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PALAIS DU PHARO
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A TES for ALPS II and other dark matter searches

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09.07.2025

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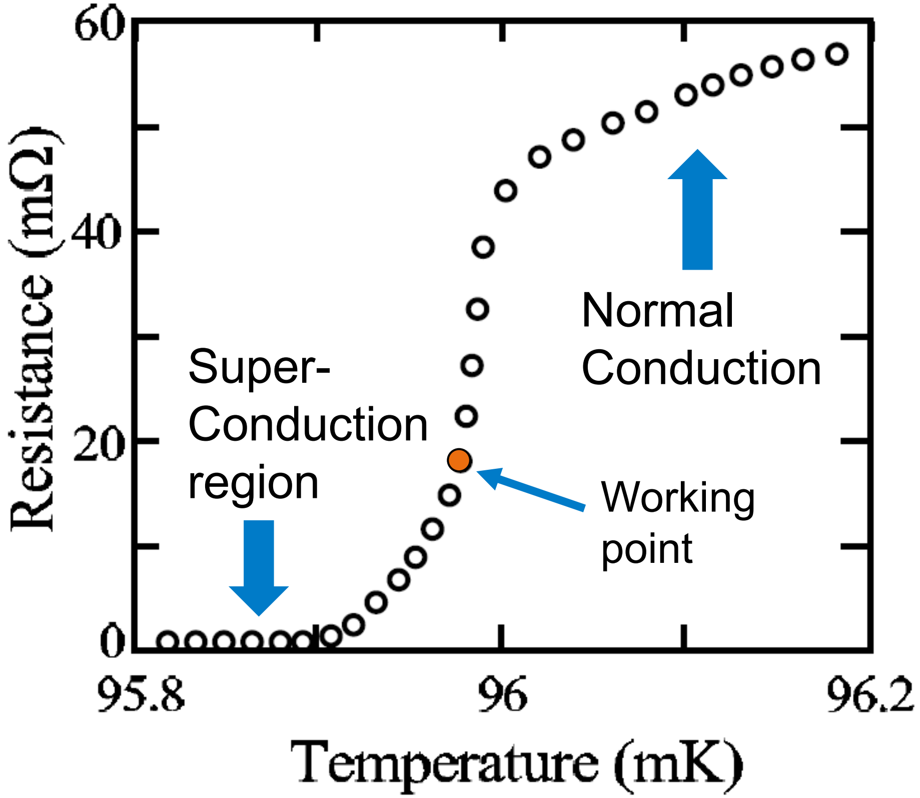
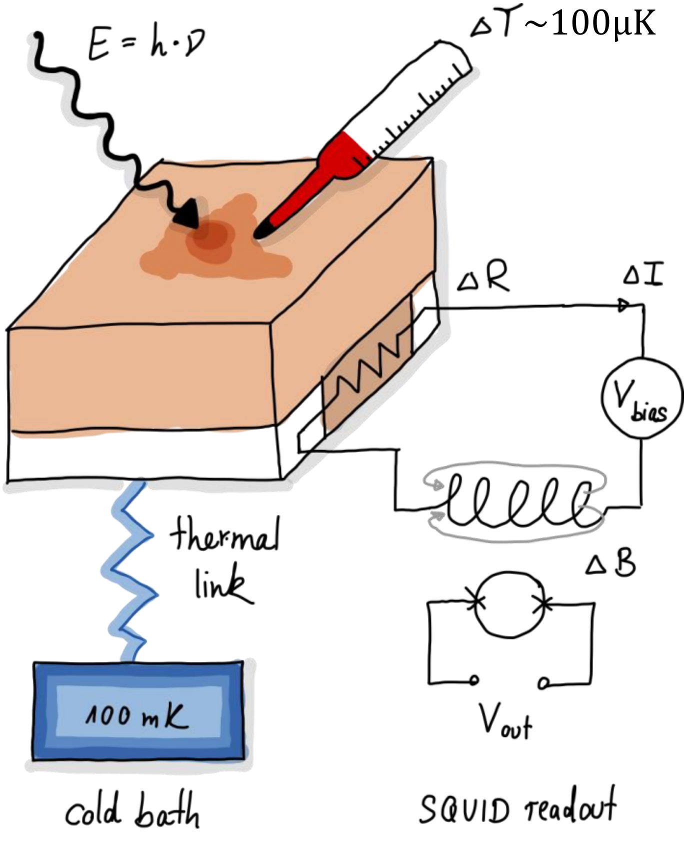
[2]Deutsches Elektronen-Synchrotron (DESY)

[3]University of Southern Denmark (SDU)

Transition Edge Sensor



K. Irwin, G. Hilton, Transition-edge sensors, in: Cryogenic Particle Detection, Springer Berlin Heidelberg, Berlin, Heidelberg, 2005, pp. 63–150, http://dx.doi.org/10.1007/10933596_3.



