Low background single photon detection with a transition edge sensor for ALPS II

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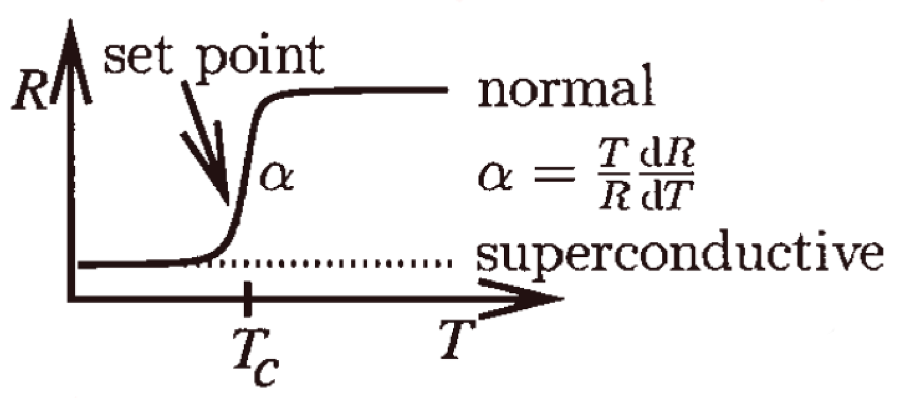
Abstract

The ALPS II experiment, Any Light Particle Search II at DESY in Hamburg, will look for light ($m < 10^{-4}$ eV) new fundamental bosons (e.g., axion-like particles, hidden photons and other WISPs) in the next years by the means of a light-shining-through the wall setup.
The ALPS II photosensor is a Transition Edge Sensor (TES) optimized for 1064 nm photons. This TES, operated at 80 mK has already allowed single infrared photon detections as well as non-dispersive spectroscopy with very low background rates. The expected quantum efficiency for such TES is > 95 % (1064 nm). For 1064 nm photons, the measured dark count rate is < 10^{-2} sec^{-1}. At this wavelength, the intrinsic dark count rate is of 10^{-4} sec^{-1}. The relative energy resolution for 1064 nm signals is < 8%. In order to set accurately the device and for reading purposes, TESs are inductively coupled to a SQUID (Superconducting Quantum Interference Device). In the near future, complete characterization, calibration and optimization (e.g., background suppression) need to be finalized.

Adiabatic Demagnetization

In order to place the TES near to its transition temperature (T_c), we use an Adiabatic Demagnetization Refrigerator (ADR).

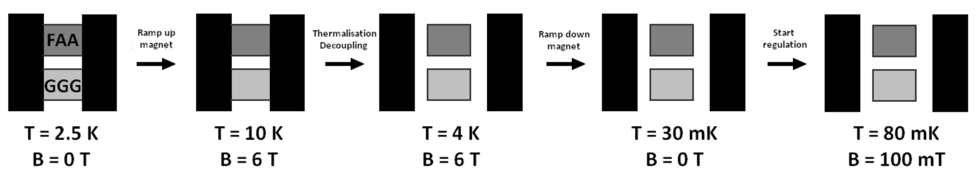


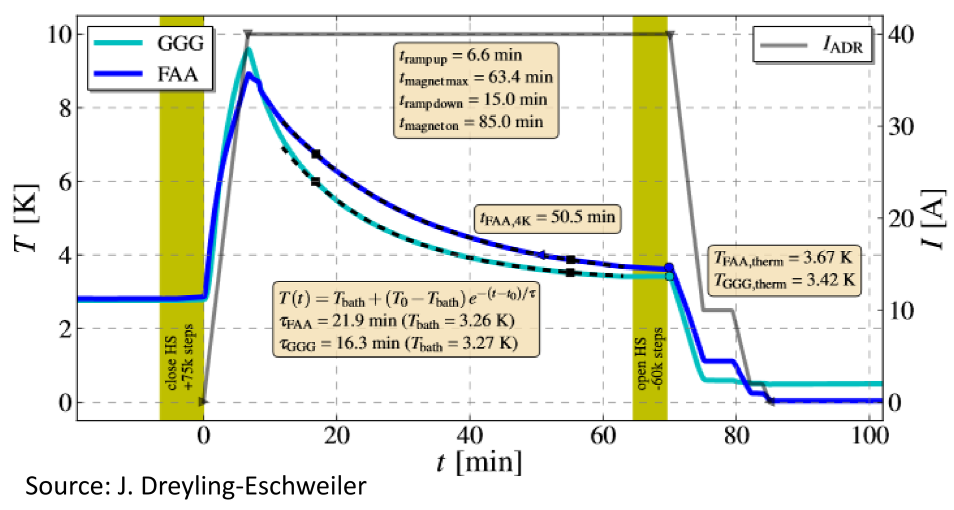
P.A.J. De Korte et. al., *Tes x-ray calorimeter-array for imaging spectroscopy. Proceedings of SPIE*, pages 779-789, 2002

