Transition Edge-Sensor for ALPS: A superconducting microcalorimeter for detecting NIR-photons

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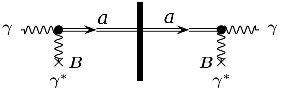
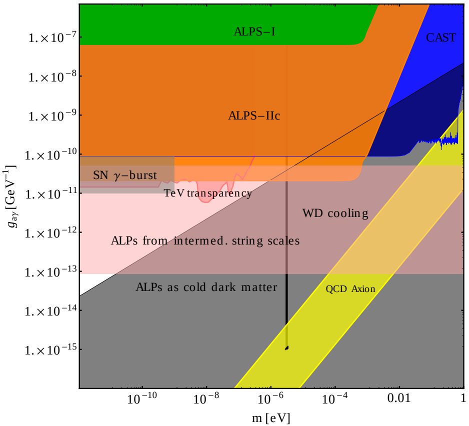
Detector Seminar (DESY-FH) on November 21^{st}, 2013

Contents:

Any Light Particle Search (ALPS) at DESY – Light-Shining-through-a-Wall?

ALPS-I: $\gamma_{\text{in}} \sim 10^{21}$ 1/s  $\gamma_{\text{meas}} = (2 \pm \mathbf{13}) \times 10^{-3}$ 1/s

K. Ehret, et al., Physics Letters B 689 (2010) 149

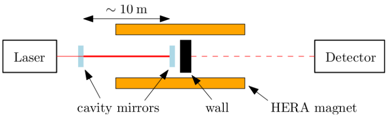


Axion-like particle specs:

- sub-eV mass, weakly interacting with SM
- could explain:
  - TeV transparency (Horns group, UHH)
  - CDM candidate
  - ...
- $g_{a\gamma} < \frac{1}{BL} \sqrt[4]{\frac{\gamma_{\text{out}}}{\gamma_{\text{in}} \times \epsilon}} \frac{1}{F(\dots)}$

ALPS-II – lower the limit!

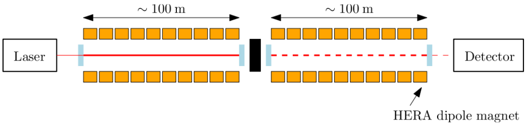
$$g_{a\gamma} < \frac{1}{BL}\sqrt[4]{\frac{\gamma_{\mathrm{out}}}{\gamma_{\mathrm{in}}\times\epsilon}}\frac{1}{F(\dots)}$$



(a) ALPS-I

specs of ALPS-I

- laser: **532 nm**
- length: 2×5 m



(d) ALPS-IIc

power-ups of ALPS-II

- length: up to 2×100 m
- regeneration cavity
- laser power (**1064 nm**)

ALPS-II – TDR: arXiv:1302.5647
What's new in ALPS-II: arXiv:1309.3965

Detectors for ALPS-I and ALPS-II

ALPS asks for…

- **Challenge:** detection of low rates (<1/h) single photons (∼1 eV)
- **Requirements:** High efficiency and low (dark) noise

Si-CCD:

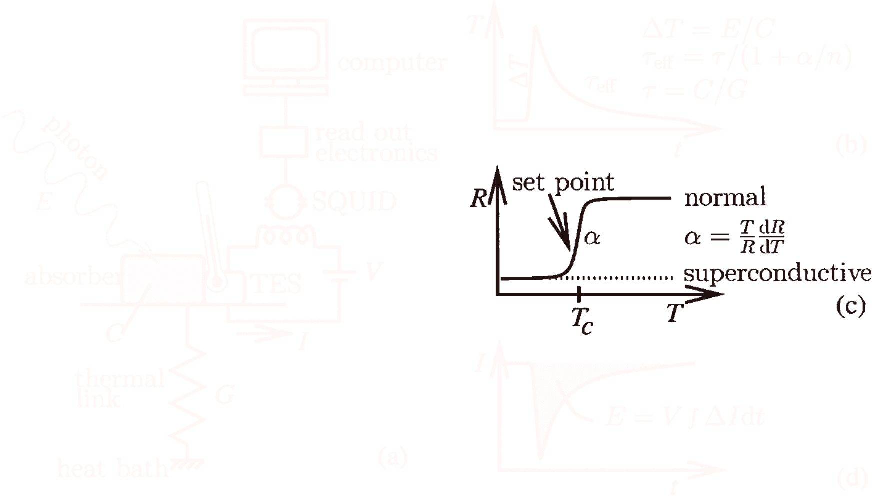
+ QE >90% (**532 nm**)
+ DC $\sim 10^{-3}$/s
- 1 h frames at ALPS-I
+ ready to use
- QE <1.2% (**1064 nm**)