*Courtesy of Katharina-Sophie Isleif

- Cryogenic microcalorimeter operated at transition region
- Connected to a colder thermal bath
- Definition of the point in the transition with a current

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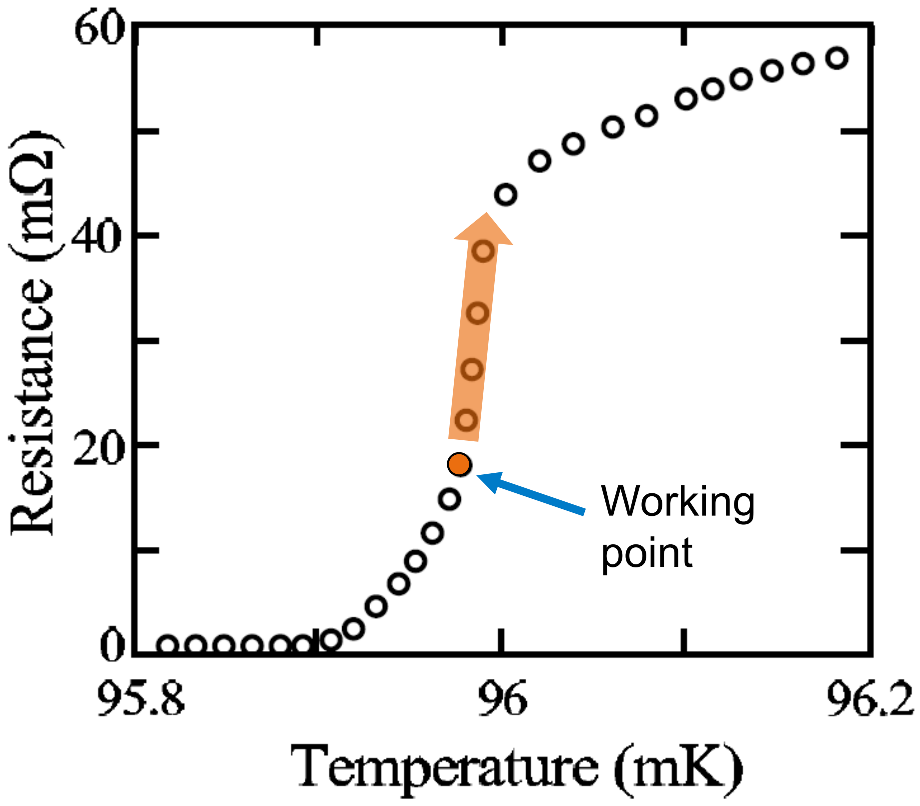

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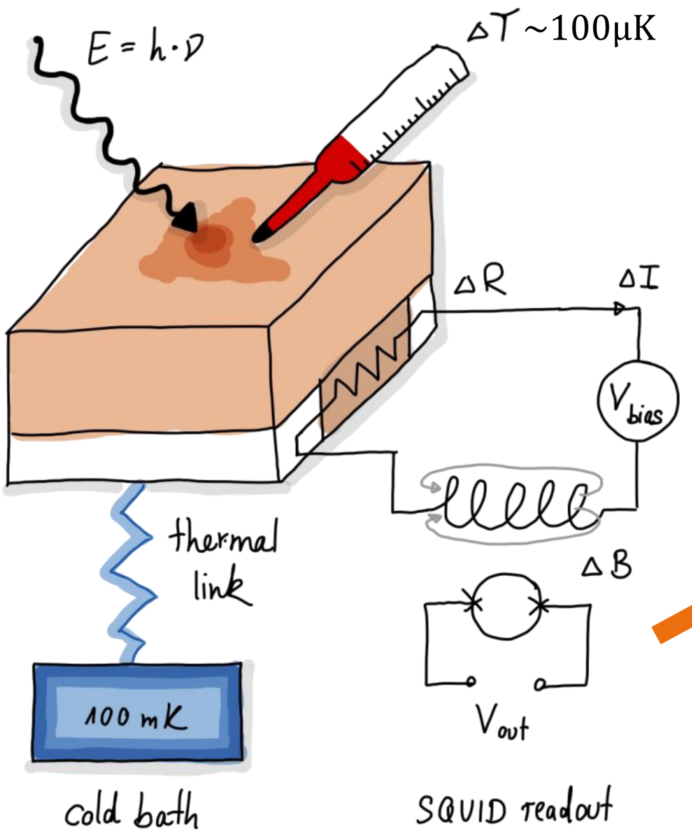

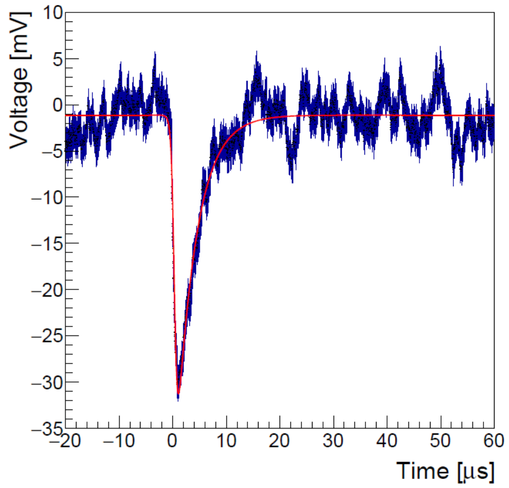

- Cryogenic microcalorimeter operated at transition region
- Connected to a colder thermal bath
- Definition of the point in the transition with a current
- Change in resistance produced by energy deposition
- Readout based on
  Superconducting Quantum Interference Device (SQUID)

