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

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for the ALPS II collaboration

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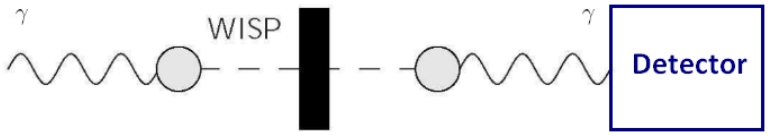
Any Light Particle Search

Any Light Particle Search experiment looks for **Weakly Interacting Sub-eV Particles** also called **WISPs**.

Axion → Possible solution for the smallness of the **CP violation** in QCD

→ Hints from astrophysics observations



Light shining through the wall experiment:

Photon-mixing + Additional light boson

→ Re-appearance of photons behind the barrier

1064 nm laser → 1.17 eV photons

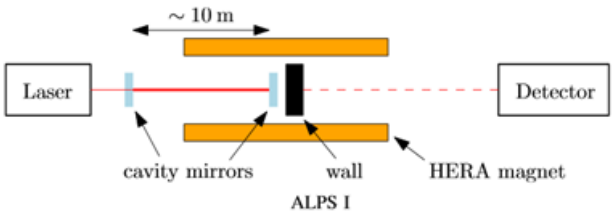
1 photon every few hours

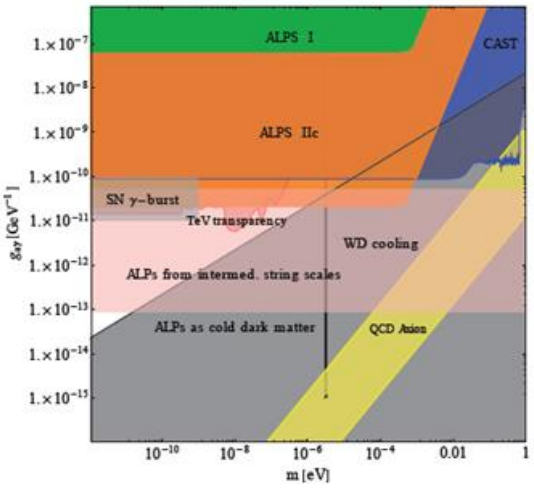
ALPS II

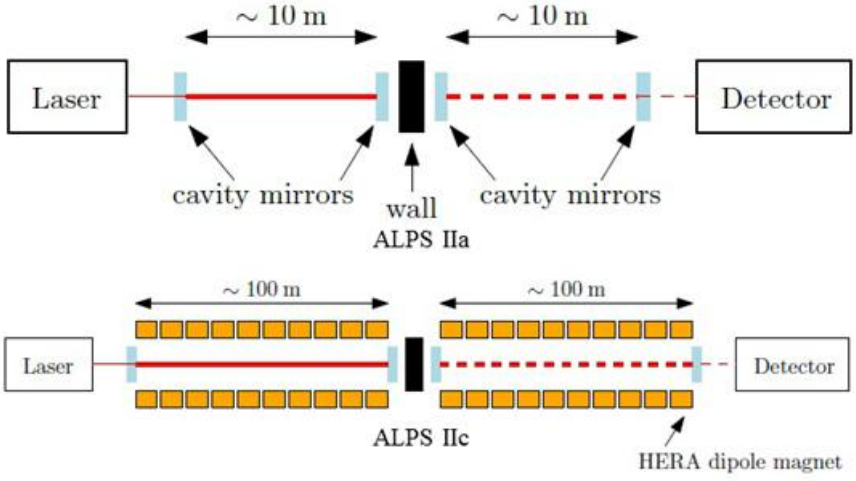
ALPS I: $g_{a\gamma} \leq 7.10^{-8}\ GeV^{-1}, m_a \leq 10^{-4} eV$

