TES Detector for the ALPS II Experiment

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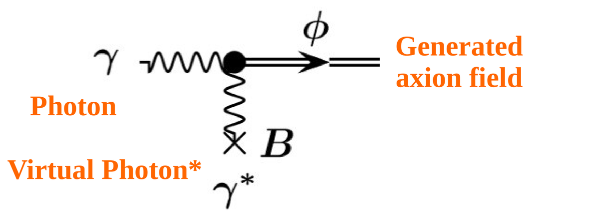
Axions and axion-like-particles

> Axions proposed in 1977 to "clean up" strong CP problem in QCD.

> Axion-like-particles (ALPs) have properties similar to the axion, both are WISPSs (Weakly Interacting Sub-eV Particles).

> Current experimental technology can search for axion-like-particles via the Primakoff-like Sikivie effect:



> Astrophysical hints for ALPs from the anomalous cooling of observed stellar systems [1].

> Axions and ALPs are prime candidates for cold dark matter in the mass range <1 meV, with photon-axion coupling strengths $<10^{-10}$ GeV.

> They can serve as a door to the dark sector, their discovery answering two of physics' biggest questions!

ALPS II: Concept and Setup

> Using the Sikivie effect in front of and behind a light tight barrier, ALPS II is a model independent light-shining-through-a-wall (LSW) experiments with LIGO derived optics.

> The axion field generated with a laser of 1064 nm light with magnetic field of 5.3 T in a Production Cavity (PC) before the barrier *(see setup image below)*.

> Reconversion of the axion field to photons of 1064 nm with same magnetic field occurs in the Regeneration Cavity (RC), after the barrier.

> Sensitivity enhanced with 150 kW circulating power in the PC, and power build-up of 4×10^4 in RC. RC held on resonance with the PC.

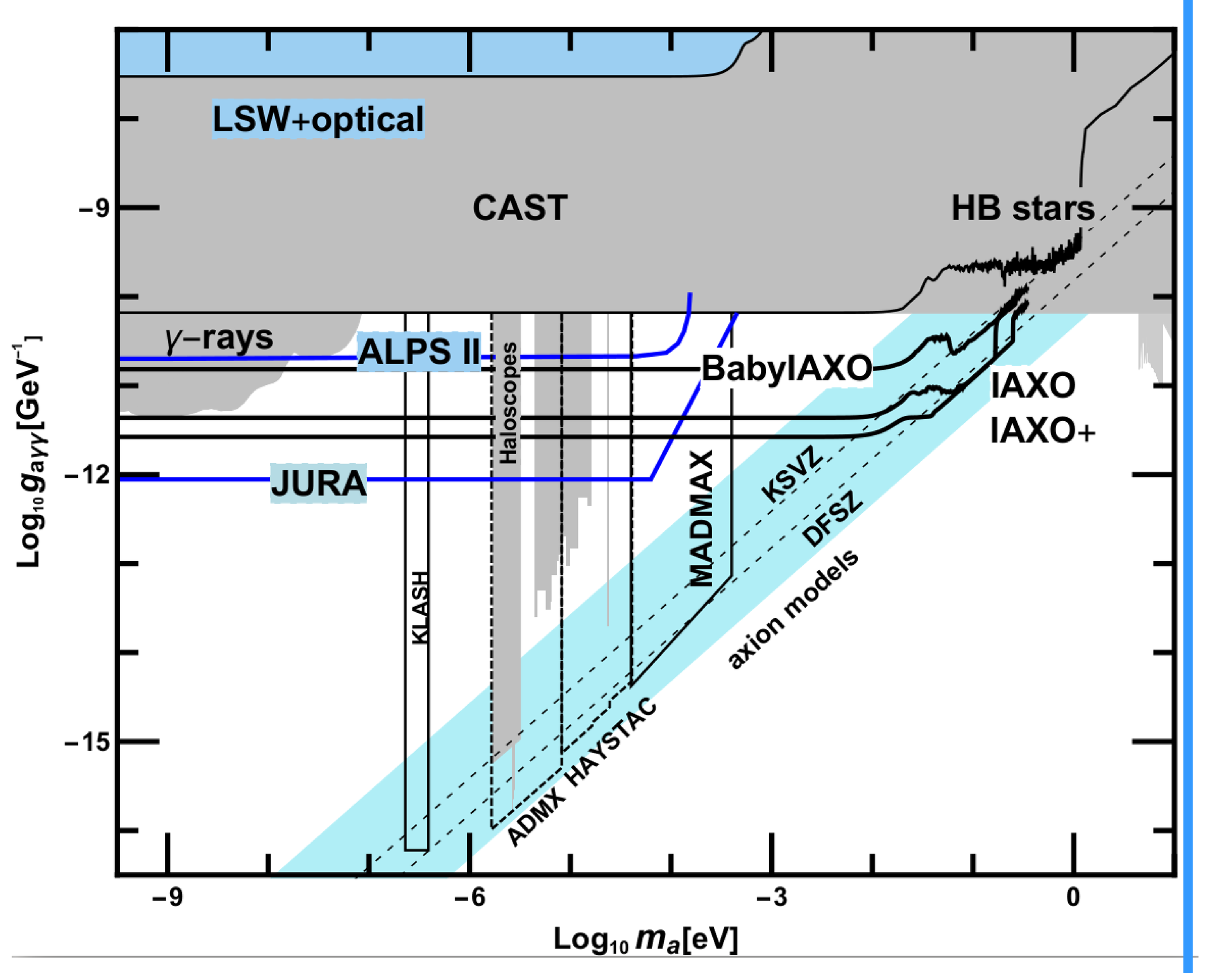
> The PC and RC are optical cavities of length 120 m, with 12 HERA dipole magnets of magnetic length 8.83 m each.

