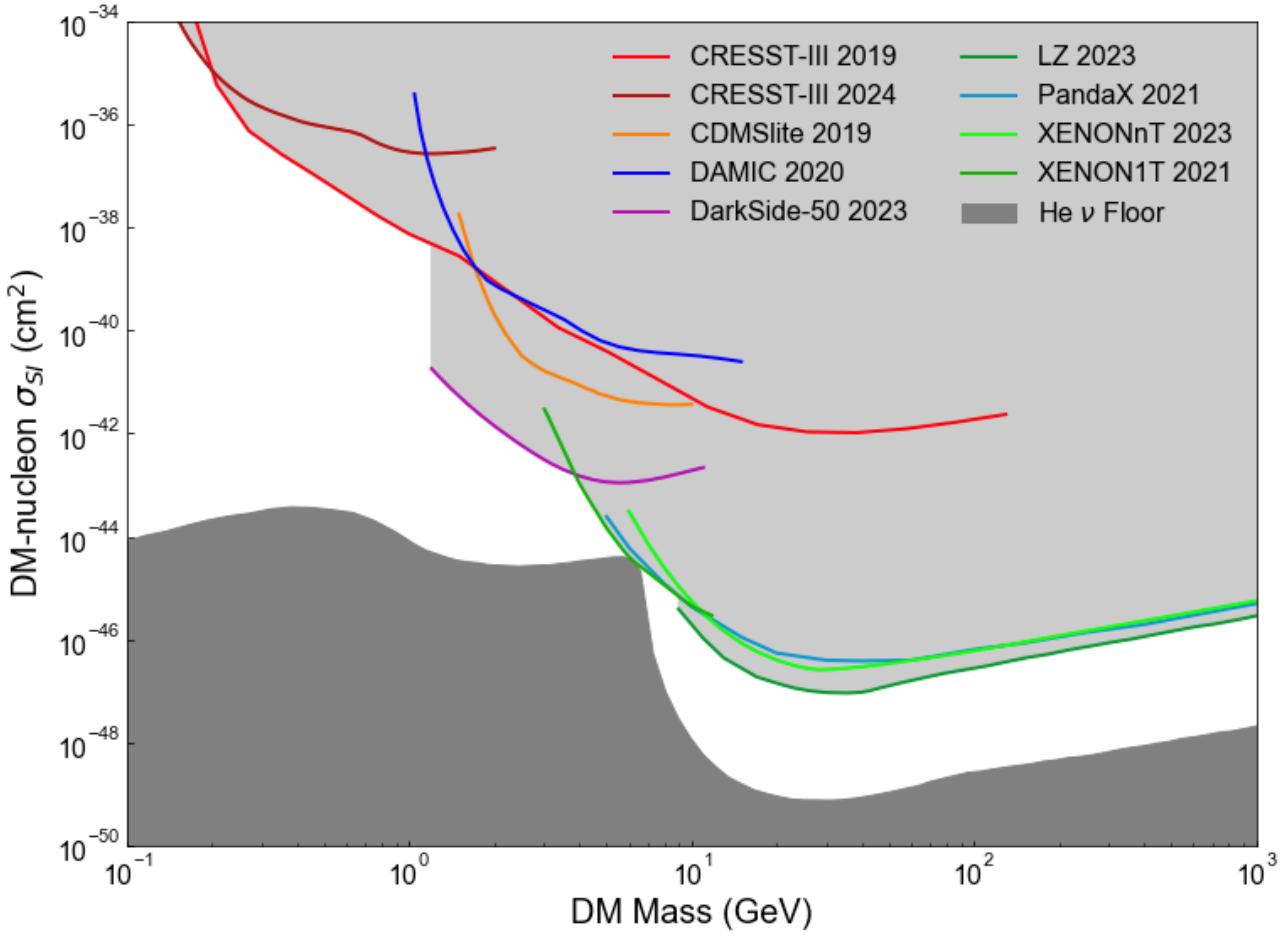
Credits: Chi-Tan/Getty Images



In Search for Light Dark Matter



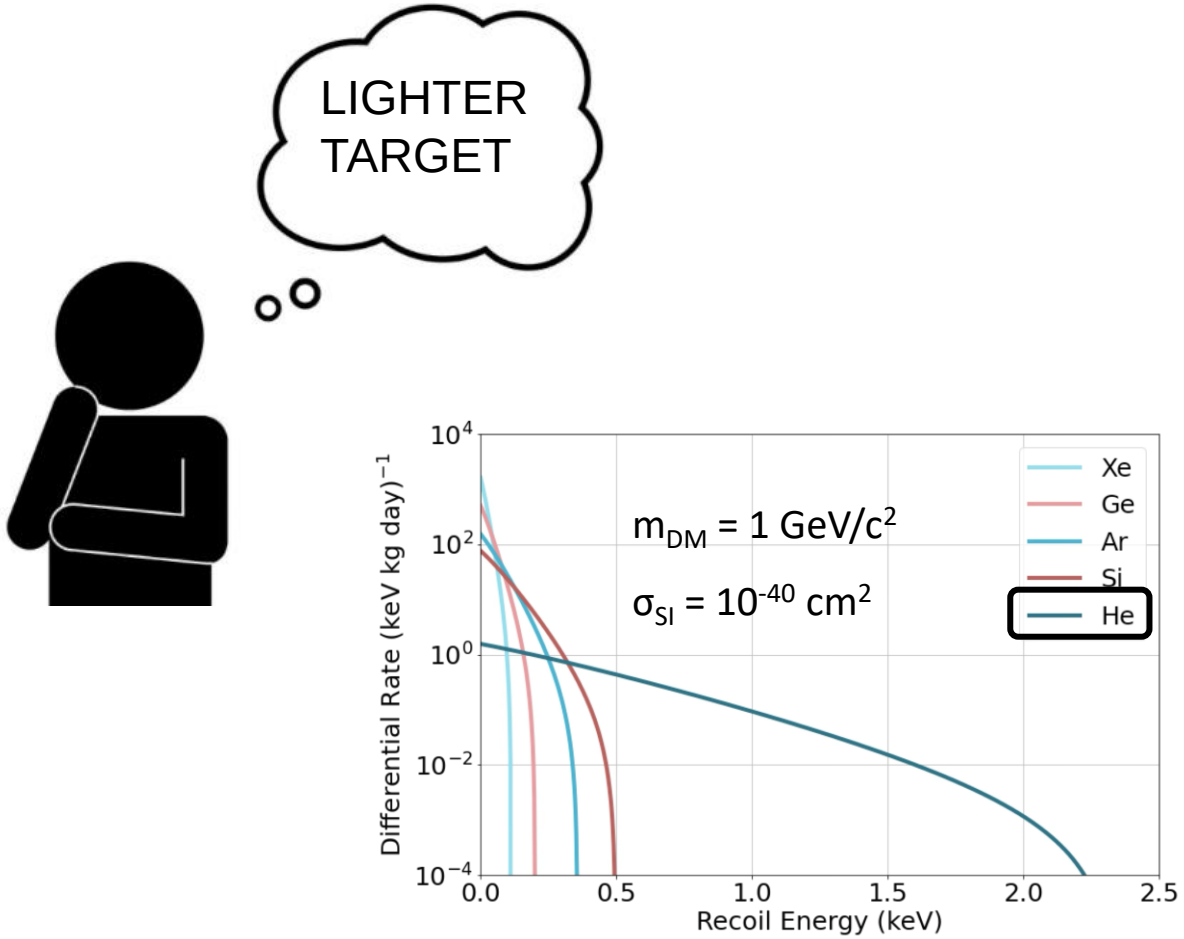


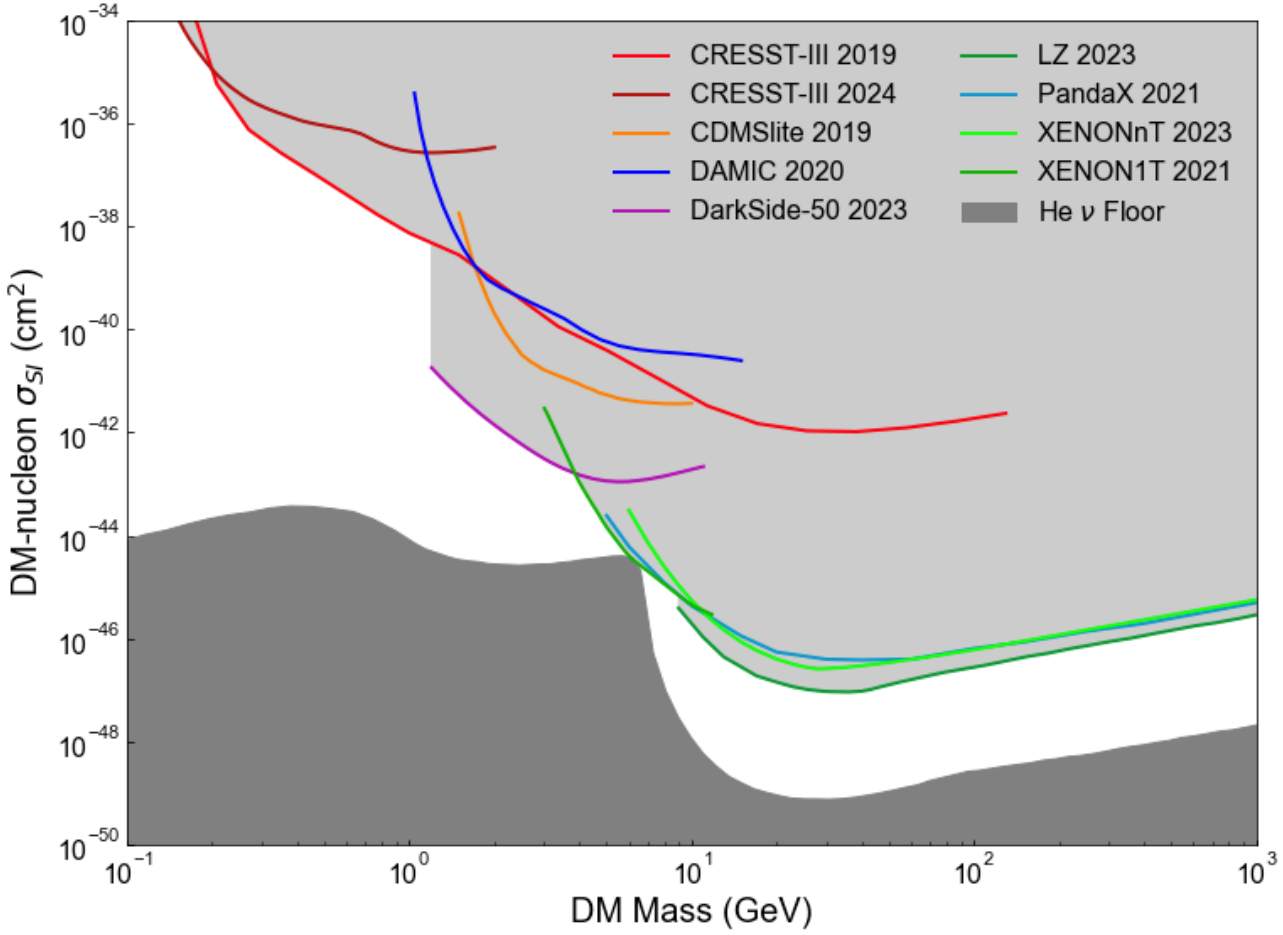


In Search for Light Dark Matter

$$E_r = E_i \left(\frac{2M_\chi M_T}{(M_\chi + M_T)^2} \right) (1 - \cos\theta)$$