ALPS II: $g_{a\gamma} \approx 2.10^{-11}\ GeV^{-1}$

→ **Three orders of magnitude**







Technical challenges for the detector

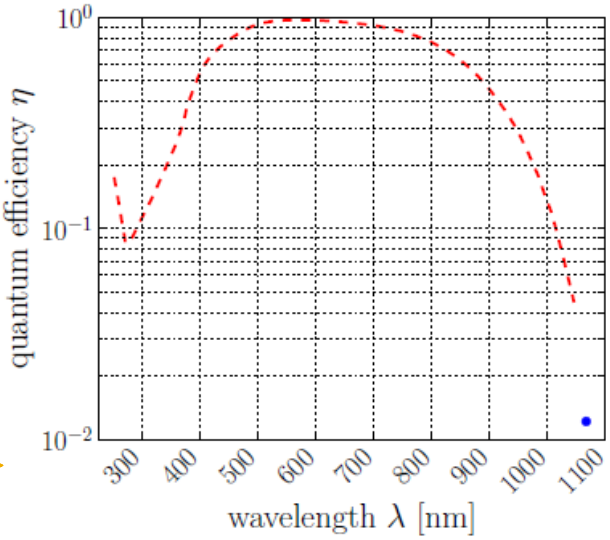
⇨ **Low energy (1.17 eV) and low rate (1 photon every few hours).**

1) **High efficiency**
2) **Low dark count rate**
3) Long-term stability
4) Good energy resolution
5) Good time resolution

CCD in ALPS II

PIXIS 1024B CCD camera	
Dark current	10^{-3} e$^-$ / *pixel* / sec
Efficiency (1064 nm)	1.2 %
Long term stability	☑
Good energy resolution	☒
Good time resolution	☒

Low efficiency due to the proximity of the wavelength to the Si band gap energy.



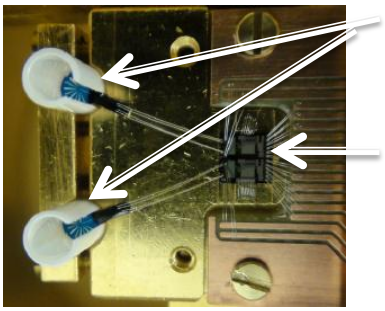
Von Seggern JE, *Constraining Weakly Interacting Slim Particles with a Massive Star and in the Laboratory*, Dissertation, Univ. Hamburg, 2014

Transition Edge Sensor

NIST

PTB

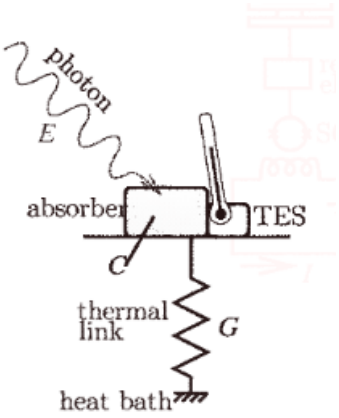
*Two channels module (3 cm * 3 cm)*



TES

SQUID

TES: Microcalorimeter measuring the temperature difference **ΔT** of the absorber material.



Tungsten chip (25 x 25 µm , 20 nm)

Tc ≈ 140 mK

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

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

Photon absorption to signal output

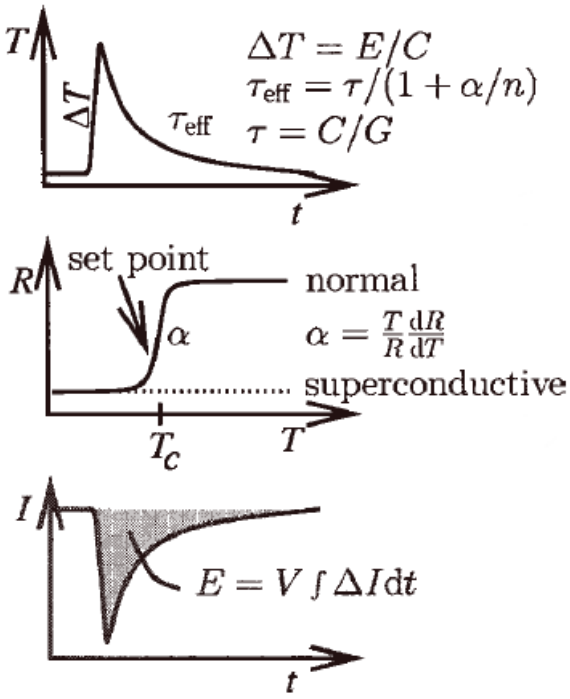
Absorption of a photon (1.17 eV)
→ ΔT ≈ 0.1 mK

Superconducting transition R ↑
(R ≈ 1 Ω)

TES electrical circuit
(I ≈ 70 nA)