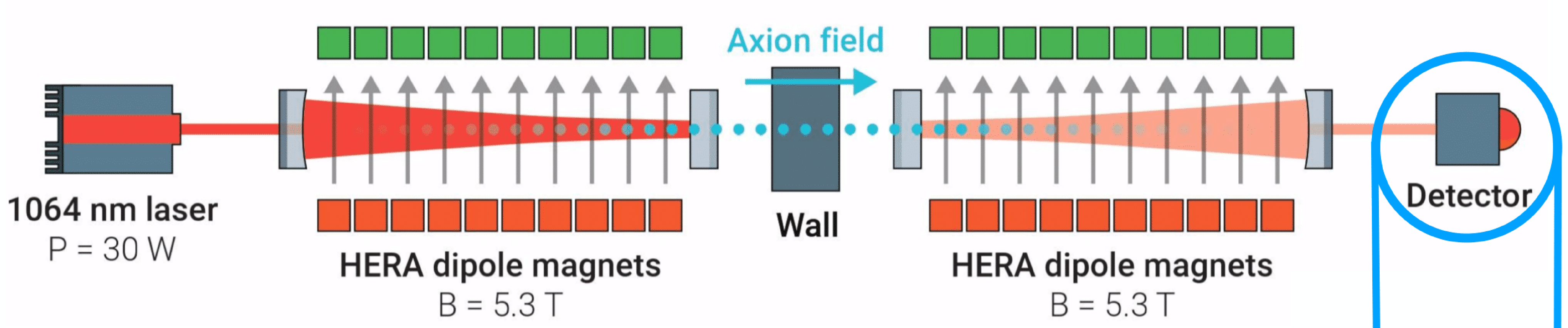
> To be located in the straight section of the former HERA accelerator, at DESY Hamburg *(see image in the middle, right)*.

> ALPS II will probe sensitivity up to $g_{a\gamma\gamma} = 2 \times 10^{-11}$ GeV^{-1} and ALP mass $m_a < 10^{-4}$ eV *(as in figure on the right, from [2])*, about 10^3 increase in sensitivity from previous LSW experiments.

> Data taking is scheduled to start in 2021.

> The photon detection sensitivity shall reach $\sim 10^{-5}$ s^{-1}, ~1/day





A TES for ALPS II

> Reconverted 1064 nm photons from the RC are detected with a Transition Edge Sensor (TES) due to

> Low energy of the photons (1.16 eV)

> High detection efficiency required

> Low background needed ($O(10^{-5})$ s^{-1}).

> Photon absorption changes the device's conductivity drastically at superconducting edge *(ΔT=100 μK, causing ΔR=1 Ω)*, and consequent signal change *(ΔI = 70 nA)* is read out.

> The NIST/PTB [3,4] TES detector is a tungsten (W) film optimized for 1064 nm with dimensions 25 µm x 25 µm, and thickness 20 nm.

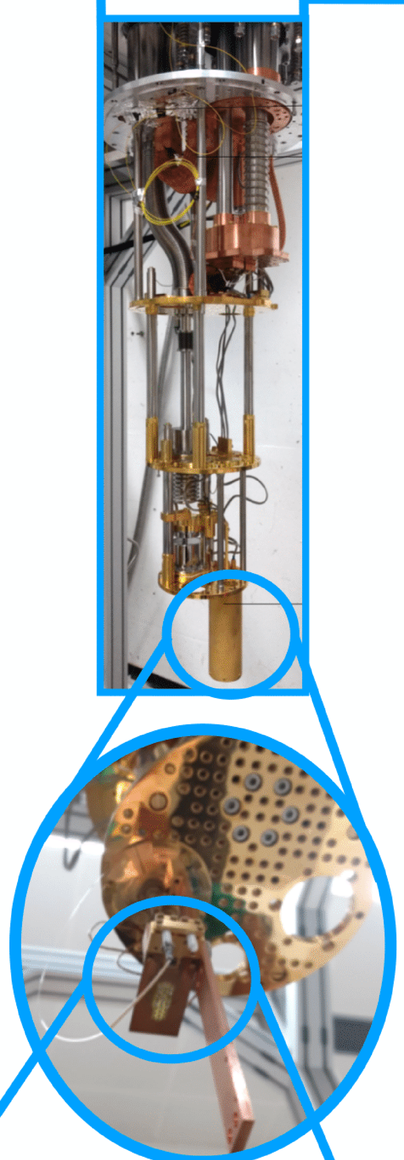
> The W film has an anti-reflective coating over it and is deposited on a silicon substrate, all prepared by NIST, USA.