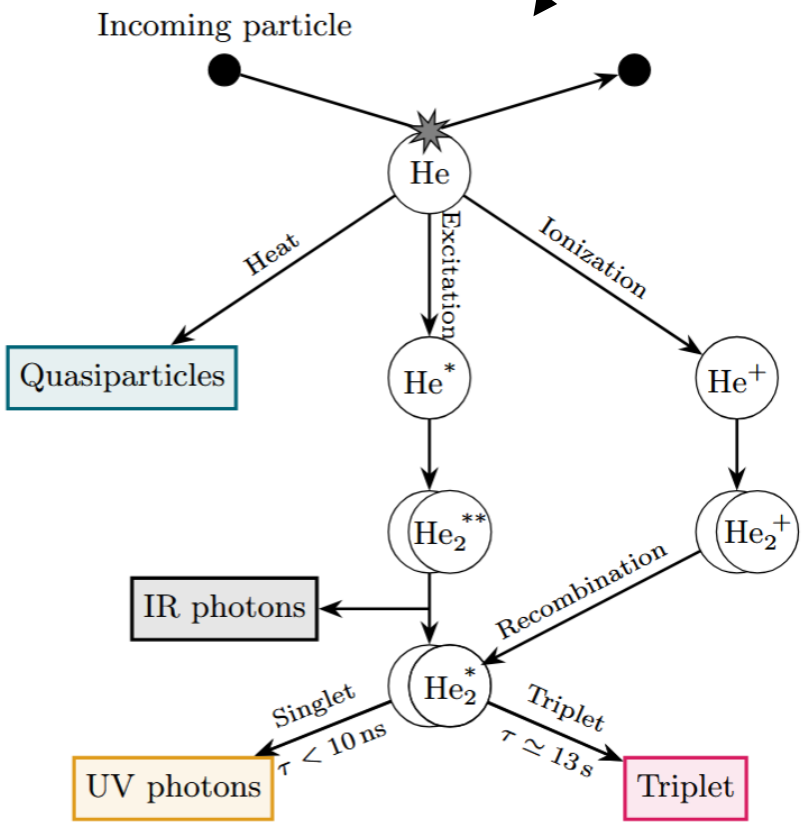
Credits: quicklatex.com





Case for Superfluid ^{4}He Target

- ✓ The recoil energy enhanced
- ✓ No intrinsic long-lived isotopes
- ✓ Impurities frozen out at superfluid temperatures
- ✓ Scalable
- ✓ Multiple signal channels
- ✓ Great potential ER/NR separation



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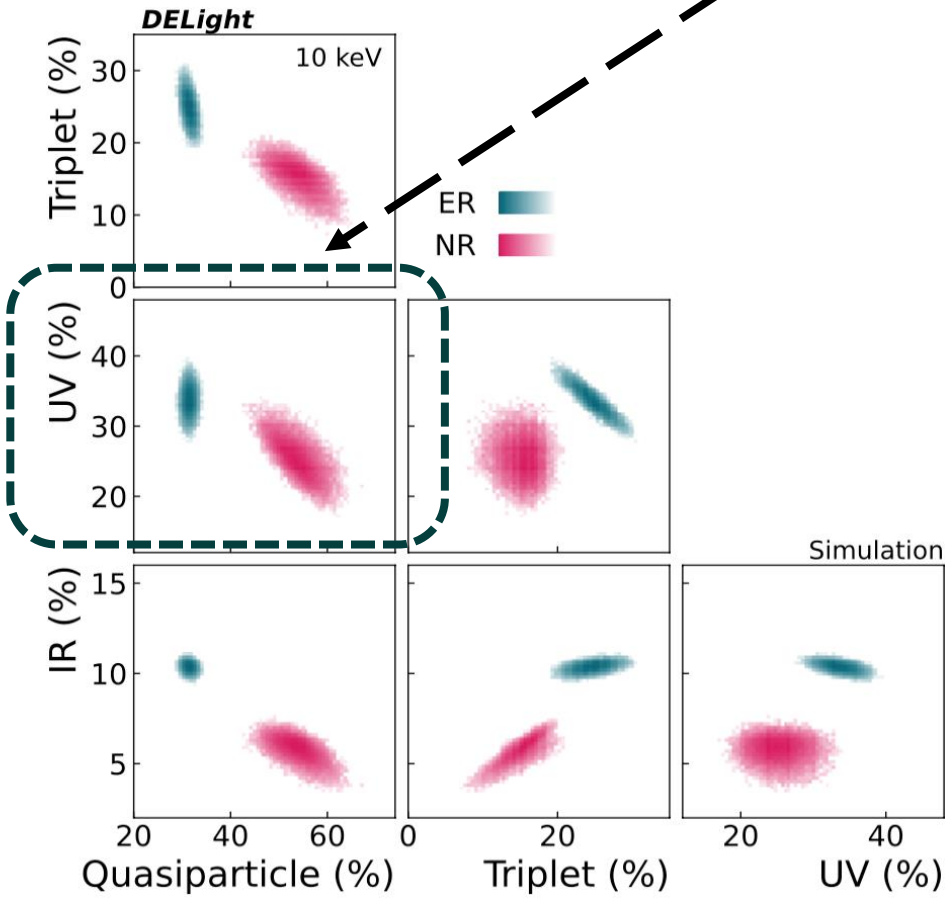
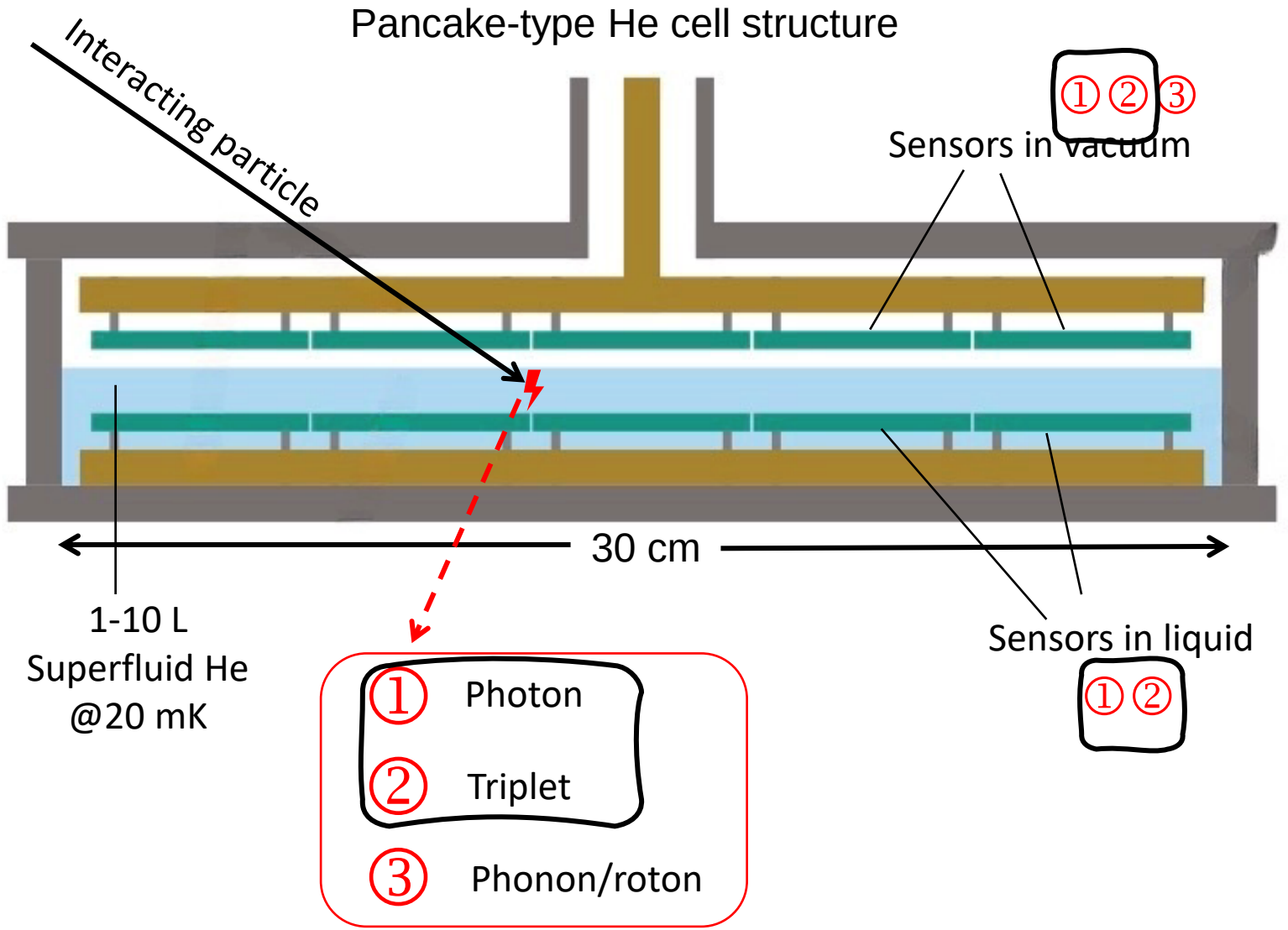


DELight Collaboration (PhysRevD.111.032013)

