A Transition Edge Sensor for the ALPS II Experiment

Background Characterization and Detector Optimization

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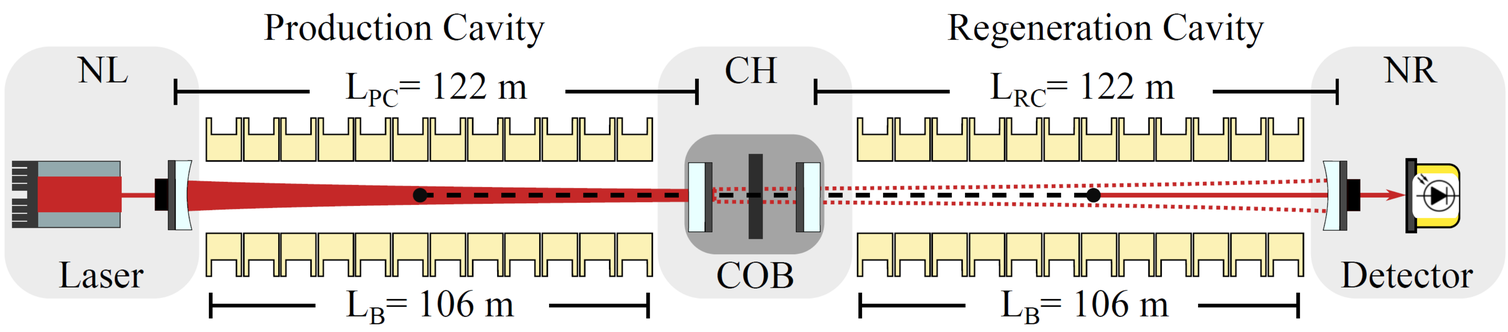
The ALPS II Experiment



Looking for axions and axion-like particles (ALPs) with Any Light Particle Search II (ALPS II):

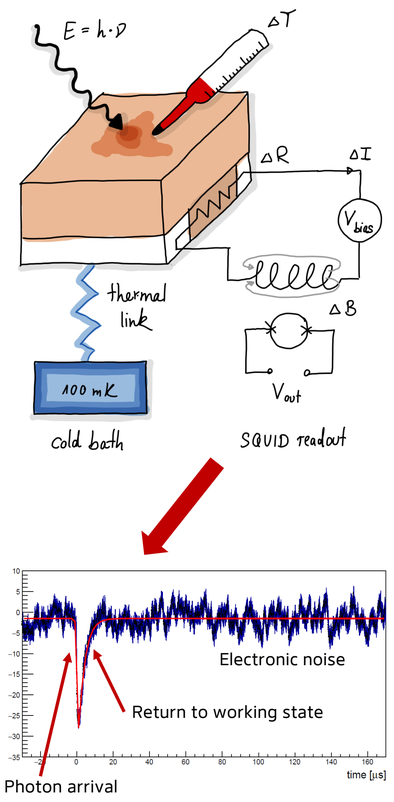
- Axions initially appeared as a solution to the Strong CP problem.
- Axions/ALPs are outstanding dark matter candidates.
- ALPS II is a resonantly enhanced Light-Shining-through-Walls (LSW) experiment.
- ALPS II is exploring photon coupling parameter space motivated by astrophysical hints in a model independent way [1].

Requirements for a TES in a single photon detection system in ALPS II at targeted sensitivity $g_{a\gamma\gamma}$ [2]:

- Measurement of a flux of 2.8 • 10^{-5} photon/s with 95% confidence level within 20 days
- 1 eV photon detection (1064 nm)
- High detection efficiency (> 50 %)
- Low background rate (< 7.7 • 10^{-6} cps equivalent to 1 photon "1064 nm – like" every 2 days)
  - Good energy resolution for background rejection

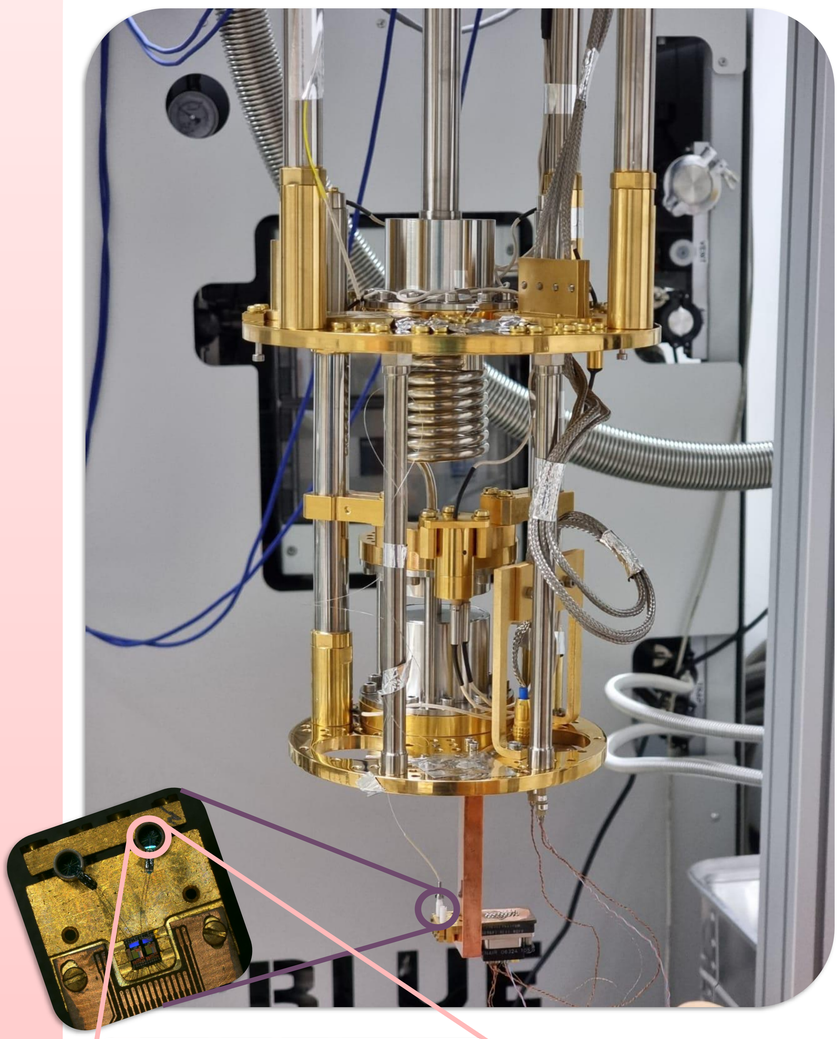
Transition Edge Sensor (TES)