Cooling Procedures

Cool-down: Baseline temperature of 2.5 K given by a compressor using helium. Length in time only limited by maintenance work and change of the setup.

Recharge: Temperature of 80 mK at the detector level reached by adiabatic demagnetization in two hours. A recharge lasts approximately 24 hours. This process can be repeated many times within a cool-down.

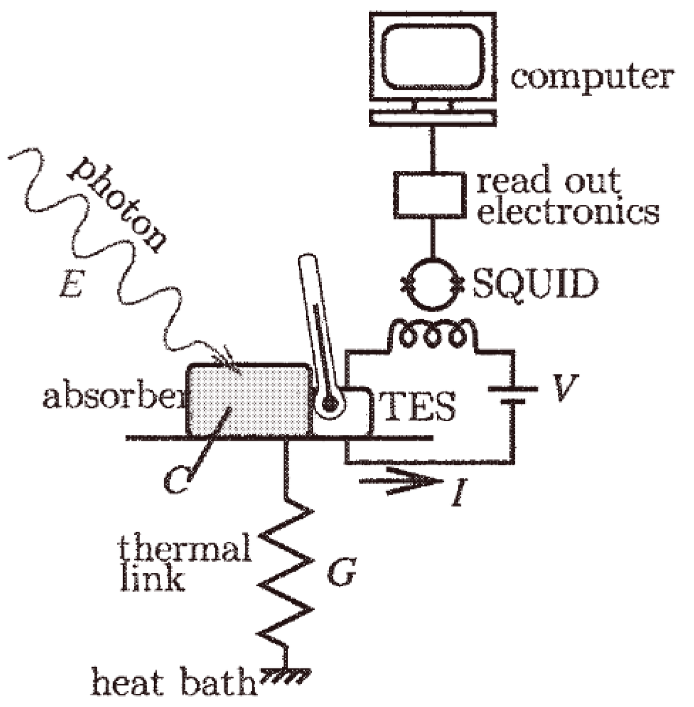




Source: J. Dreyling-Eschweiler

Transition Edge Sensor

A TES is a microcalorimeter measuring the temperature difference ΔT of the absorber material. In our case, the tungsten chip plays the role of absorber and thermometer.



P.A.J. De Korte et. al., *Tes x-ray calorimeter-array for imaging spectroscopy. Proceedings of SPIE*, pages 779-789, 2002

Absorption of a photon (1.17 eV) → ΔT ≈ 0.1 mK

↓

Superconducting transition R ↑ (R ≈ 1 Ω)

↓

TES electrical circuit (I ≈ 70 nA)