TES (from NIST/AIST:)

+ QE >95% (**1064 nm**)
? DC <1/s, but no details
+ time/energy res. $\sim 1\mu$s/0.1 eV
- sensor availability
- mK cryogenics

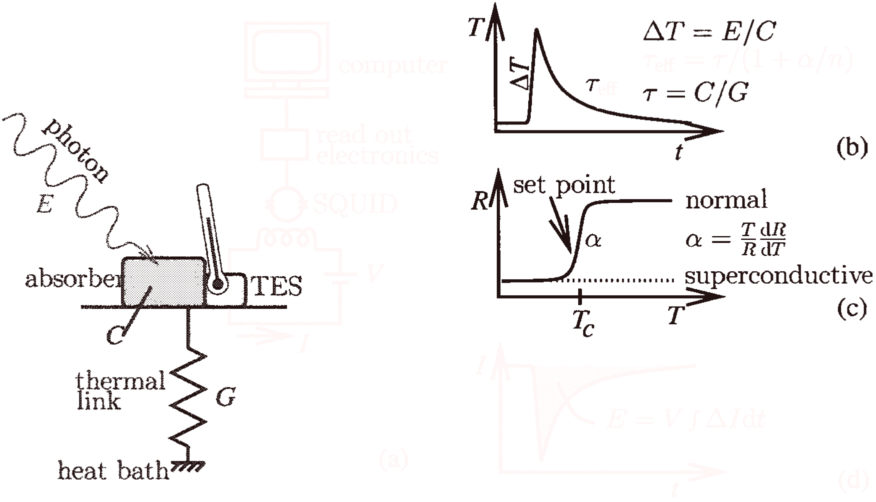
…how does a TES work?

(Superconducting) Transition-Edge Sensor (TES) . . .



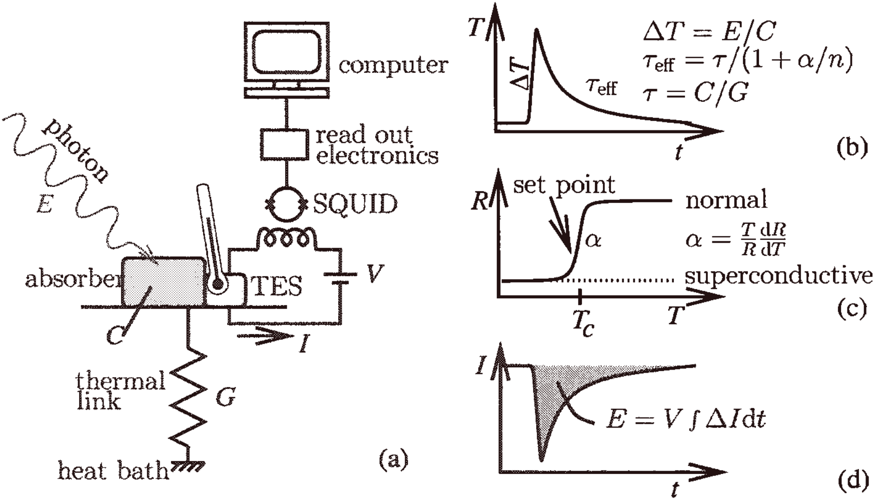
P.A.J. De Korte et. al., Tes x-ray calorimeter-array for imaging spectroscopy. Proceedings of SPIE, pages 779-789, 2002

. . . is a calorimeter with . . .