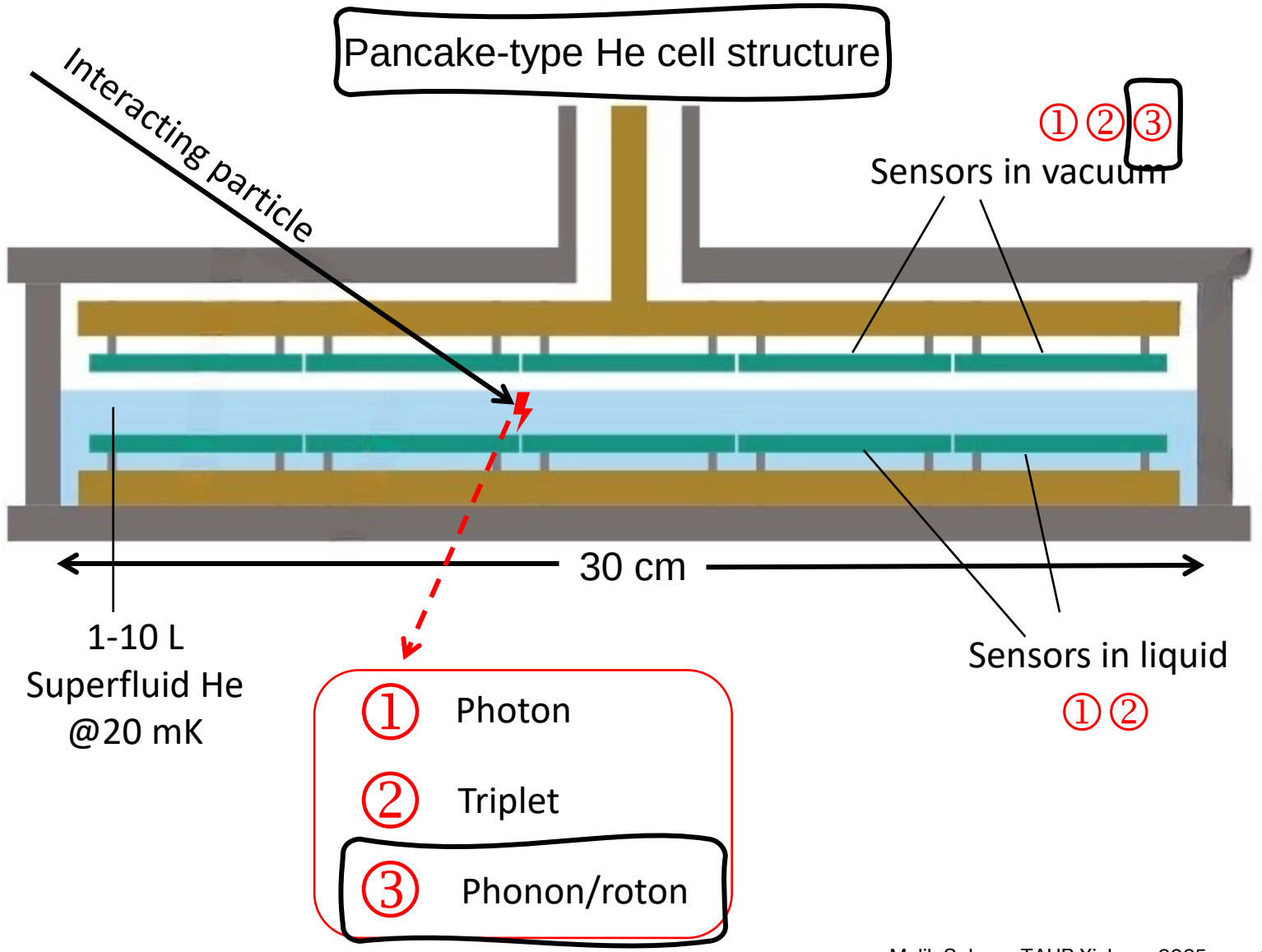
Detection Principles - Scintillation

- ✓ Prompt UV and IR photons
- ✓ Delayed triplet decays
- ✓ No scintillation below 19.8 eV
- ✓ Transparent medium
- ✓ Detected by both sensor arrays

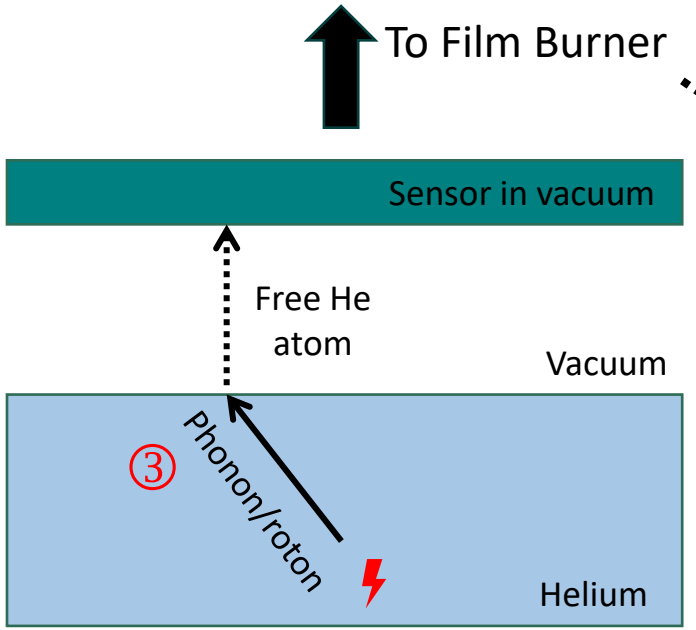


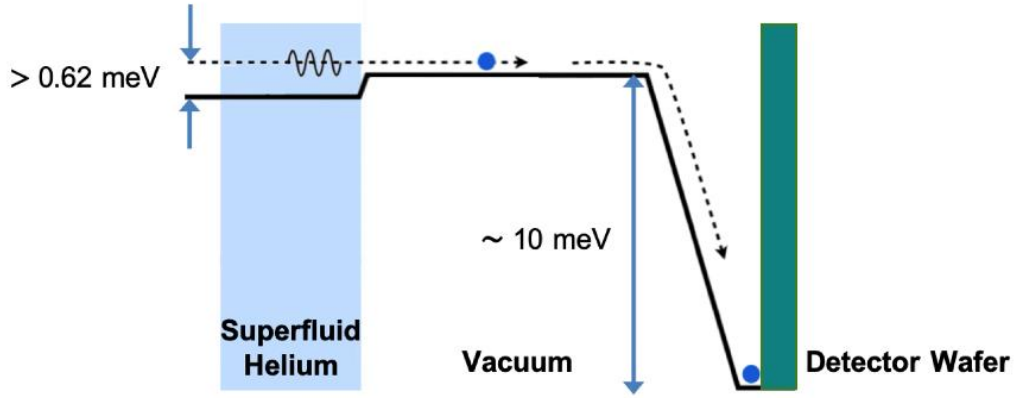
Detection Principles – Quasiparticles

- ✓ The quasiparticles propagate ballistically inside helium (150-200 m/s)
- ✓ Non-prompt signals
- ✓ Detected by the top sensor array only
- ✓ Cell geometry dictated by their detection



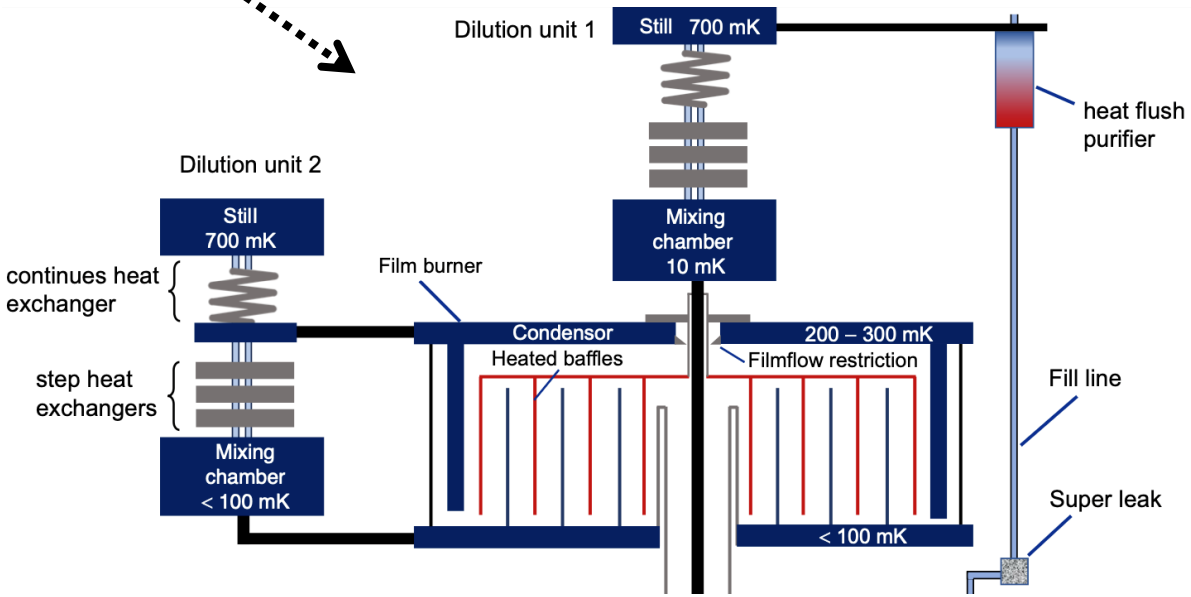
Detection Principles – Quasiparticles (II)