Benefits of TESs for Quantum Sensing

- Sensitivity to energies down to $\sim 0.1\ \mathrm{eV}$
- High quantum efficiency ($> 90\%$)
- Broad spectral range (e.g., for optical TES $\sim 0.1\ \mathrm{eV}\ - \sim 3\ \mathrm{eV}$)
- Good energy resolution (e.g., for optical TES $\sim 0.1\ \mathrm{eV}$)
- Photon number resolution
- Low background rate ($< 1\ \mathrm{cps}$)

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Pushing the limits in fundamental physics experiments

Search for axions and ALPs with ALPS II

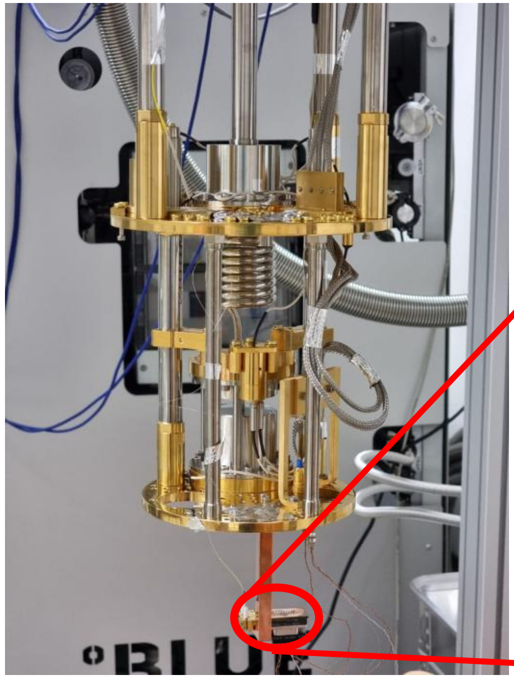
Direct Dark Matter (DM) searches via DM scattering

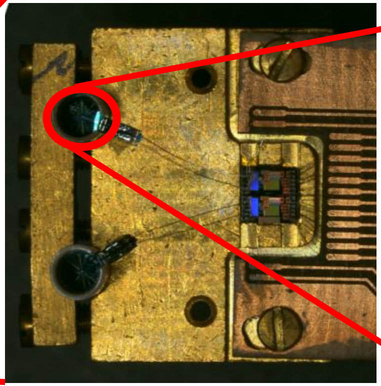
TES at DESY

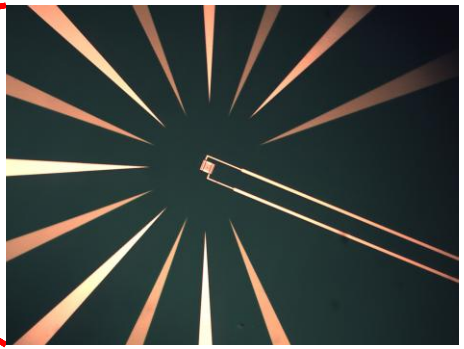
Use of an optical fiber to transmit photons to the TES

Two fully equipped cryostats for R&D and fundamental physics research

A tungsten chip ($25\ \mu\mathrm{m} \times 25\ \mu\mathrm{m} \times 20\ \mathrm{nm}$) provided by NIST, and SQUIDs and packaging by PTB.
TES stabilized in the transition region (~ 140 mK)



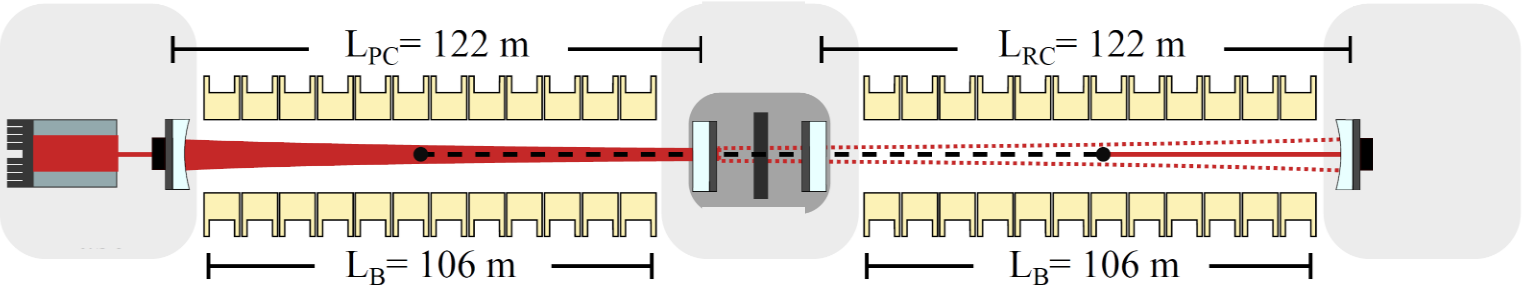


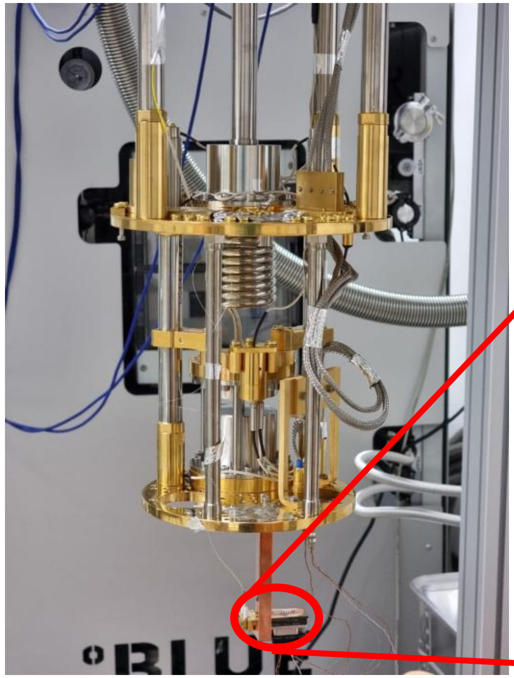


Optimized for $1064\ \mathrm{nm}$ photon $\mathrm{E} \approx 1.2\ \mathrm{eV}$ with an optical stack