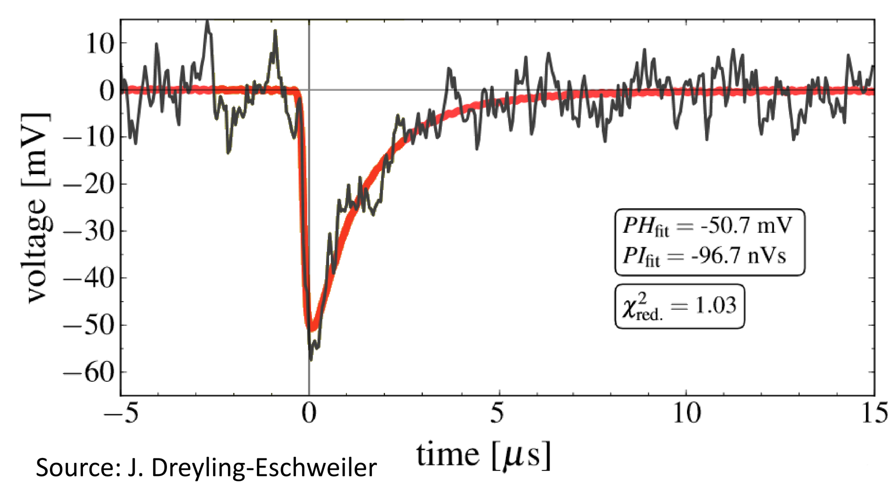
↓

SQUID (inductive coupling)

↓

ΔVout ≈ 50 mV

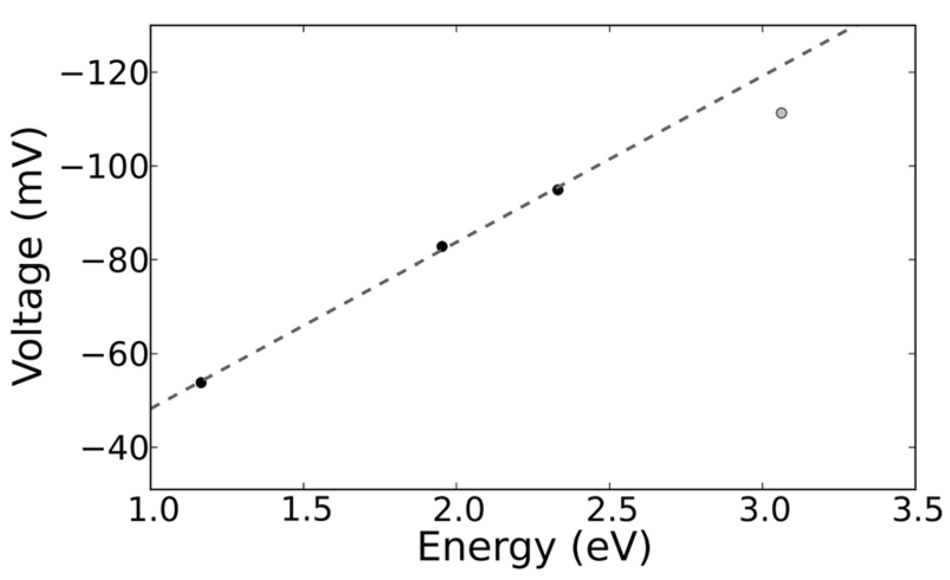
Single Photon Events



Source: J. Dreyling-Eschweiler

Linearity

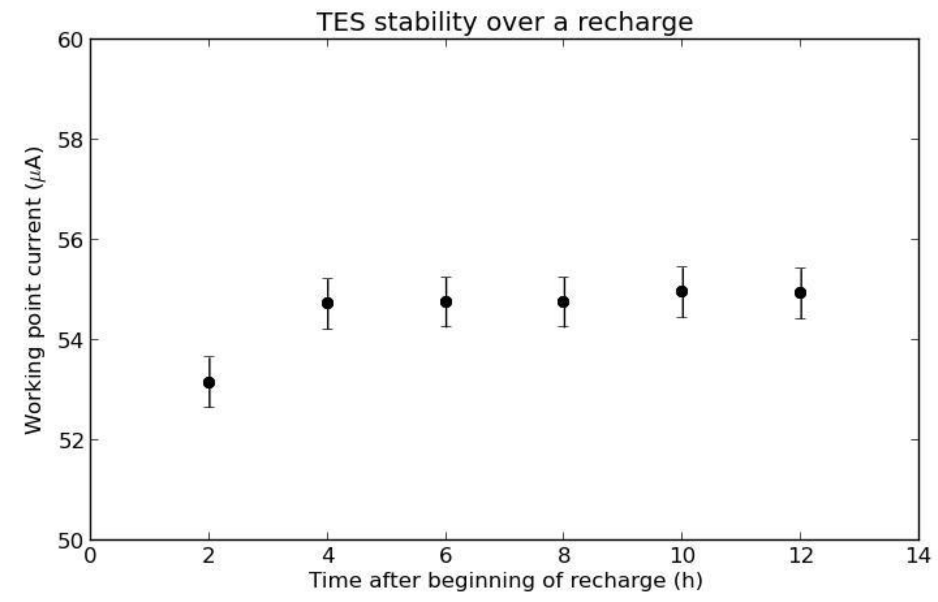
W-TESs are linear in our region of interest (1.17 eV). The non-linearity at higher energies matches expectations (saturation of the detector).