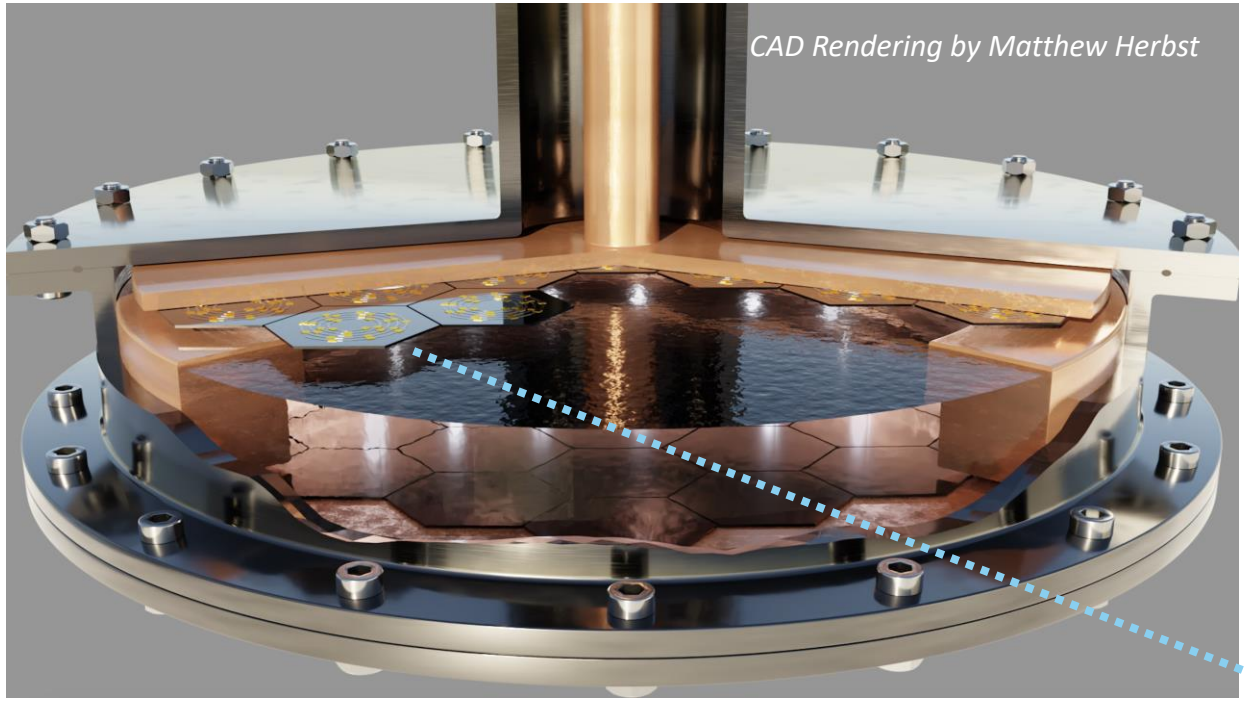


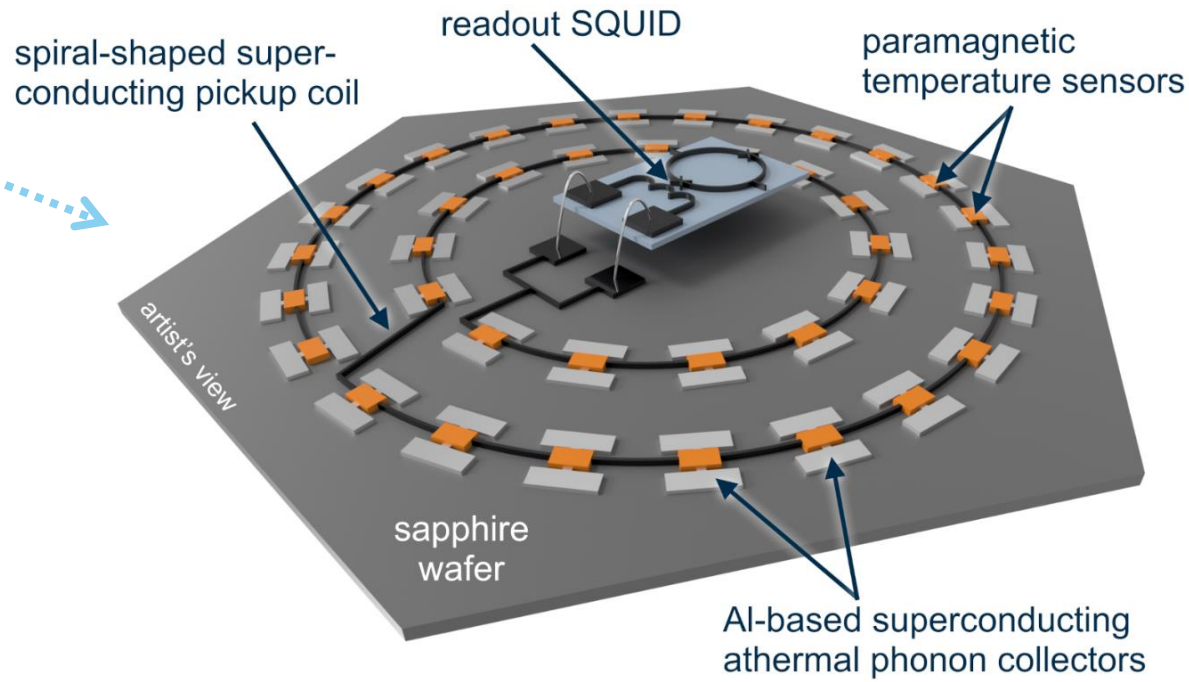
Noise-free amplification of factor of >10

- ✓ Quantum evaporation at the vacuum interface, releasing a He atom.
- ✓ Free He atom condensed by the sensor in vacuum
- ✓ Signal comprises resulting evaporation burst
- ✓ Pancake design enhances the detection efficiency
- ✓ Sensor in vacuum must be free of He film



Large-Area Microcalorimeters (LAMCALs)





- ✓ Top array: 37 LAMCALs
- ✓ Bottom array: 19 LAMCALs
- ✓ Expected resolution: ~eV
- ✓ Noise threshold: 4 eV

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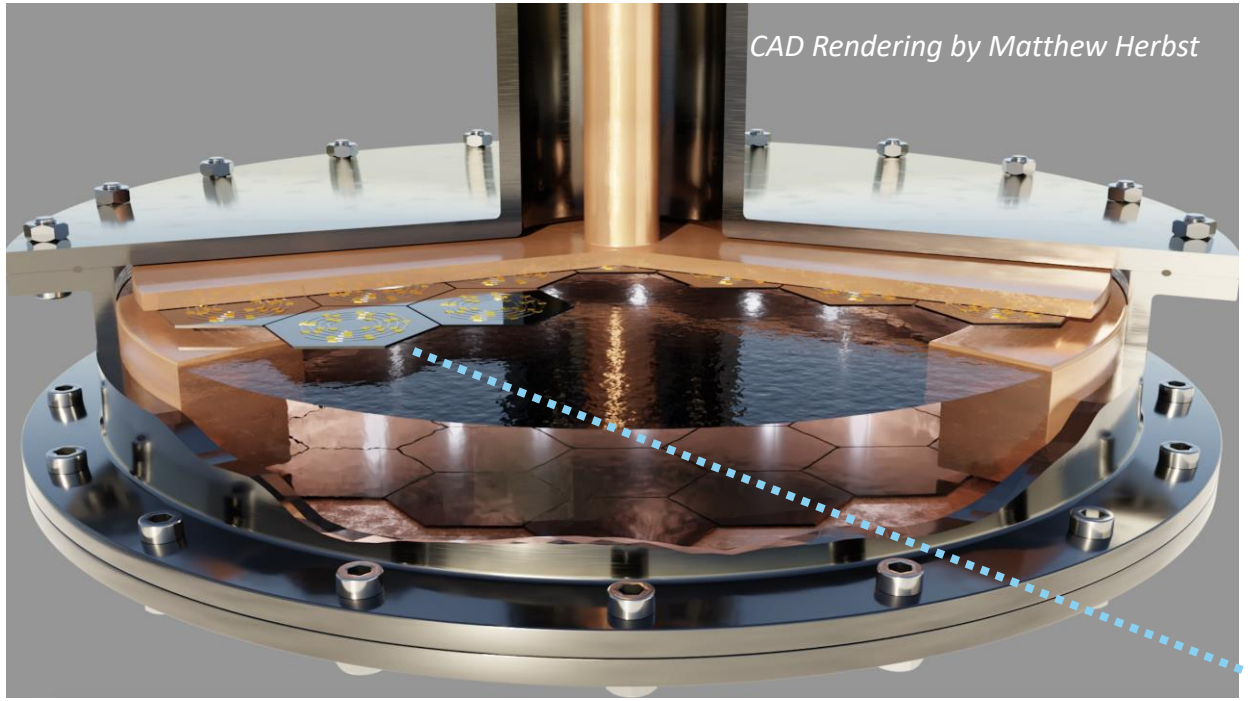