TES for ALPS II

TES as a photon counting detector, presently <u>heterodyne sensing</u> used





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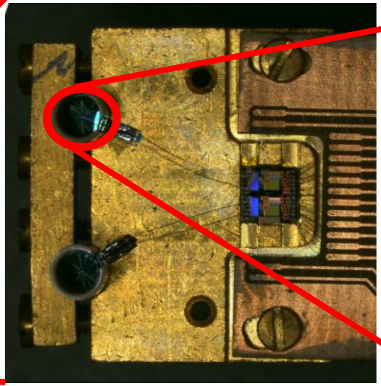

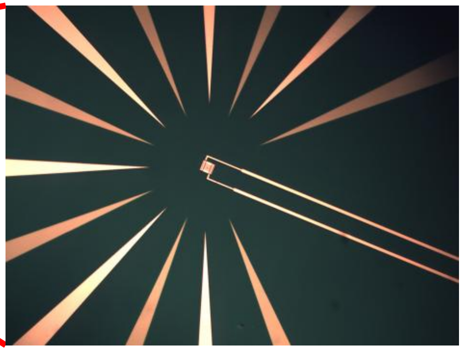

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[2] Shah, R. et al., PoS EPSHEP2021 (2022) 801
[3] Meyer, M. et al., Annalen d. Physik (2023)

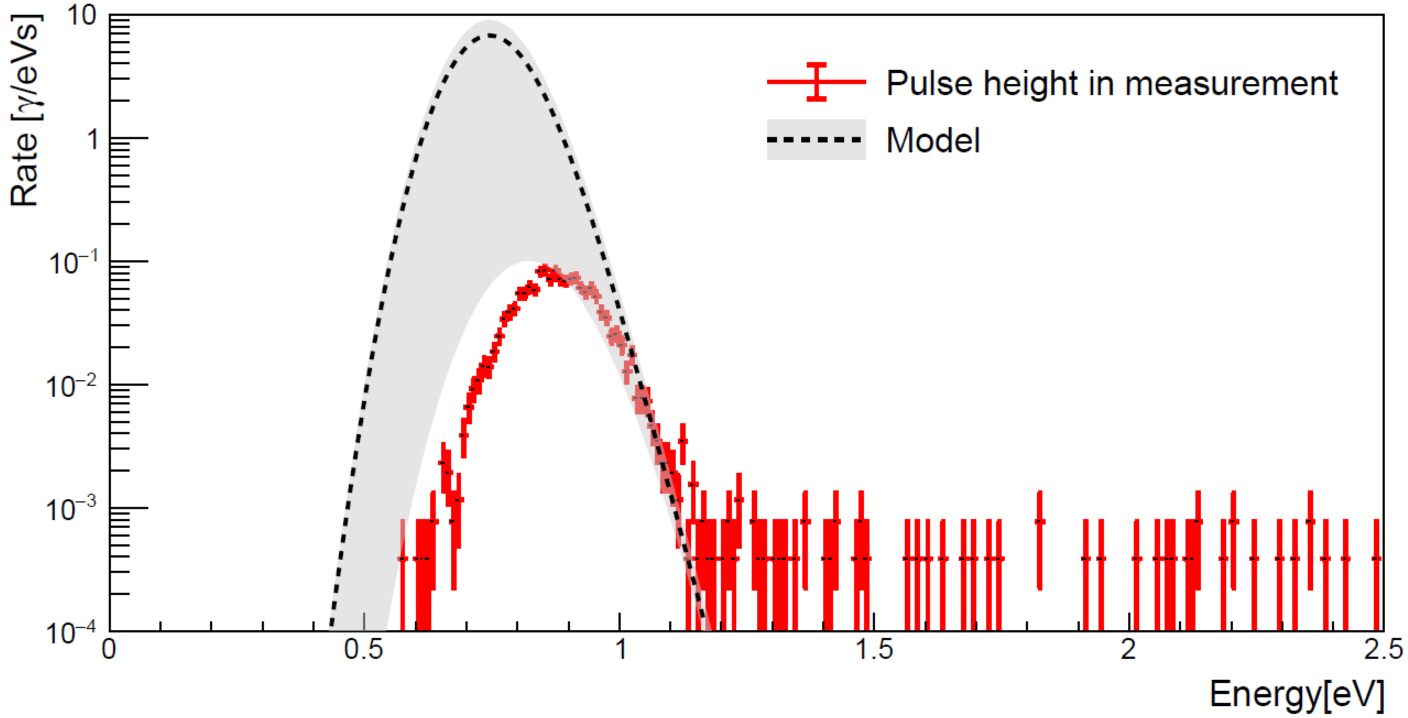
Requirements for ALPS II (50 % efficiency, 5σ detection):

- Sensitivity to very low rates (1-2 photons a day) ✓
- Low energy photon detection (1064 nm equivalent to 1.165 eV) ✓
- Long term stability (~ 20 days) ✓
- High system detection efficiency ⟶ > 80% [1] ✓
- Low background rate: $< 7.7 \cdot 10^{-6}\mathrm{cps} \sim$ 1 photon (1064nm−like) every 2 days ✓
  - Good energy resolution (for background rejection) [1] ✓
  - Background with **no fiber attached** to TES [2, 3] ✓
  - Background with **fiber attached** to TES ?