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

. . . negative electro-thermal feedback

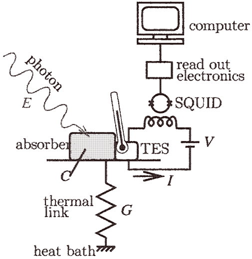


P.A.J. De Korte et. al., Tes x-ray calorimeter-array for imaging spectroscopy. Proceedings of SPIE, pages 779-789, 2002

Setting up a TES detector for ALPS

Very brief history

- 2011: gaining experience (Trieste, Camerino, Berlin, ...) and connecting to small TES-community
- 2012: 30 mK in ALPS-IIa lab, DESY
- 2013: 1064 nm single photons and more...



TES detector for ALPS:

- **Sensor:** high-efficient fiber-coupled TES from NIST
- **Read-out:** low-noise SQUIDs from PTB
- **mK-cryogenis:** cryostat from Entropy GmbH

NIST

PTB

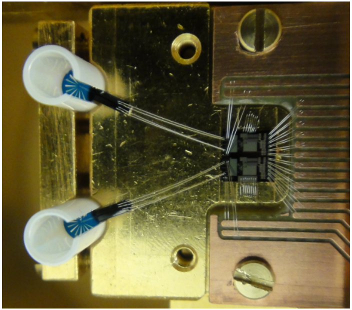
ENTROPY

Sensor: TES and SQUID

- NIST:
  chip development over 10 years
- TES chip (NIST):
  - Tungsten (W) film:
    $T_c \sim 140$ mK
  - sensitive area (volume):
    $25 \times 25\ \mu\text{m}^2$ ($\times 20$ nm)
  - multilayer structure:
    QE >99 % for 1064 nm

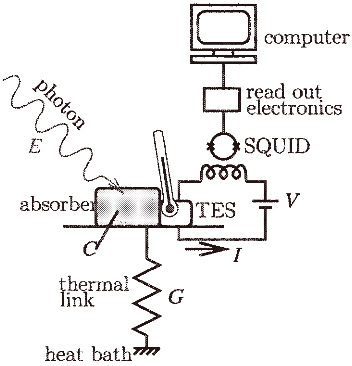
module with two channels

(scale ∼ 3cm x 3cm)



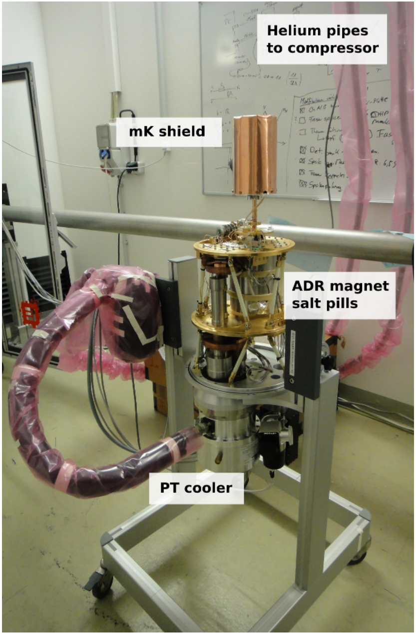
- Optics: sleeve to connect single mode fiber (losses <1 %)
- SQUID chip (PTB) for read-out
  - Superconducting QUantum Interference Device
  - PTB-Berlin ("Kryosensoren")
  - noise: $2.5\ \text{pA}/\sqrt{\text{Hz}}$ (TES noise: $7.0\ \text{pA}/\sqrt{\text{Hz}}$)

Read-out: Converting energy in a voltage output



- Δ 1064 nm = 1.17 eV
- $\downarrow$ absorption
- Δ $\sim$0.1 mK
- $\downarrow$ superconducting transition (TES)
- Δ $R_{\mathrm{TES}} \sim 1\ \Omega$
- $\downarrow$ TES electrical circuit
- Δ $I_{\mathrm{TES}} \sim 70$ nA
- $\downarrow$ inductive coupling
- Δ $n\Phi_0$ flux quantum level (SQUID)
- $\downarrow$ transformation and amplification
- Δ $V_{\mathrm{out}} \sim 50$ mV