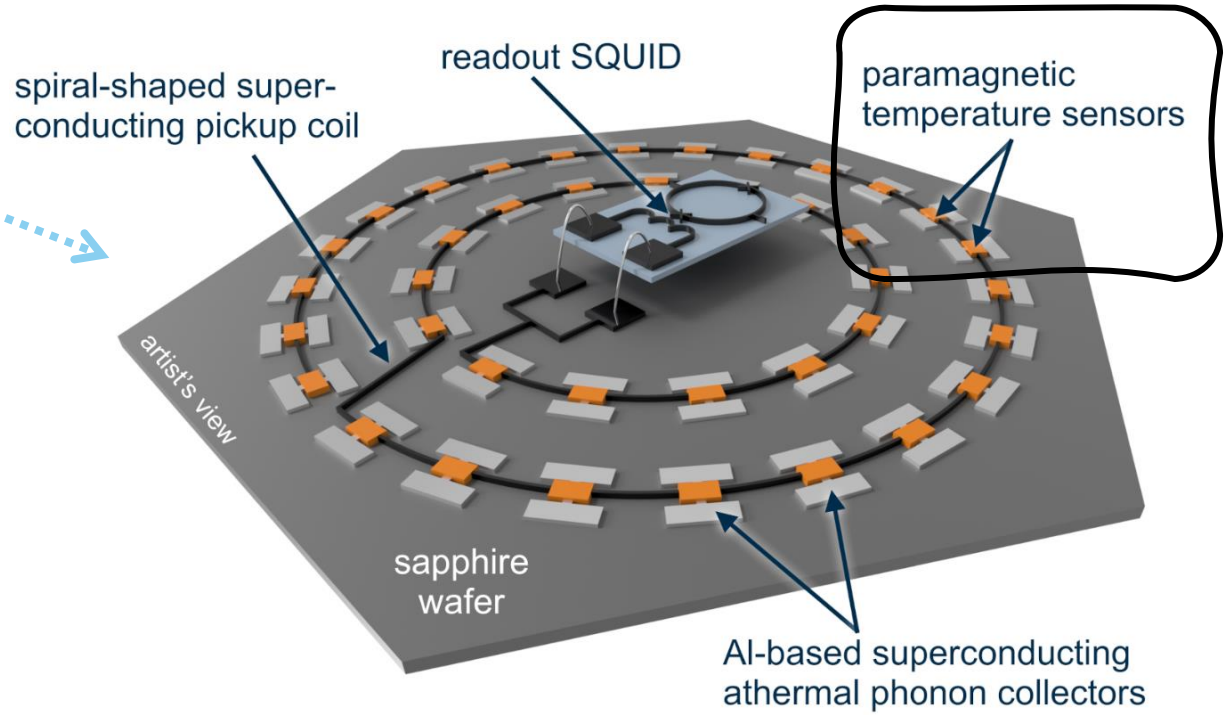

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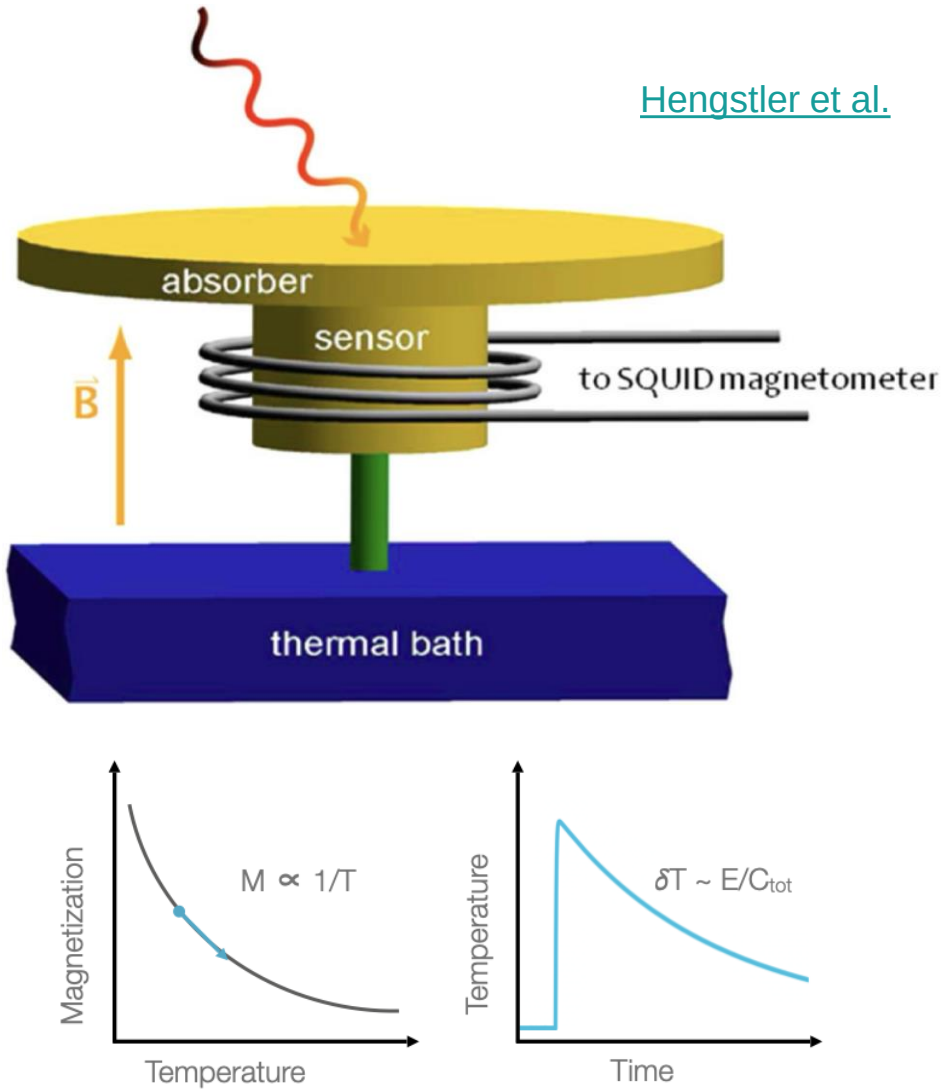
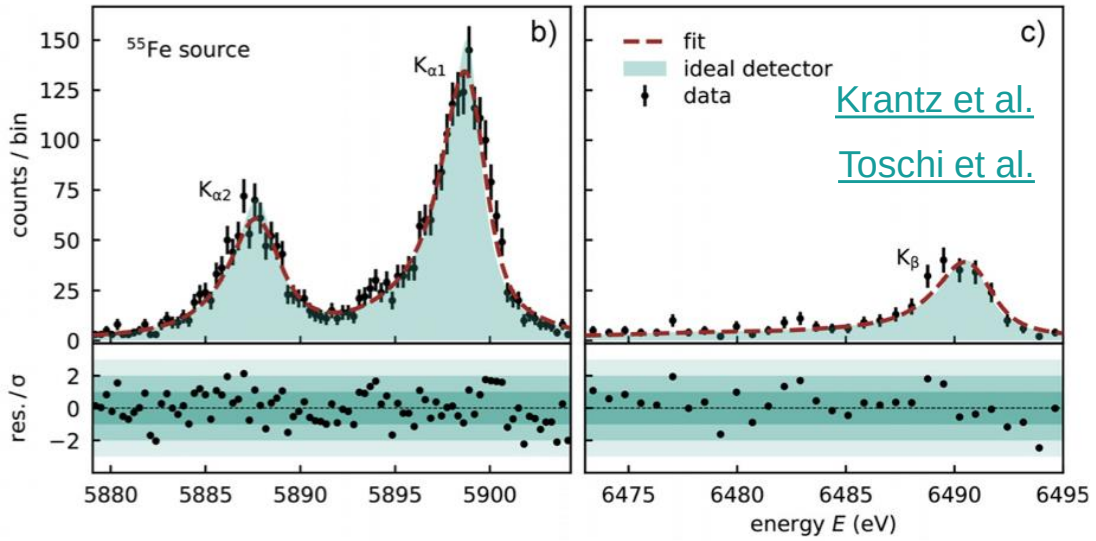
Magnetic Microcalorimeters (MMCs)



Hengstler et al.

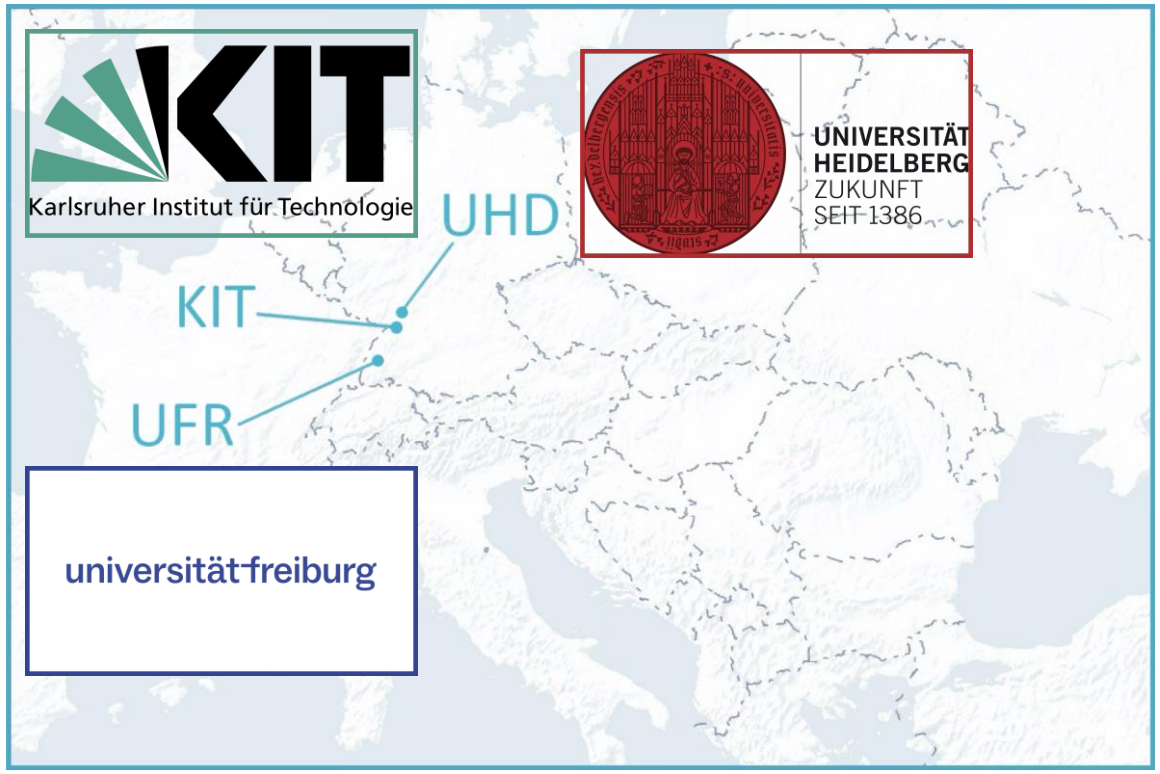
- ✓ Temperature increase leads to decrease in magnetization of the paramagnetic sensor
- ✓ Change in magnetization read out via SQUID
- ✓ The Collaboration members demonstrated that MMCs achieve at present a world-leading energy resolution of ΔE_{FWHM}=1.25 eV at 5.9 keV



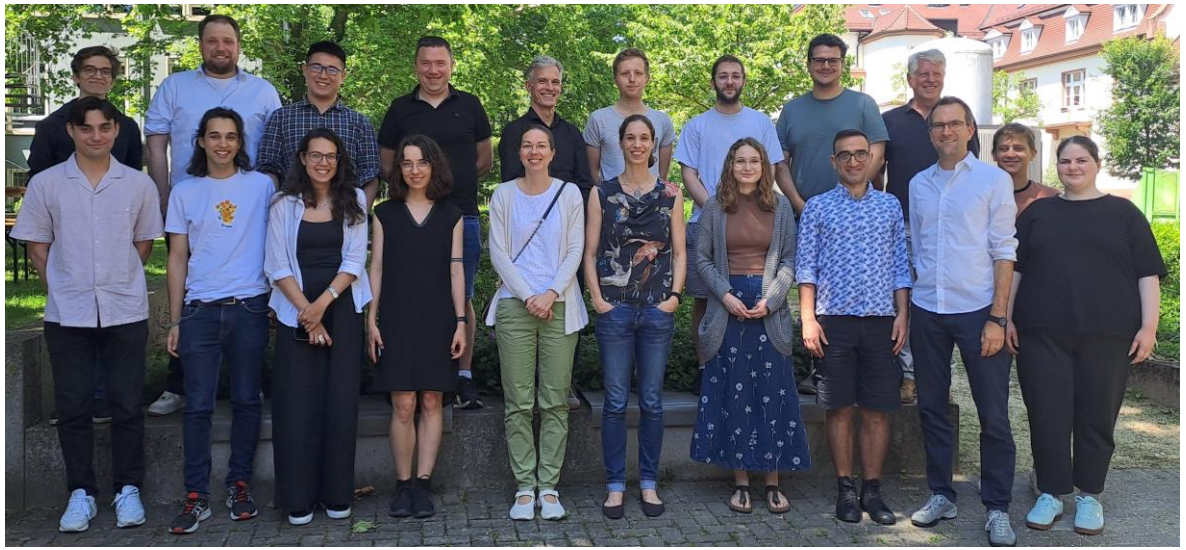
Krantz et al.

Toschi et al.

The DELight Collaboration

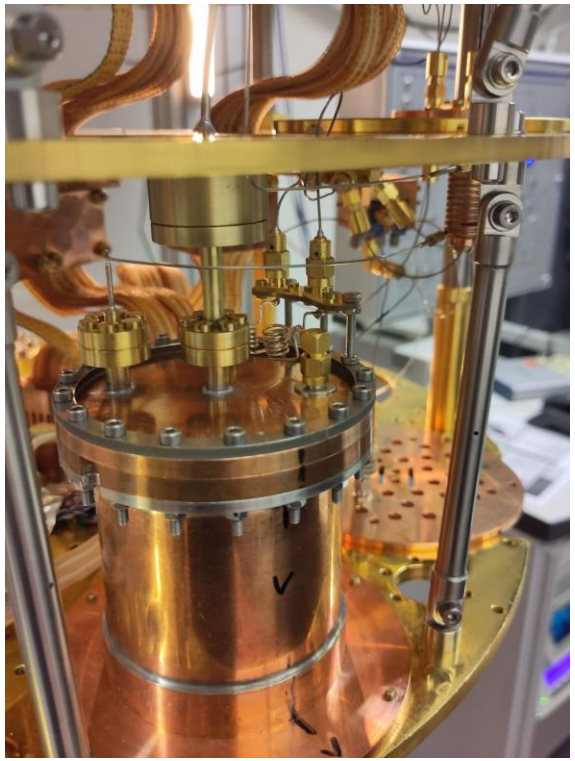


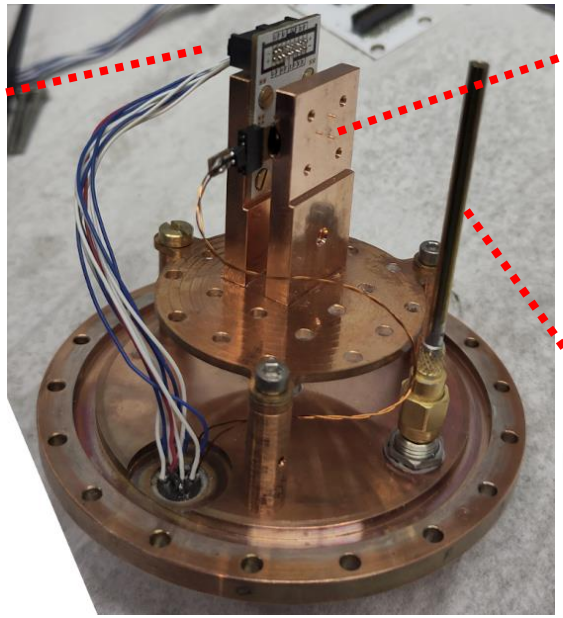
- ✓ 3 institutions from the state of Baden-Württemberg in Germany
- ✓ Paving the way for the upcoming superfluid ^{4}He-based light dark matter search