Background with fiber-coupled TES

[4] Rubiera Gimeno, J.A. et al., Phys. Rev. D (2025) [Accepted for publication]

Developed a Black Body Radiation (BBR) simulation framework to compare to measured background spectrum [4]



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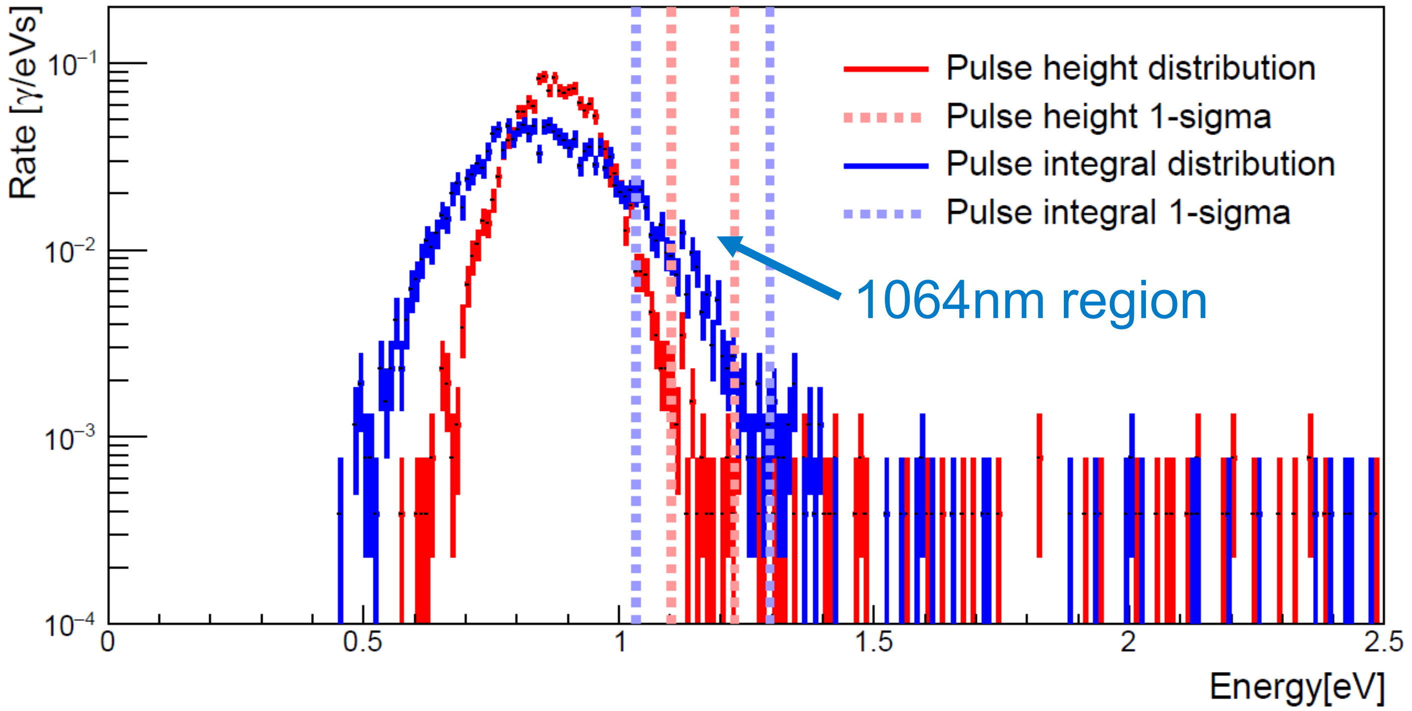