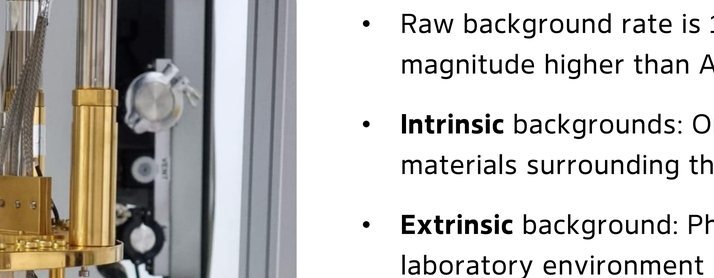
- Cryogenic microcalorimeter
- Operates in **transition region** between superconducting and normal conducting states
- Energy deposition slightly changes the temperature
  - ➢ Produces **detectable change** in the **resistance**



- **Tungsten microchip** provided by NIST
- Transition region: **~140 mK**
- Readout: Superconducting Quantum Interference Device (**SQUID**) based
- SQUIDs and packaging of sensor modules provided by PTB

A TES for ALPS II





Background caracterization

Background

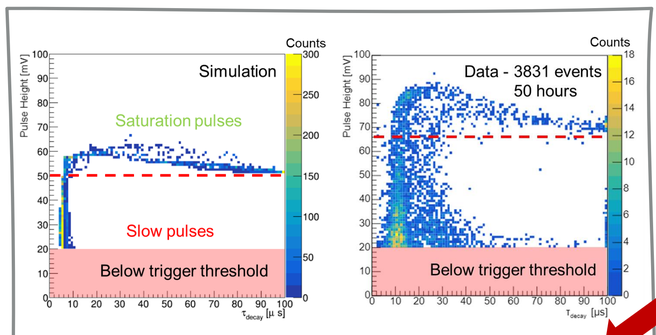
- Raw background rate is 10^{-2} cps, several orders of magnitude higher than ALPS II requirements
- **Intrinsic** backgrounds: Originated from **radioactivity** in materials surrounding the detector and **cosmic rays**
- **Extrinsic** background: Photons from the warm laboratory environment coupling into the optical fiber, i.e. **Black Body Radiation**

Background rejection

Intrinsic background meets ALPS II requirements:
- Cut-based fit analysis [2]
- Principal component analysis [3]
- Machine learning and training of convolutional neural networks [3]

Extrinsic background close to meet ALPS II requirements:
- Improvement in **energy resolution** [4]
- Development of hardware solutions, e.g. **Optical filters** in the cold

Simulation and detector optimization

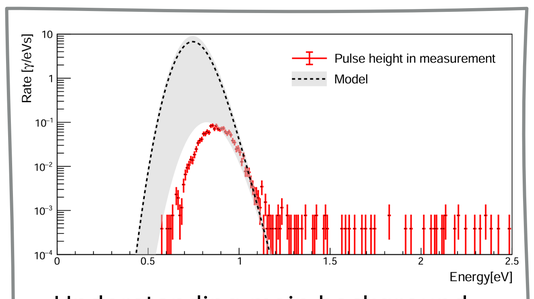


- Intrinsic background could be further reduced for other direct dark matter searches beyond ALPS II.
- Simulation predicts the zirconia in the fiber sleeve as the main background contributor.

Simulations

Geant4 + COMSOL simulation of **radioactivity** and **cosmic ray** background events in the TES

Simulation framework for computation of expected **Black Body Radiation** spectrum



- Understanding main background contribution for ALPS II
- Simulation results compatible with experimental data
- Background rate reduced to $\mathcal{O}(10^{-4})$ cps photon-like events

Direct dark matter searches with TES

- We use TES without fiber coupling for sub-MeV dark matter searches based on DM-electron scattering [5].
- The results from the first science run will be published soon.
- A run is ongoing with new dedicated sensor module (without zirconia fiber sleeves).
- Preliminary results show a reduction in the raw background rate from $\mathcal{O}(10^{-2})$ cps to $\mathcal{O}(10^{-3})$ cps.

Summary

The **TES** could be used as a **single-photon detector** in the **ALPS II** Experiment looking for **ALPs**.

Intrinsic background simulation shows **zirconia fiber sleeve** as main background contributor, validated by experimental data.

Extrinsic background is dominated by **Black Body Radiation**. Further optimization of the experimental setup is in progress.

References

[1] Wei, L.W. et al., PoS TAUP2023 (2024) 049
[2] Shah, R. et al., PoS EPSHEP2021 (2022) 801
[3] Rubiera Gimeno, J.A. et al., PoS EPSHEP2023 (2024) 567
[4] Meyer, M. et al., Annalen d. Physik (2023)
[5] Schwemmbauer, C. et al., PoS EPSHEP2023 (2023) 120