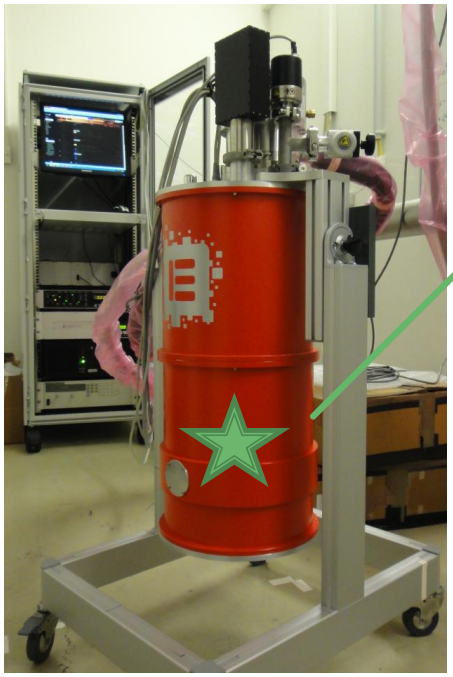
SQUID (inductive coupling)

ΔVout ≈ 50 mV



TES environment in ALPS II

CLOSED



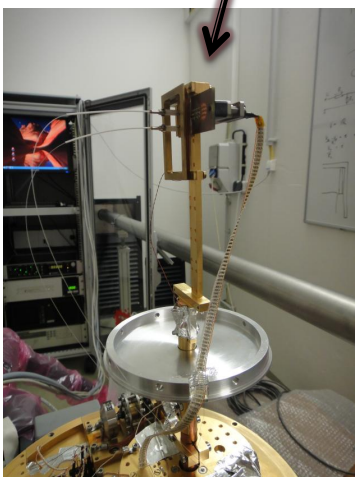
Adiabatic Demagnetization Refrigerator (ADR)

OPENED

Transition Edge Sensor (80 mK)

4K - plate

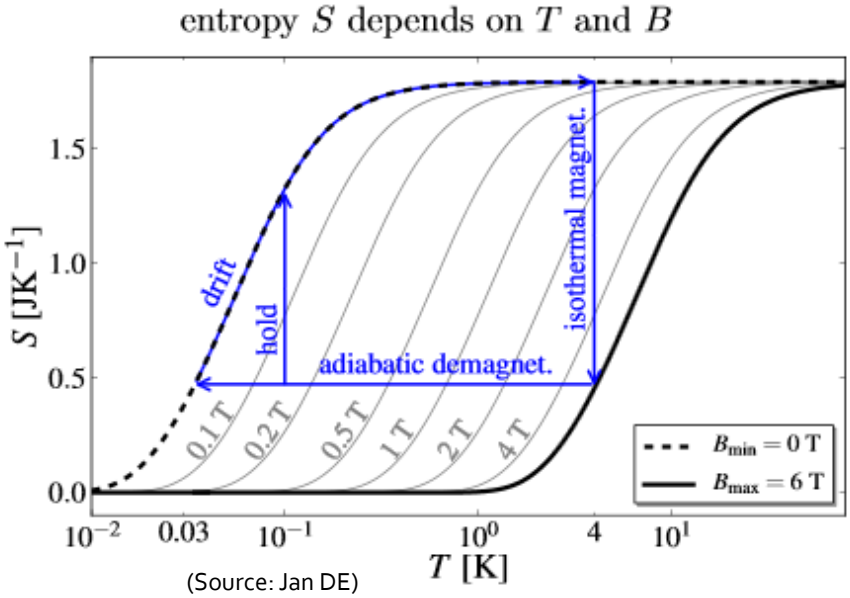
77K - plate



ADR cryocooler

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

Recharge:
-Last approximately 24 hours.
- Temperature of 80 mK at the detector level.



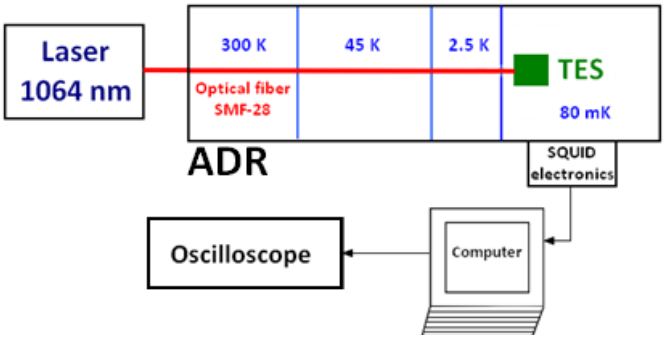
(Source: Jan DE)