mK-cryogenics: Compact cryostat

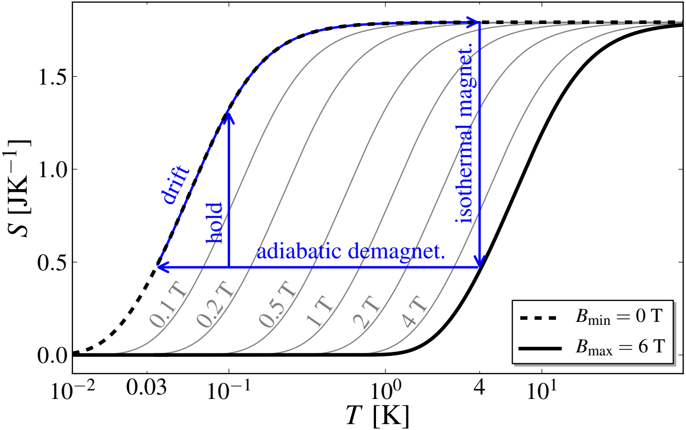


- 2^{nd} cryostat from Entropy
- Vacuum dewar (70x33 cm) in a moveable trolley
- Pre-cooling by pulse-tube cooler
  - He4 cycle (20 l at 17.2 bar)
  - water and heavy current

$\rightarrow$ from 300 K to 2.5 K: in $\sim$24 h

Adiabatic Demagnetization Refrigerator (ADR)

entropy S depends on T and B



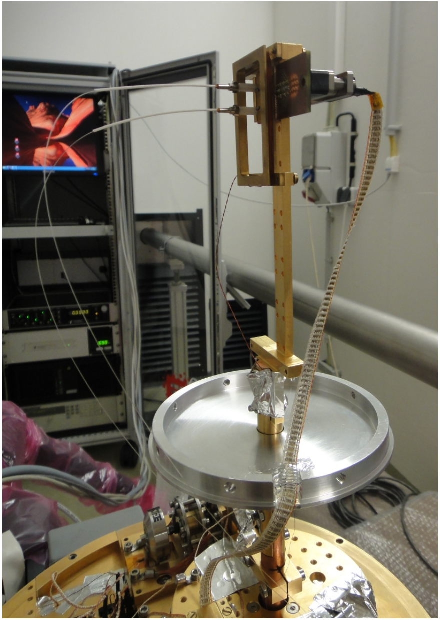
- paramagnetic salt pills (spin-system) with 6 T magnet

$\rightarrow$ 2.5 K to 30 mK: 1-2 h

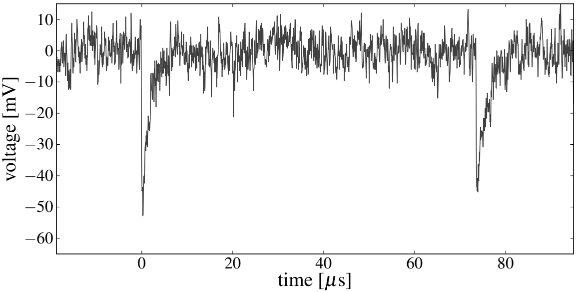
$\rightarrow$ $T_{\text{bath}} = 80$ mK $\pm$ 25 μK (rms) for 24-60 h

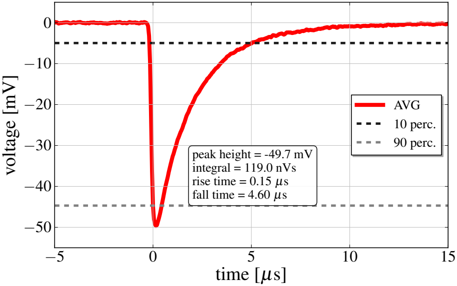
Ready for signals!?

- Assembling all in the warm and getting cold… wait 24 h
- Check Cryogenics: $T_{\mathrm{bath}} = 80$ mK or heat switch problems?
- Check SQUID: Quiet environment? Ready for read-out!
- Check TES: Superconductive? Working point!