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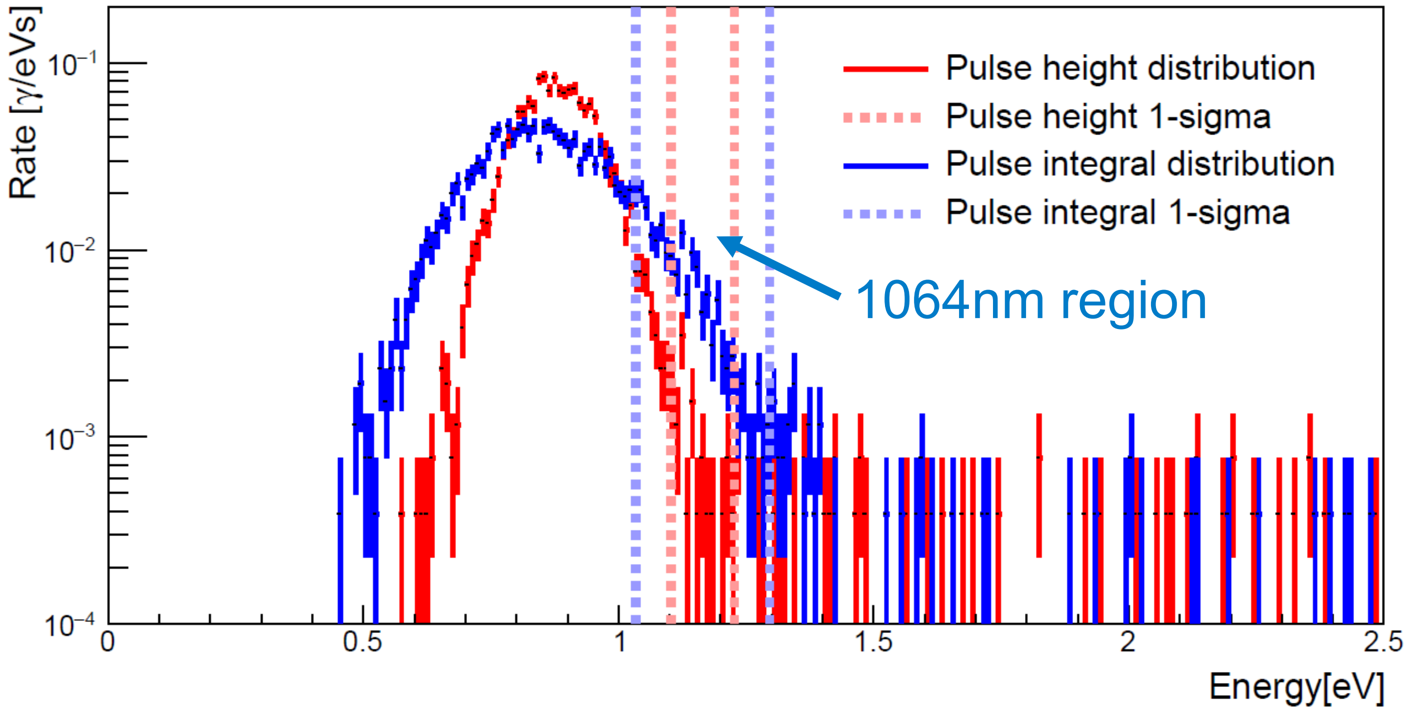

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How can we reduce the background to meet ALPS II requirements?

- Exploring strategies to improve energy resolution even further
- Developing filter bench at cryogenic temperatures for filtering non-1064 nm photons

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Search for non-axionic direct dark matter

Direct DM searches with TES as a target

- Using our TES as a detector and target with a mass of 0.2 ng, parameter space can be explored for low DM masses:
  - Below 1 MeV for DM-electron scattering and DM-electron absorption
  - Below 100 MeV for DM-nucleon scattering

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  - Below 1 MeV for DM-electron scattering and DM-electron absorption
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- 489 h run with TES under characterization for ALPS II without an optical fiber attached
- Pulse shape discrimination and cut based analysis
- Photon-like background rate of $7.2 \times 10^{-5}\mathrm{cps}$ with overall acceptance higher than 50 % in the energy range $0.3\ \mathrm{eV} - 3.0\ \mathrm{eV}$ (loose set of cuts)

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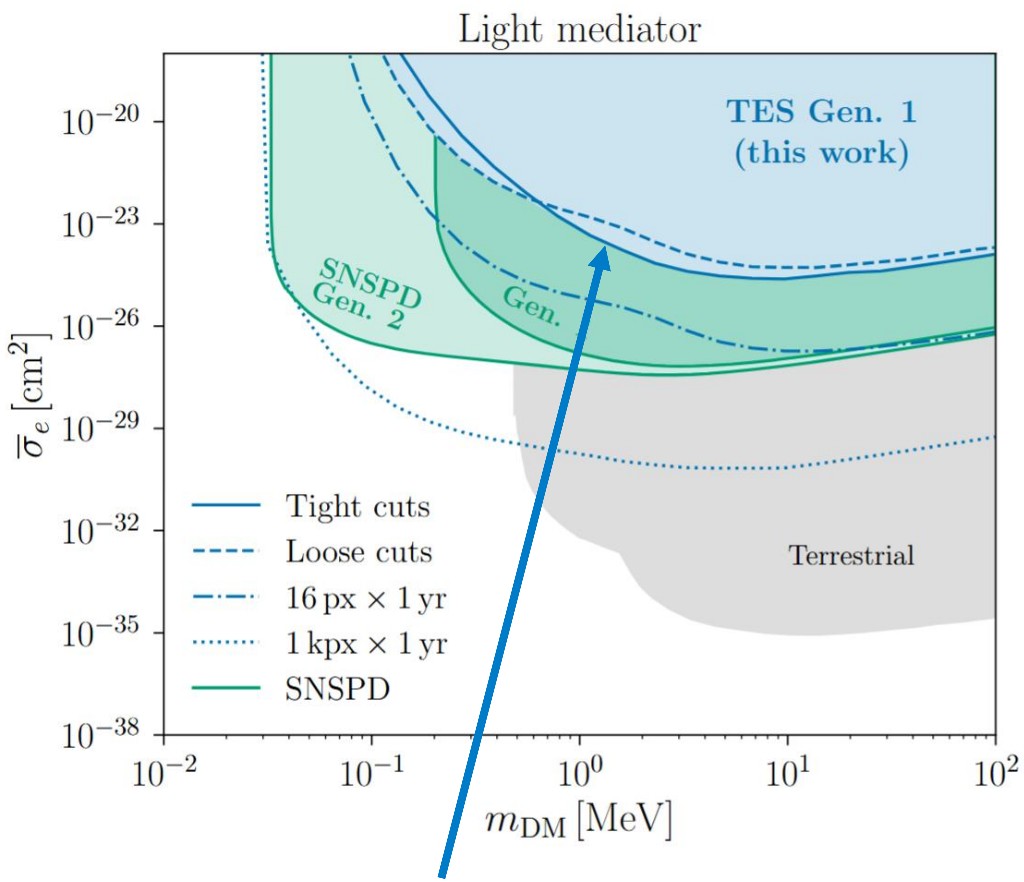