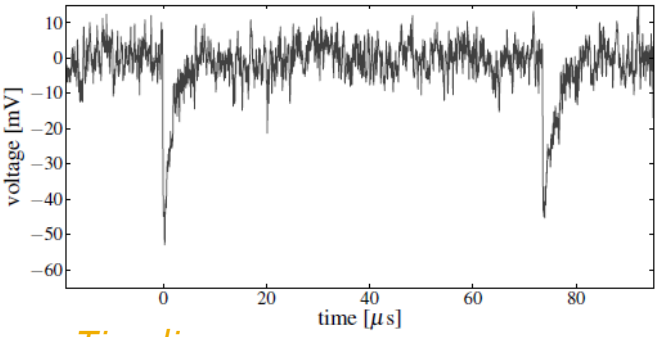
D. Wernicke , Entropy GmbH: Closed-cycle cryostats for the Kelvin and milli Kelvin temperature range

Detector characterization

- Pulse shape
- TES linearity
- TES stability
- Background
- Quantum efficiency

Single photon events



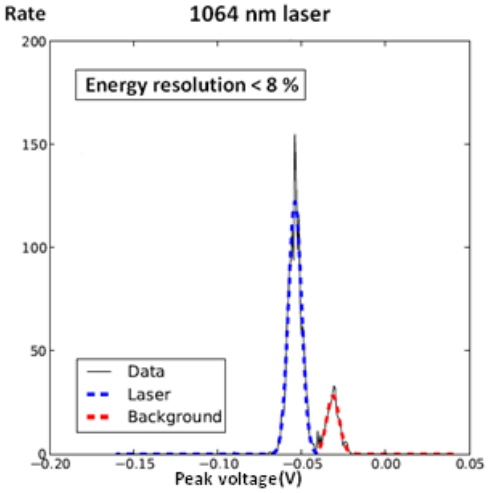


Timelines

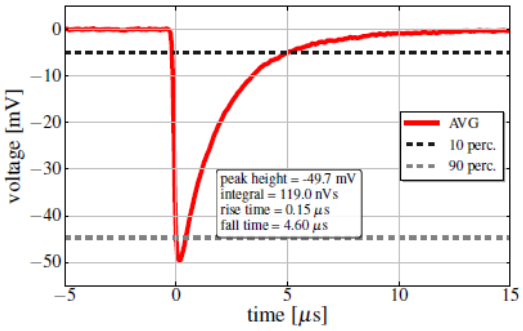
(source: J. Dreyling)

Average pulse

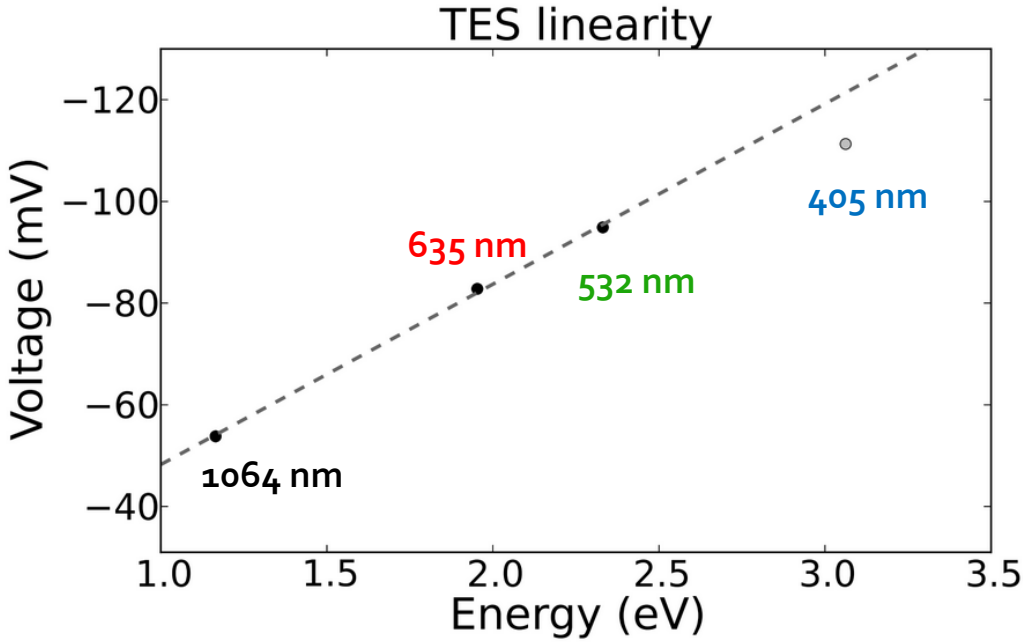
(source: J. Dreyling)