Signals: 1066.7 nm single photons

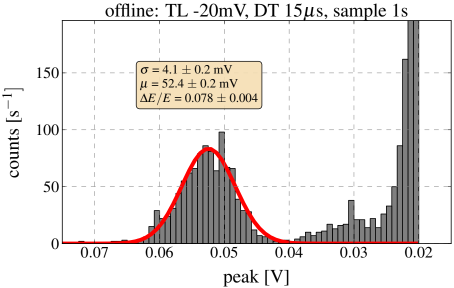


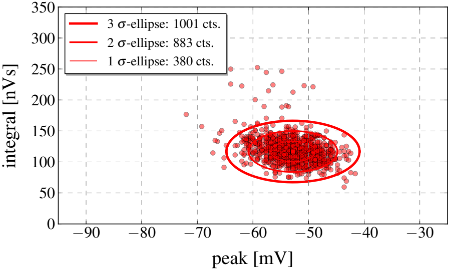


1064 nm photon = 1.17 eV event:

- rms <5 mV
- $\text{peak}_{\text{average}} \simeq 50$ mV
  $\text{integral}_{\text{average}} \simeq 120$ nVs
- rise time $\simeq 0.2\ \mu$s
  fall time $\simeq 4.6\ \mu$s
- energy resolution: <8 %

2D signal region: integral-peak-plot



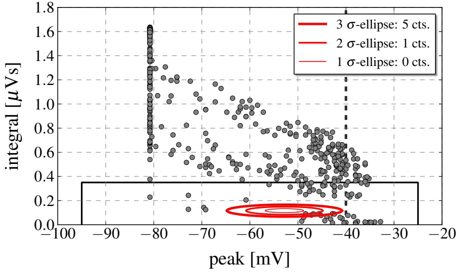


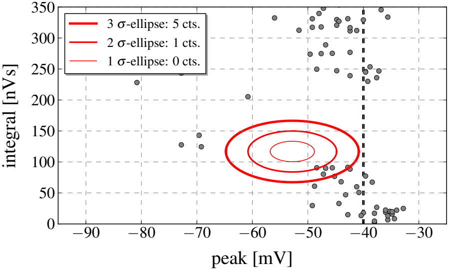
Single photon source:

- ~70 dB attenuated 10μW laser
- signal rate $\simeq$ 1000/sec

$\rightarrow$ 1 s sample $\rightarrow$ 1000 photons

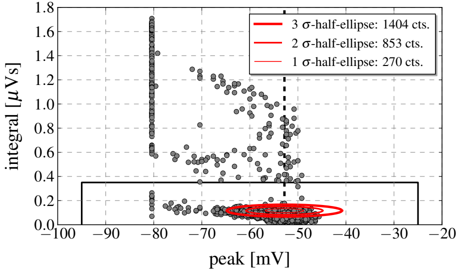
Background with no fiber: TES sees 80 mK

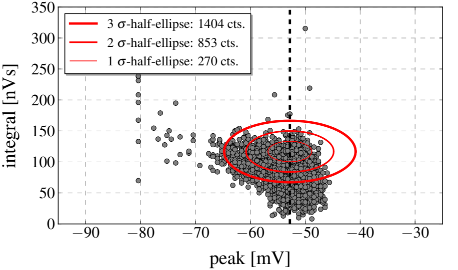




- 14 h measurement
- rate (3σ region): 9.8×10^{-5}/sec
- no events induced by SQUID

Background with “dark” fiber end at 300 K





- 16 h measurement
- rate (half 3σ region): 42 sec/# $\rightarrow 2.4\times10^{-2}$/sec
- lighttight ADR
- thermal photons from fiber

Summary and Outlook

Summary

- ALPS-II
  - is a light-shining-through-a-wall experiment
  - searching for weakly interacting sub-eV particles
- TES is a microcalorimeter
  - with high efficiency for NIR-photons
  - but needs a lot of effort
- 1064 nm signals are well detected,
  but 300 K background is an issue!

Outlook

- Measure detector efficiency
- Reduce thermal background:
  - Advanced analysis and bandpass filter
- Data of ALPS-IIa in 2014, ALPS-IIc (200 m) in 2017.