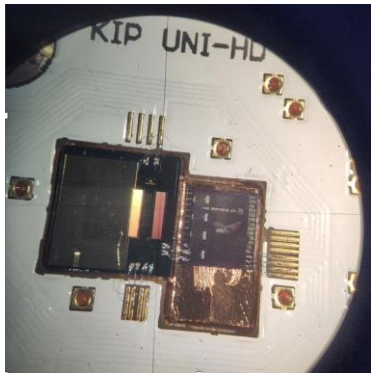
DELight Demonstrator

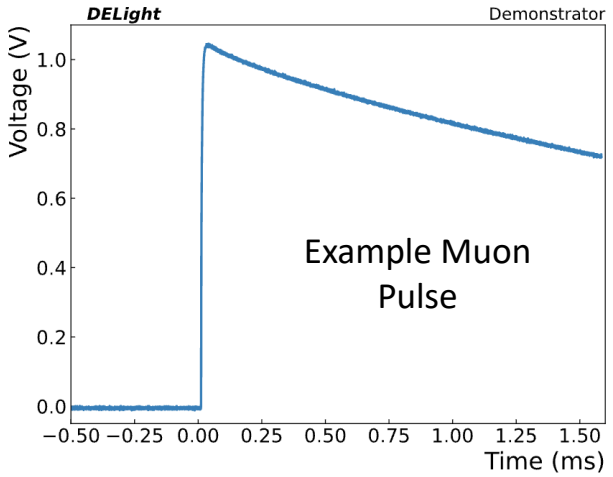
- ✓ Small helium R&D cell in operation at Heidelberg
  - ✓ MMC tests in liquid
  - ✓ DAQ and event construction
- ✓ Filled with liquid helium @ ~15 mK
- ✓ Later equipped with an MMC and a heater
- ✓ Muon data taken with an empty cell
  - ✓ Setting the landscape prior to helium fill