Histogram of peak voltages



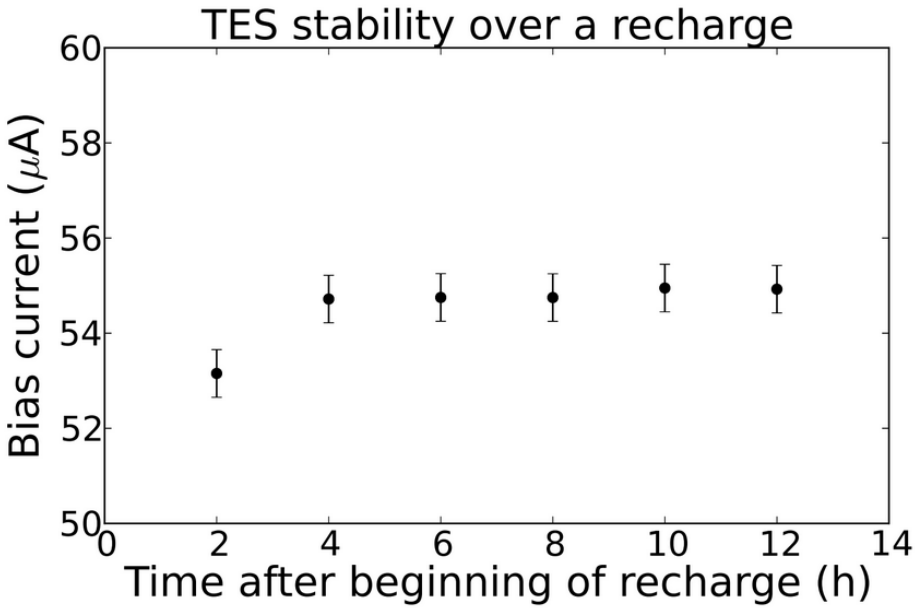
Linearity



- Linearity in the region of interest.
- Non-linearity at higher energies matching the 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.

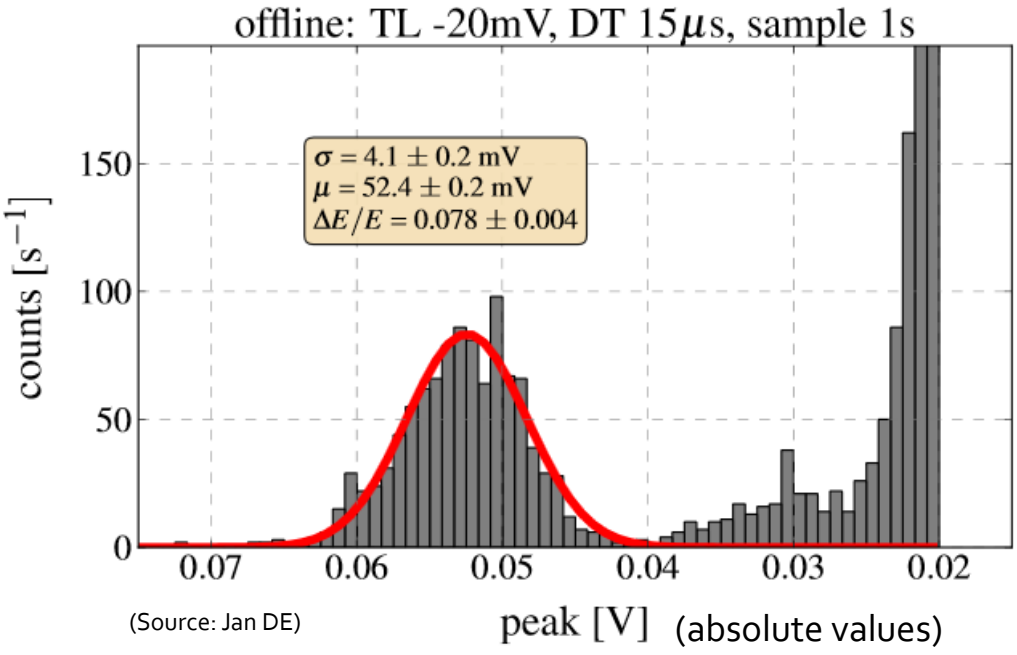
Stability



The TES bias current equivalent to Ro= 30 % R_{normal} as a function of time after the beginning of a recharge.