First limits using TES as detector and as a target [5]

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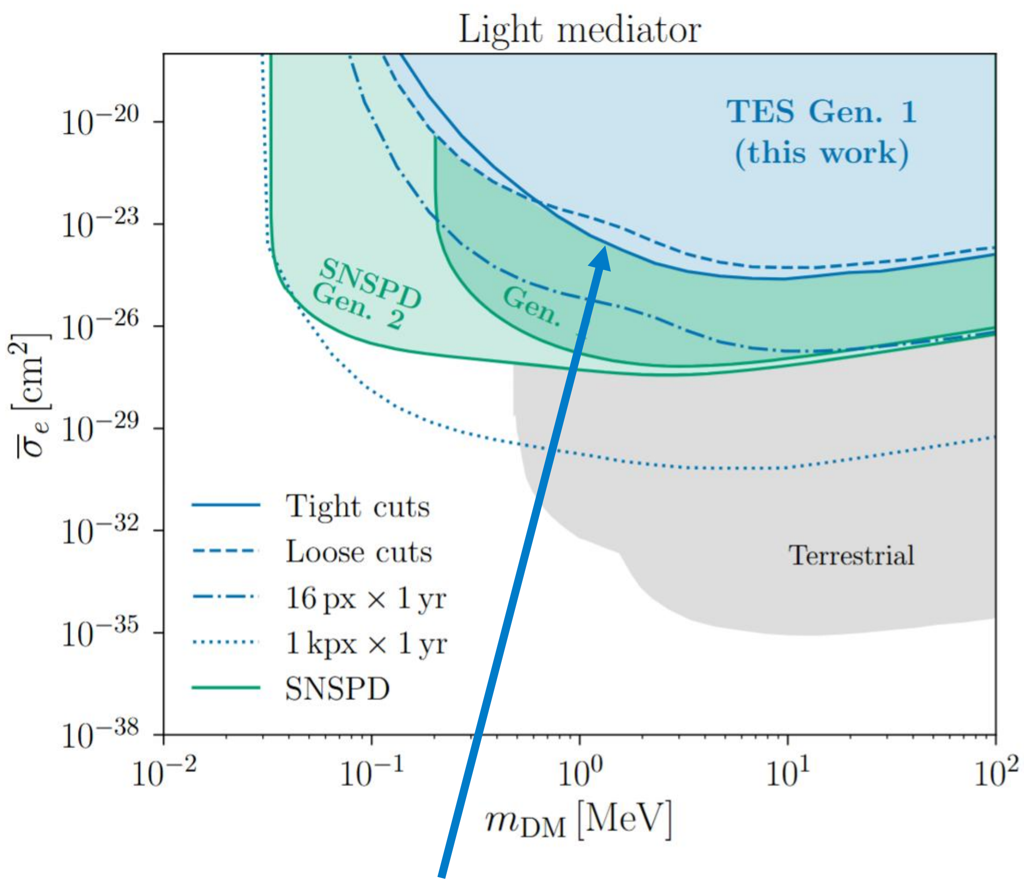
Background with no fiber connected under study with simulations



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Simulation of background in no-fiber configuration

[6] Rubiera Gimeno, J. A., Dissertation (2024)

Large background contribution from zirconia

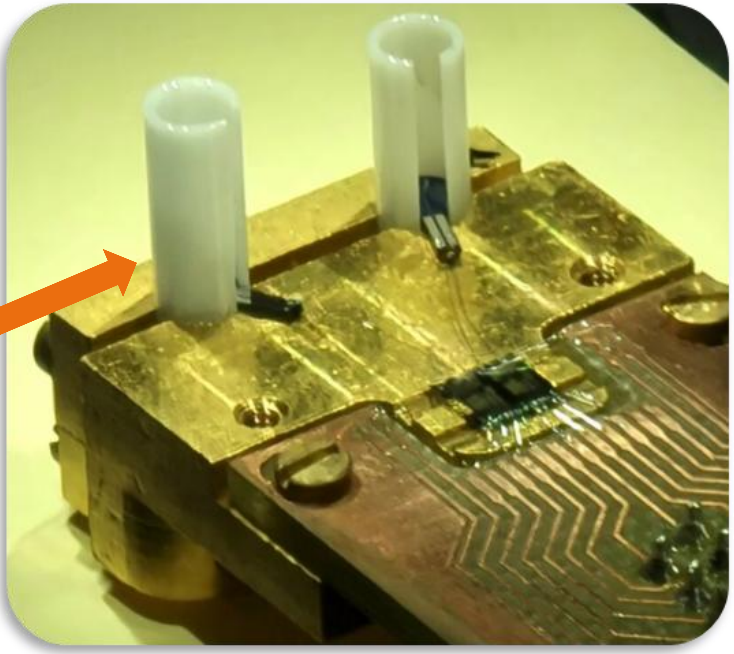
- Pulse shape describe different types of events
- Rate of events passing the threshold is compatible with data [6]