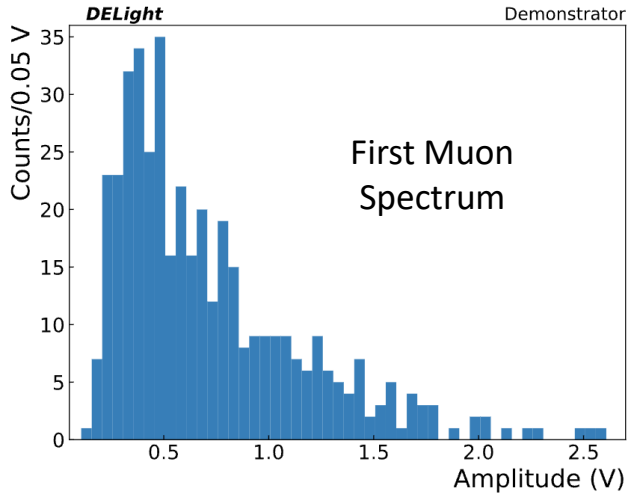




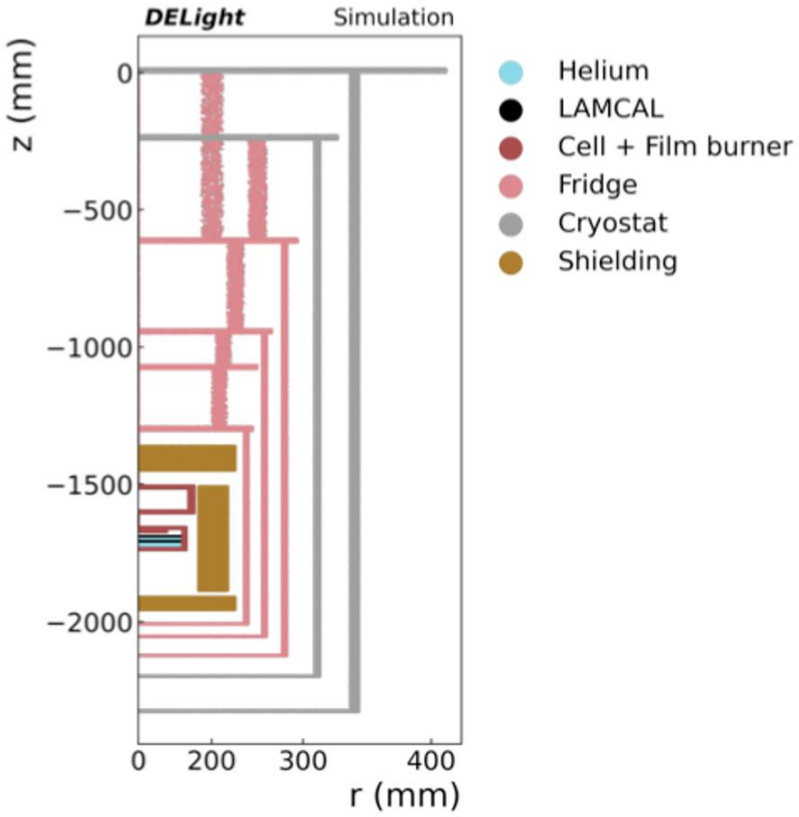
MMC connected to a SQUID



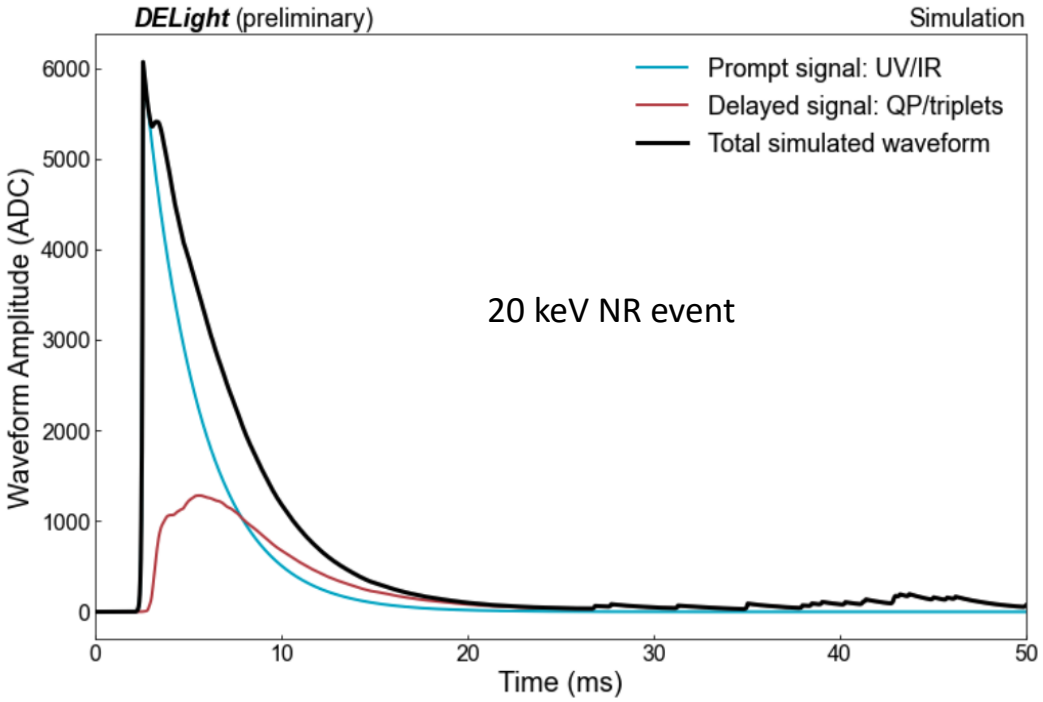




Simulation Framework

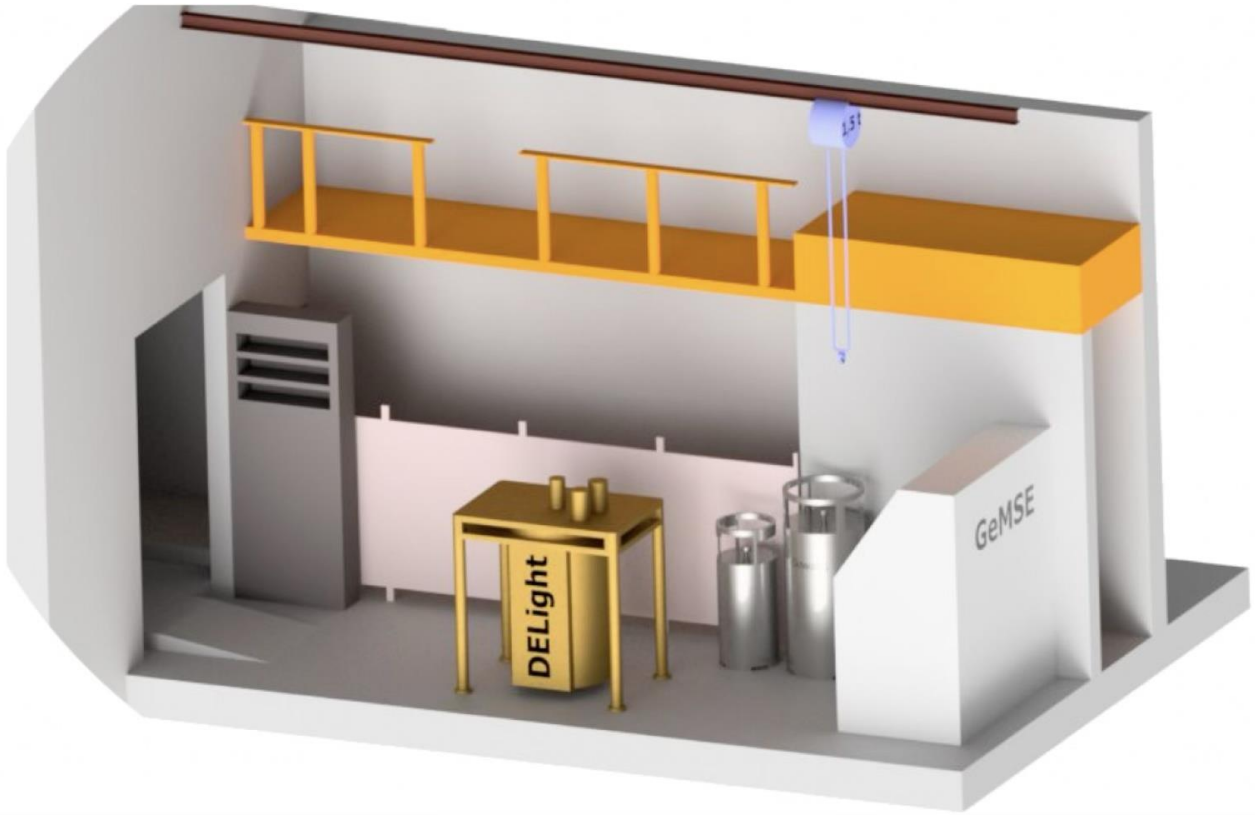


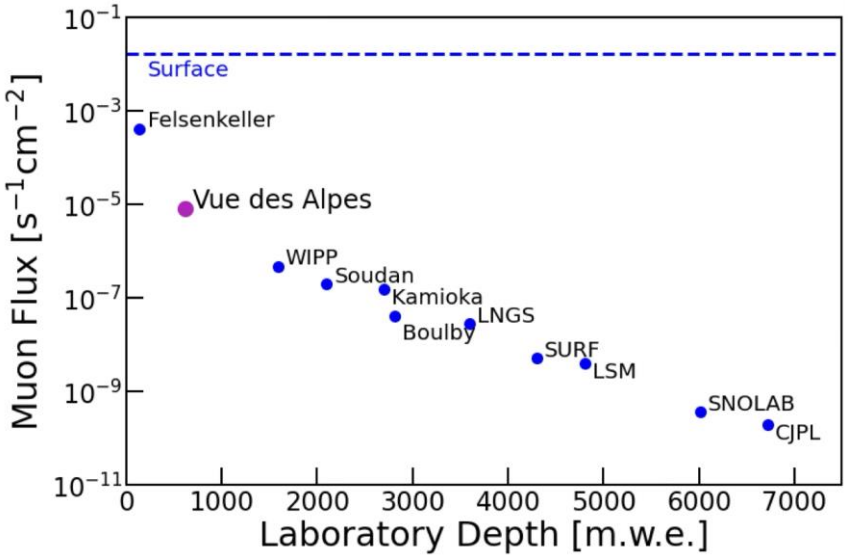
- ✓ Preliminary geometry implemented in Geant4
- ✓ Signal generation
- ✓ Quasiparticle physics
- ✓ Full background model
- ✓ Waveform simulations

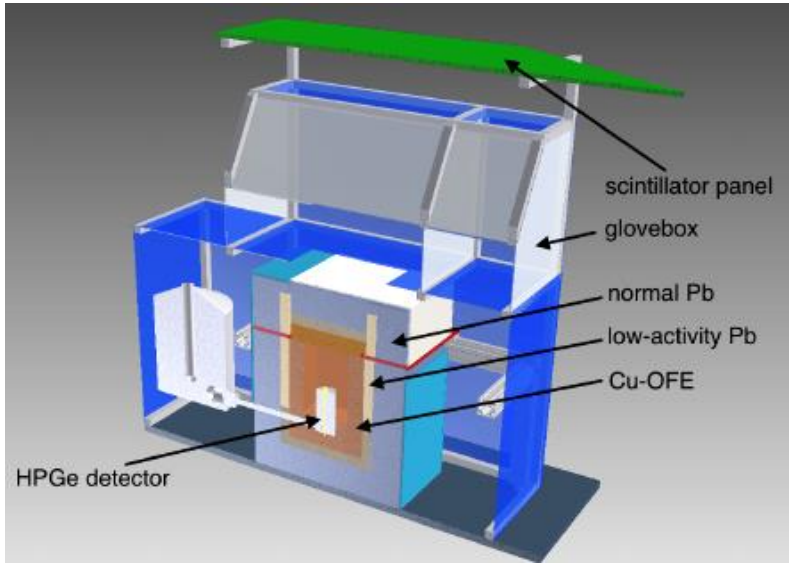


Vue-des-Alpes Underground Lab

- ✓ Shallow underground laboratory in Switzerland
- ✓ 230 m rock overburden (620 m.w.e)
- ✓ Hosting GeMSE gamma spectrometer for material screening

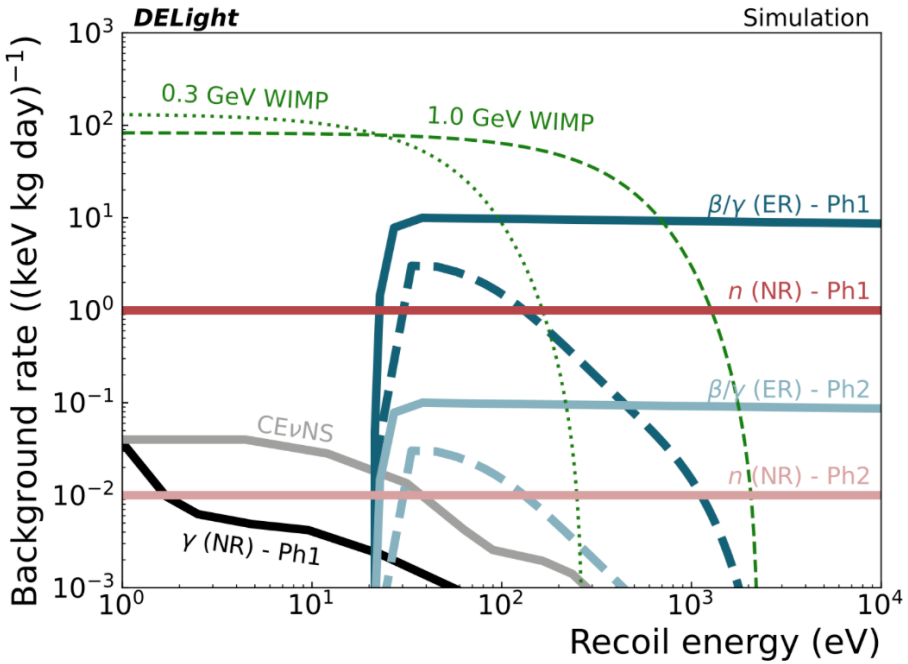


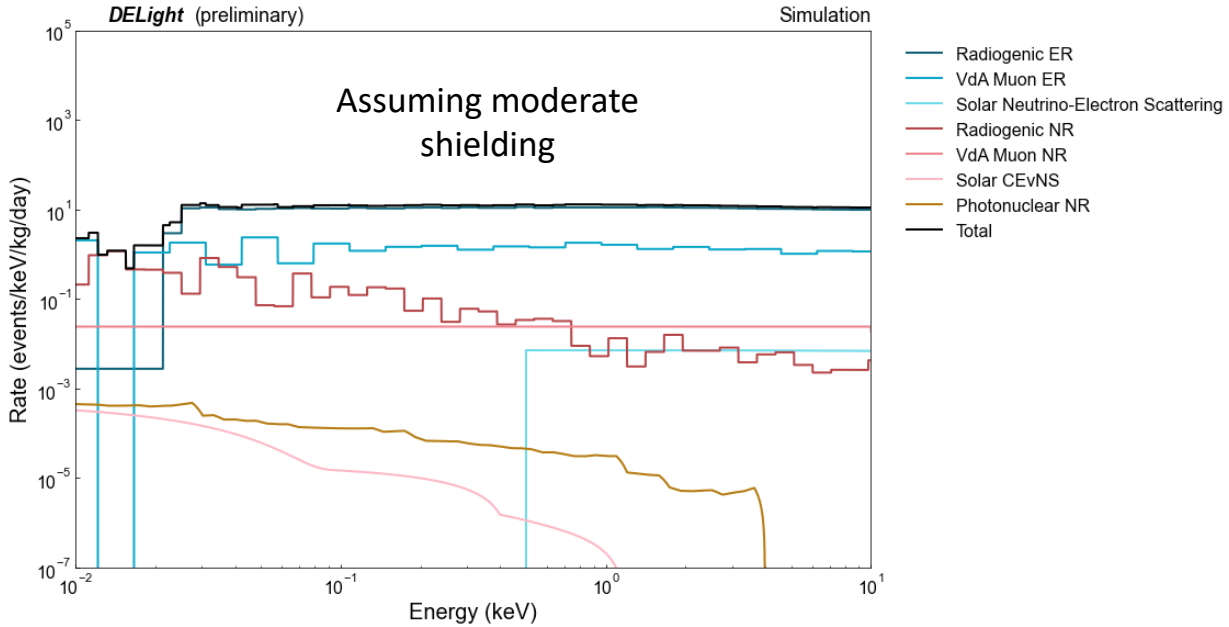


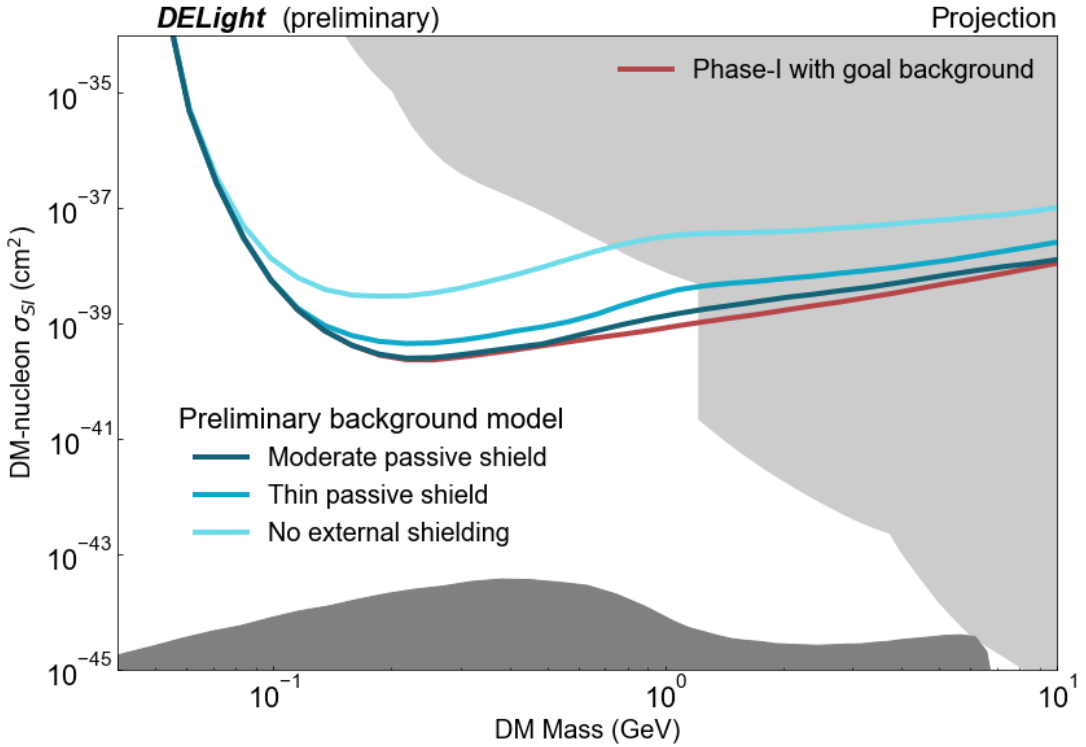


Background Projections

- ✓ Radiogenics due to detector parts and lab
- ✓ Solar neutrinos
- ✓ Muons at VdA
- ✓ Photonuclear events
- ✓ VdA background mitigation (work in progress)
  - ✓ No external shielding
  - ✓ Thin shielding (10^2 reduction)
  - ✓ Moderate shielding (10^3 reduction)