→Stable during a recharge.
→ Stable during one cool-down.
→ Stable during different cool-downs.
→ Not depending on operator (adjustment method).

Background

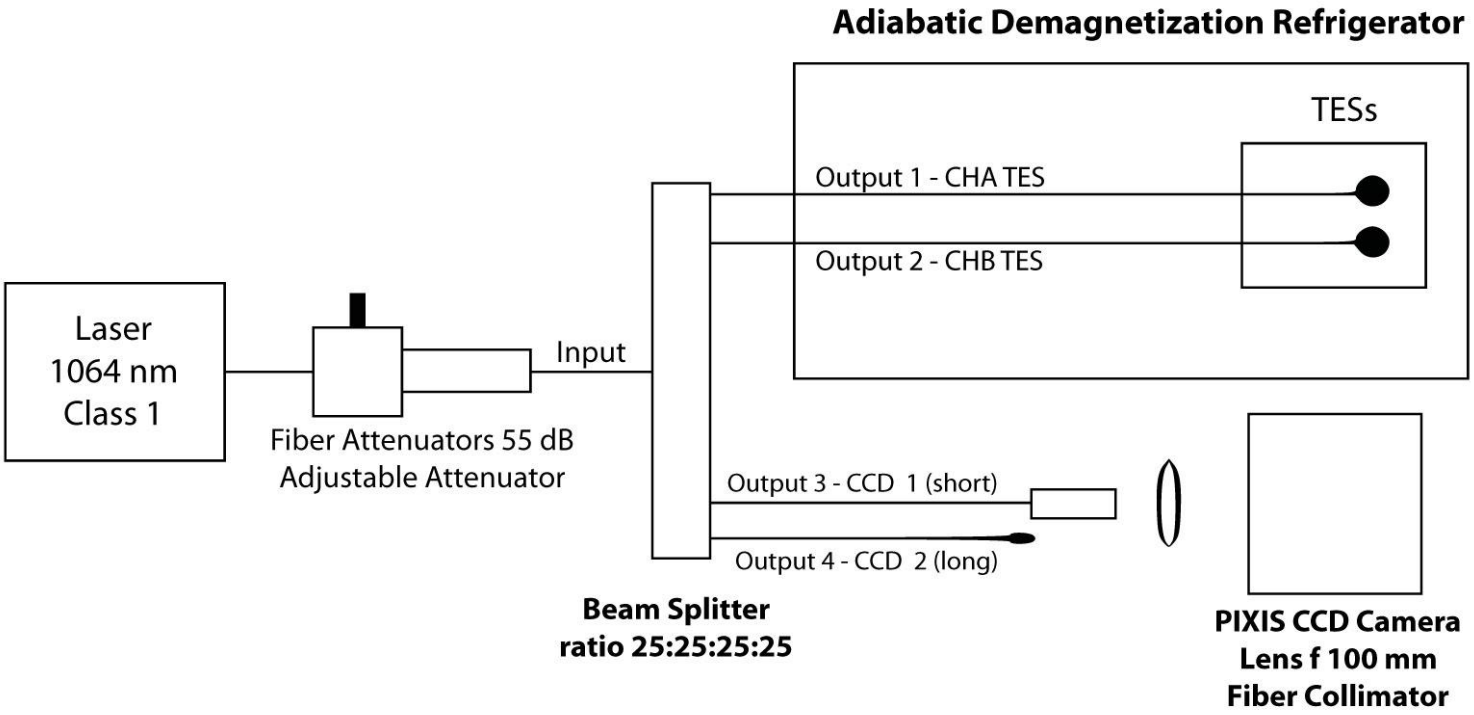


(Source: Jan DE)

(absolute values)

Background events dominated by black-body photons.