Rates from Geant4 + COMSOL simulation

Zirconia: rate $\in [0.33\ ;\ 2.1] \cdot 10^{-2}$ cps
Muon: rate = $8 \cdot 10^{-5}$ cps

Rate from data: $2.1 \cdot 10^{-2}$ cps

Radioactivity present in zirconia from fiber sleeve



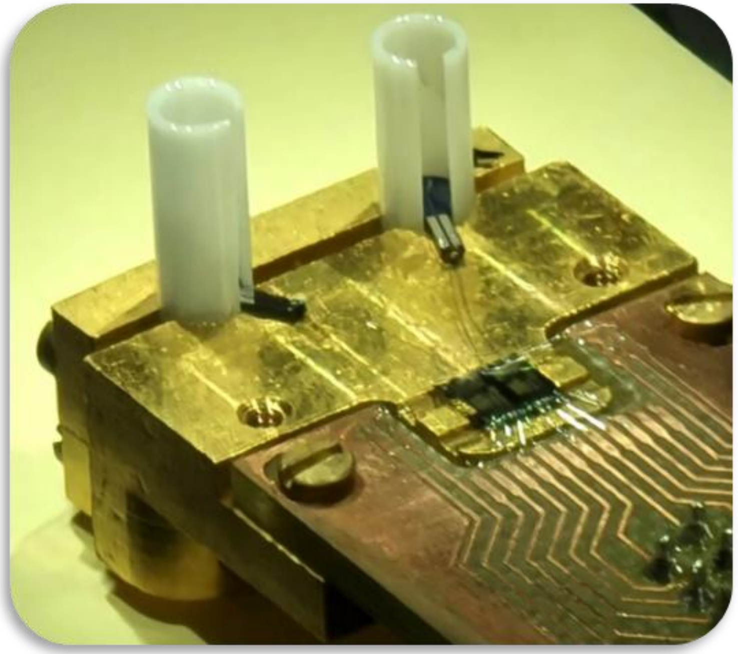
Proposed approaches for background reduction:

- Reduction or removal of the zirconia fiber sleeve
- Substitution of the zirconia with a more radiopure material
- Reduction of sensitive volume (e.g. membrane)
- Veto detector

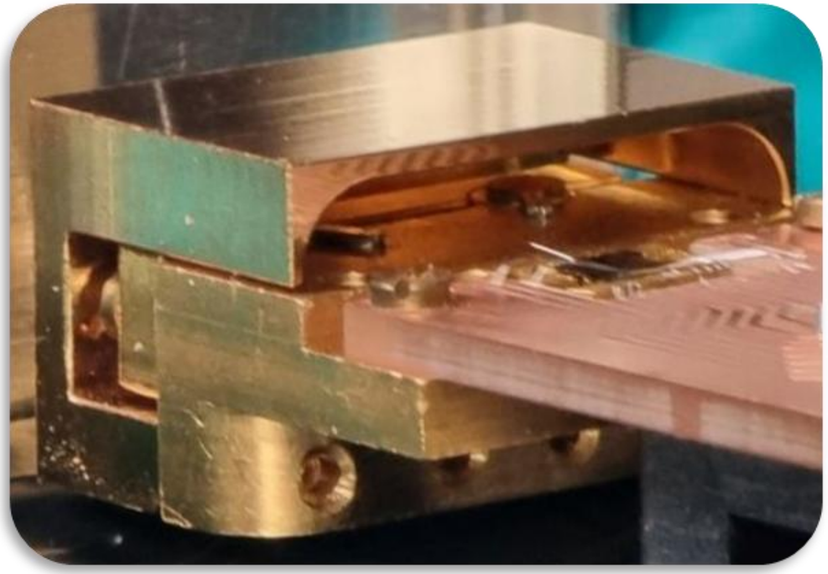
New sensors for direct dark matter searches

- Removed fiber sleeve and included copper cover
- Reduction in the raw background rate from $\mathcal{O}(10^{-2})$ cps to $\mathcal{O}(10^{-3})$ cps
- Analysis of new dark matter run ongoing

With fiber sleeve



Without fiber sleeve



A second module in preparation without zirconia fiber sleeve and TES on a membrane

Conclusions

- TESs are an excellent tool for quantum sensing, and background reduction is crucial to avoid false signals limiting the TES sensitivity.
- A TES is under study for ALPS II in a photon counting scheme.
  - Black Body Radiation simulated spectrum consistent with measured background [4].
  - The background rate is below 10^{-4} cps when the TES is coupled to an optical fiber. Further background reduction measures are in progress.
- Results of first direct dark matter searches with a TES as a target already published [5].
  - The simulation of the background when the TES is not connected to an optical fiber allowed first strategies to mitigate background from radioactivity [6].
  - A new direct dark matter run with a new dedicated sensor is finished. The analysis is in progress.