Average pulse height in units of voltage output as a function of photon energy for the TES. The dashed line is a fit to the first three points.

Stability

Detections with TESs are stable during a recharge,during one cool-down as well as during different cool-downs.
The results are not operator dependent (adjustment method).



The TES working point current equivalent to R0= 30 % Rnormal as a function of time after the beginning of a recharge.

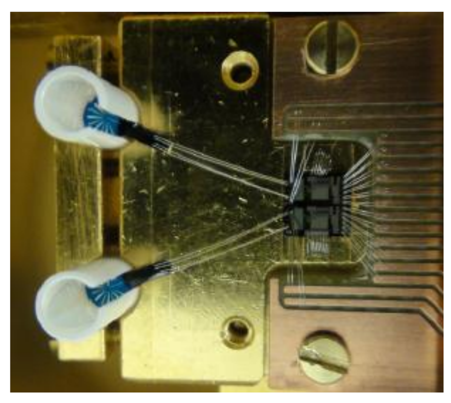
Technical Challenges

LOW ENERGY (1.17 eV)
LOW RATE (1 γ every few hours)

- ❑ **High detection efficiency**
- ❑ **Low dark count rate**
- ❑ **Long-term stability**
- ❑ **Good energy resolution**
- ❑ **Good time resolution**

NIST W-TES	
Efficiency (1064 nm)	95 % (*)
Dark current	10^{-4} sec^{-1}
Long term stability	☑
Good energy resolution	< 8%
Good time resolution	☑

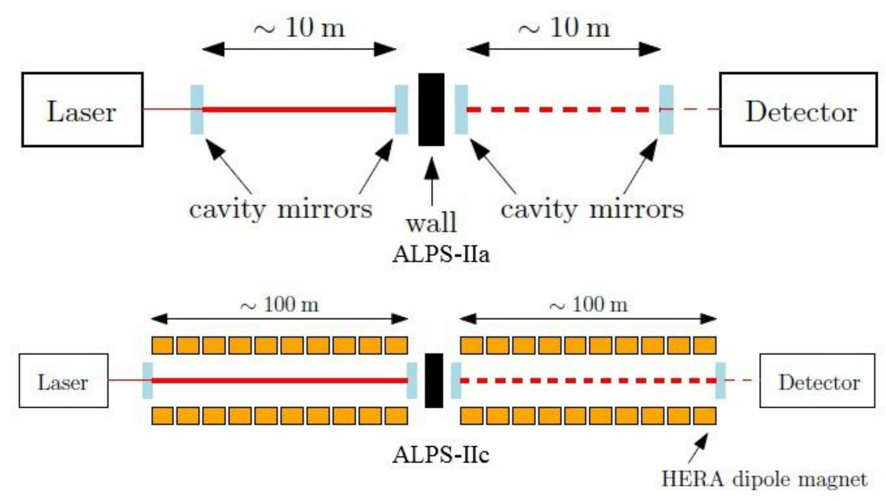
(*) A.E. Lita, A.J. Miller, S.W. Nam, *Counting near-infrared single photons with 95 % efficiency*, Opt Expres. 2008



Two chanels module (3 x 3 cm^2)
Tungsten chip (25 x 25 μm^2 , 20 nm)
Tc ≈ 140 mK
Inductive coupling to a SQUID

Outlook

First ALPS II data taking in 2016 (ALPS II a - search for hidden photons).



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Characterization, 1064 nm photon signals and background events of a tungsten TES detector for the ALPS experiment, JMO (2015) arXiv:1502.07878v1

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