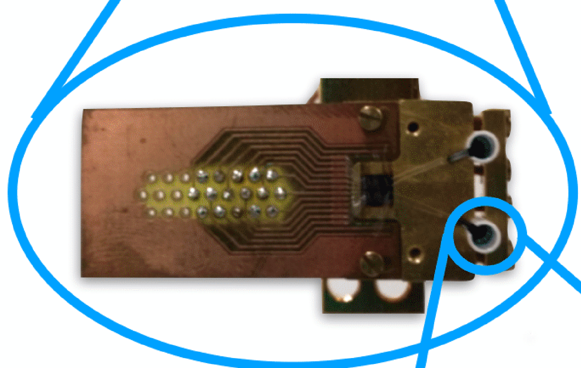
> The chosen W film has a T_c of 140 mK, and is operated at ~80 mK.

> Sensor module used has SQUIDs and two TESs.

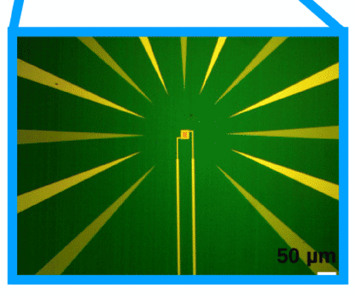
> TES signals detected by the SQUIDs prepared by PTB, Germany. They are read out by SQUID electronics from Magnicon GmbH, Hamburg.

> The entire setup placed within a cryogenic environment. Cryocooler used for this is a (He-3, He-4) Dilution Refrigerator (DR) from BlueFors, Helsinki.





Sensor Module with the SQUIDs. The TESs are in each white ferrule. Here, the module is attached to the detector housing arm (UHV copper) within the cryogenic environment.



Magnified view of the NIST TES chip

TES Backgrounds

> With dark setup (no light/optical fiber attached to the TES) the intrinsic backgrounds include:

> Single photon-like events with rate 10^{-4} s^{-1}.

> Other photon-like event populations (possibly from radioactivity and cosmic muons) with rates $\sim 10^{-3}$ s^{-1}
(Depends on TES architecture).

> With an optical fiber attached to the TES, open for thermal photons:

> Background dominated by pile-up of black body radiation photons with a rate $\sim 8 \times 10^{-3}$ s^{-1} [5], possibly from the warm end of the optical fiber.

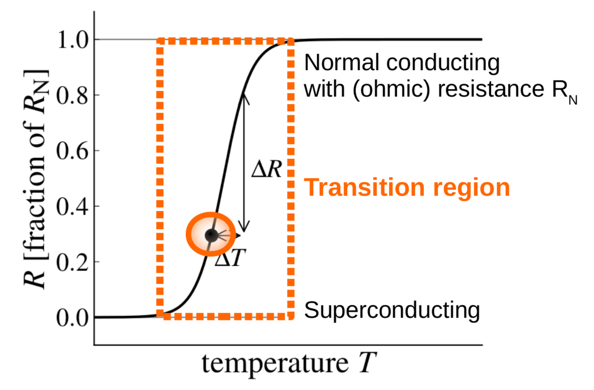
> Planned suppression of the black-body photons with a filter at the 40 K stage of the cryocooler. Feasible with ~50% transmittance drop [6].

TES: Operation and Signals

> TES operated in transition region

> Operating point selected for maximal energy resolution and dynamic range → with resistance ~30%R_N.

> To bias the TES correctly, the IV-characteristics scoped out with input (biasing) signal.



The resistance plot for TES temperature. The circled dot represents a TES temperature corresponding to a TES resistance of about 30% of the TES's normal conducting resistance R_N. Adapted from [7].