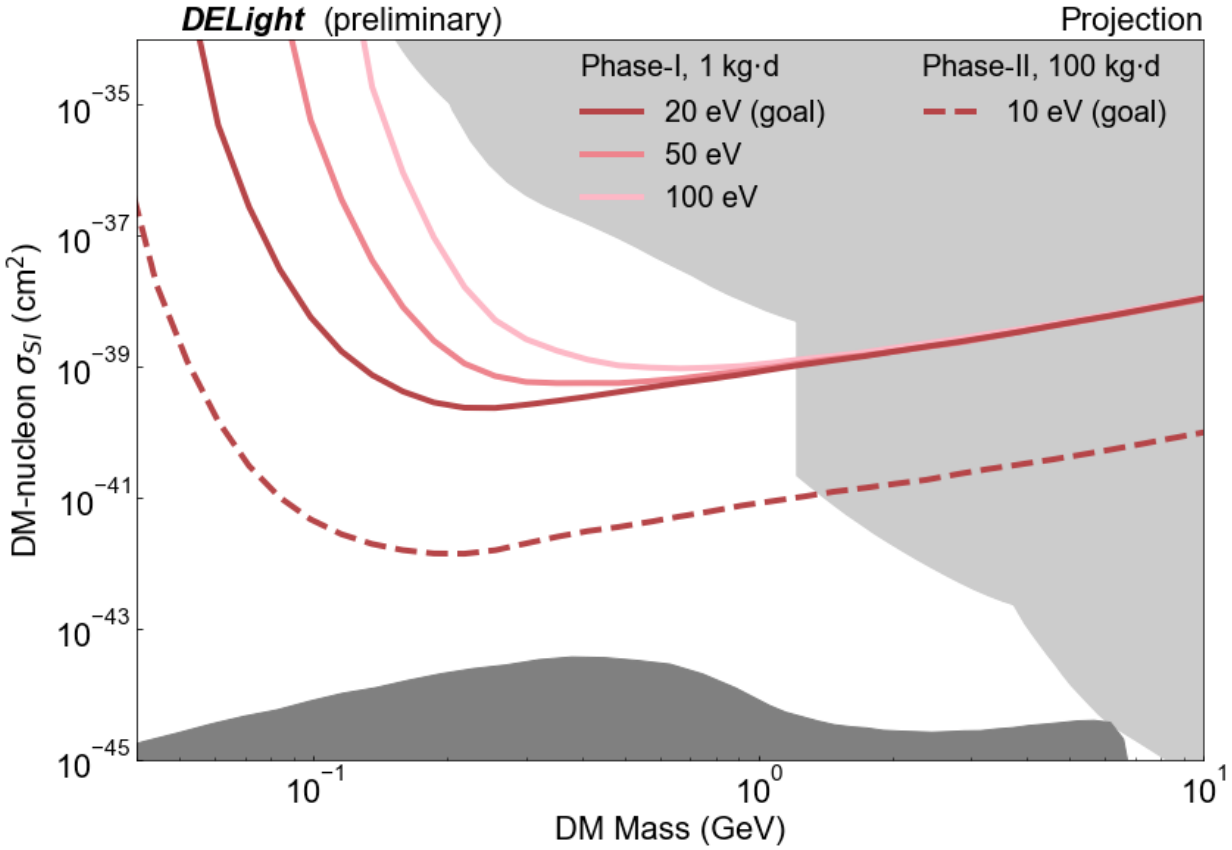


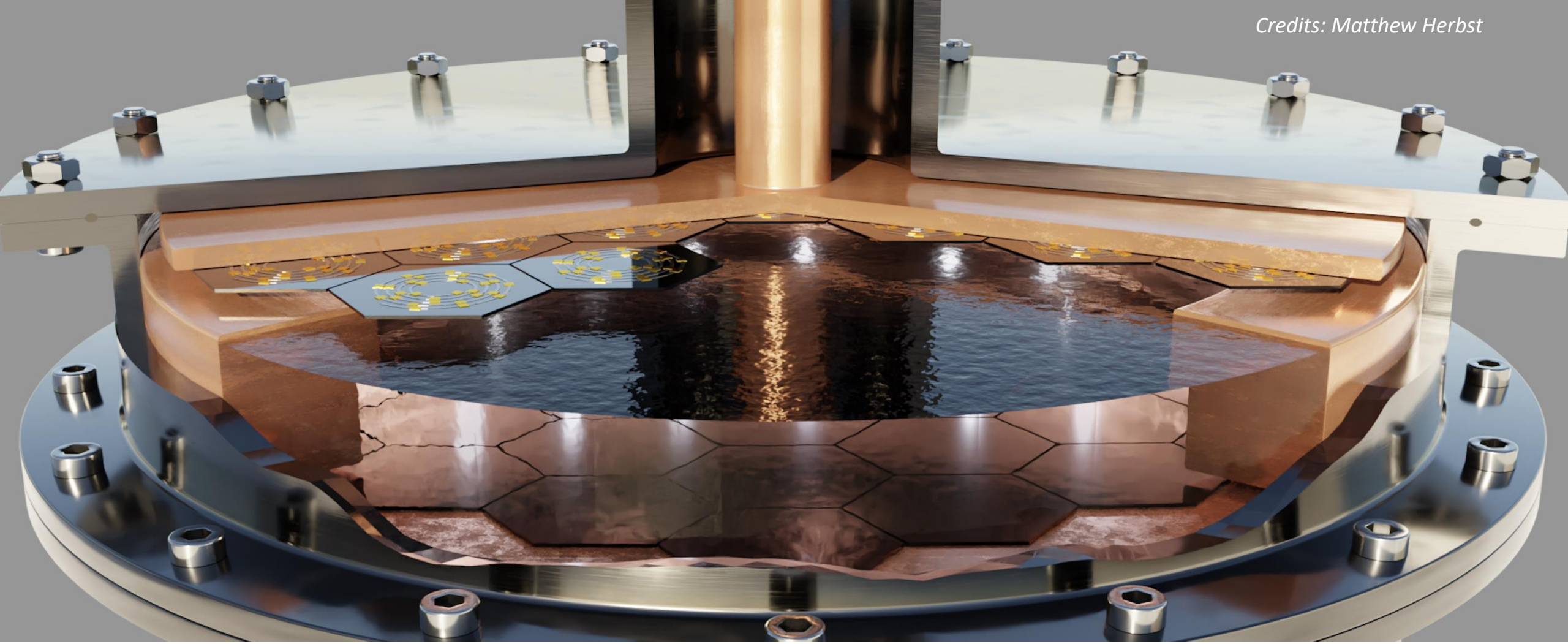




Outlook and Projections

- ✓ Achieving goal threshold of 20 eV for Phase I will be one of the large benefits and yet challenges of the DELight
- ✓ At VdA
  - ✓ 1 (10) L of target for Phase I (II)
  - ✓ Phase I, 20 eV threshold and 1 kg·day exposure
    - ✓ First LDM search result by 2030
  - ✓ Phase II, 10 eV threshold and 100 kg·day exposure
- ✓ Long range plan
  - ✓ Deep underground laboratory
  - ✓ ~200 L of target
  - ✓ <10 eV threshold and 1 kg·year exposure

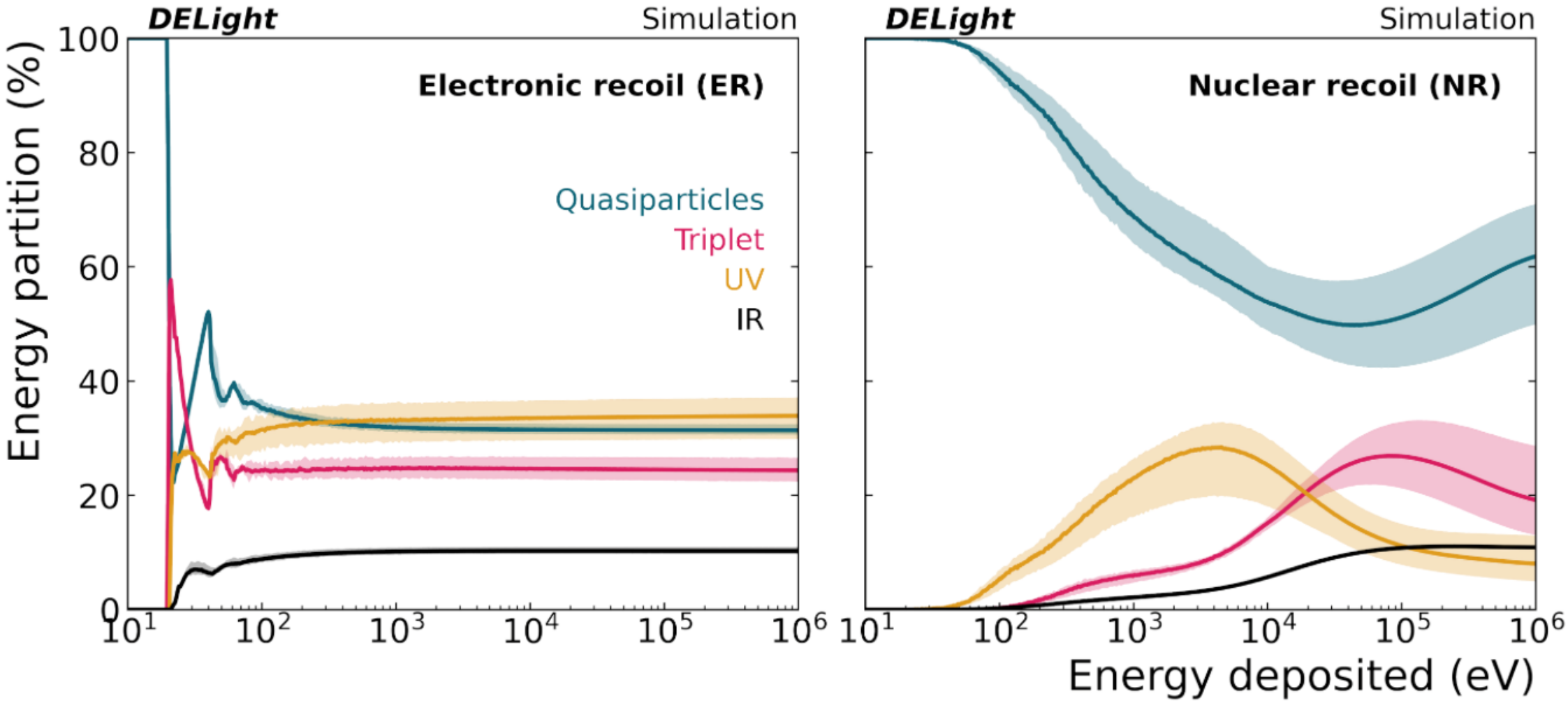




THANK YOU

BACKUP SLIDES

Signal Partitioning in Superfluid Helium



PhysRevD.111.032013

Phonons in Superfluid Helium