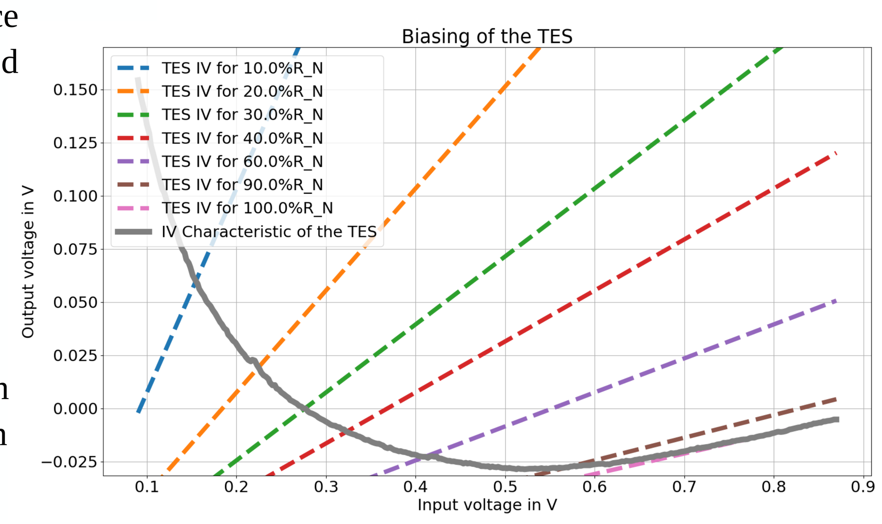
> SQUIDs read out signals once TES is biased. They are operated in feedback-locked-loop (FLL) mode to use them as a voltmeter/ammeter.

> Laser light introduced in system with 1064 nm laser.

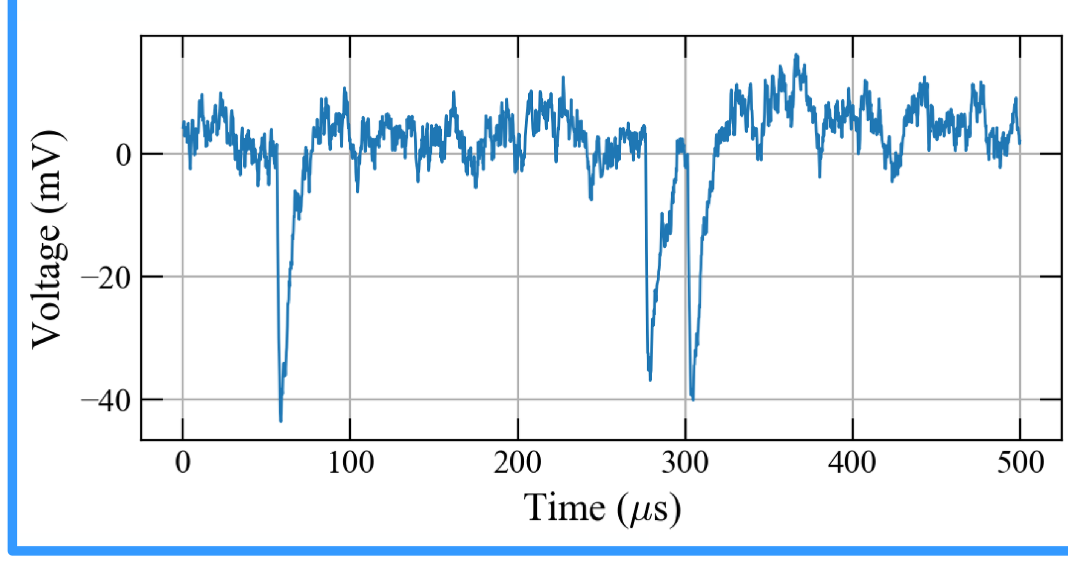
> Photon pulse characterization with TES data being undertaken

> Background reduction by filtering, testing using filter bench underway.

> DAQ and control system for the detector to be set up.



The IV characteristics of the TES, made by biasing it with an external, linear, time-varying input. The extreme right on the IV characteristic displays normal conduction (Ohmic behaviour) with resistance R_N and the extreme left displays superconducting behaviour. The curved section in between these two is the transition region where different points are scoped out to achieve various fractions of R_N viz. 10%R_N, 20%R_N etc.



The photon pulses in the TES signal, with the laser light input to the optical fiber on the TES. This is the light signal seen after appropriately biasing the TES and reducing sources of noise from the electronics setup.

1. Maurizio Gianotti, et al. *Cool WISPs for stellar cooling excesses*, 2016
2. Courtesy of Jörg Jäckel, *U. Heidelberg*
3. National Institute of Standards and Technology
4. Physikalische-Technische Bundesanstalt, National Metrology Institute of Germany
5. Jan Dreyling-Eschweiler. *Characterization of 1064 nm photon signals and background events of a tungsten TES detector for the ALPS experiment*, 2014
6. Elena Mazzeo et al. *The challenge of filtering photons in a cold environment*, DESY Summer Student Report, 2018
7. Jan Dreyling-Eschweiler. *A Superconducting Microcalorimeter for Low-Flux Detection of Near-Infrared Single Photons*, PhD Thesis