Detection efficiency

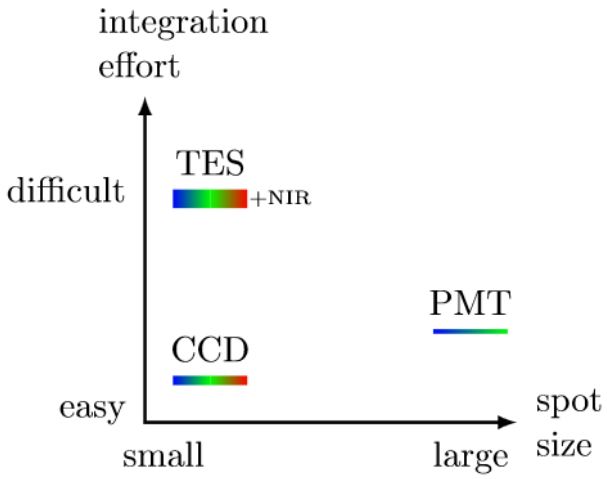


Low-fluxes detectors

- Comparison of a few low-temperature detectors
- Other experiments using TESs

Comparison of a few low-fluxes detectors

	QE (%)	Dark count (s^{-1})
CCD (NIR)	1.2	$8 \cdot 10^{-4}$ per pixel
TES	95	$1 \cdot 10^{-4}$
PMT	25	0.5

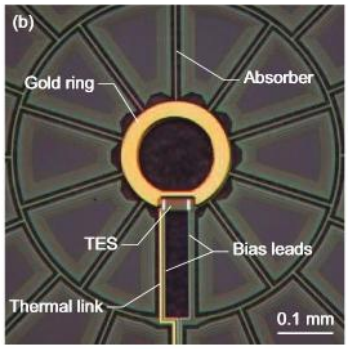


The TES and CCD weak point comes from the necessity of a good beam focusing on the chip.

J. E. von Seggern, *Overview of low-fluxes detectors (2013), arXiv:1310.0660v1*

ACT – Atacama Cosmology Telescope

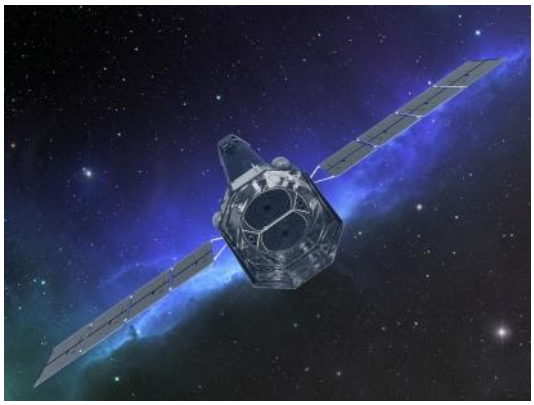
(Source: http://www.astro.puc.cl)

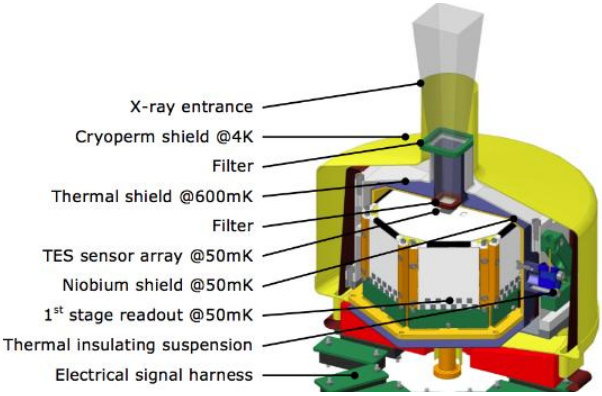


(Source: http://arxiv.org/pdf/1008.0342v2.pdf)

Material	Molybdenum-Gold (MoAu) bilayer
Size	75 x 75 μm^2
T operation	300 mK
Setup	3 times 32x32 arrays of TESs
Wavelength of interest	mm

ATHENA - Advanced Telescope for High Energy Astrophysics





(Source: http://athena2.irap.omp.eu)

Material	Molybdenum-Gold (MoAu) bilayer
Size	250 μm²
T operation	50 mK
Setup	An array of 3840 TESs
Wavelength of interest	X ray

Summary

- ALPS II experiment (DESY, Hamburg) follows the light-shining through the wall concept.
- A tungsten Transition Edge Sensor operated below 100 mK has been successfully used to detect single-photons in the near-infrared.
- The low rate and energy represent lots of challenges. Our TES will rise up to them.

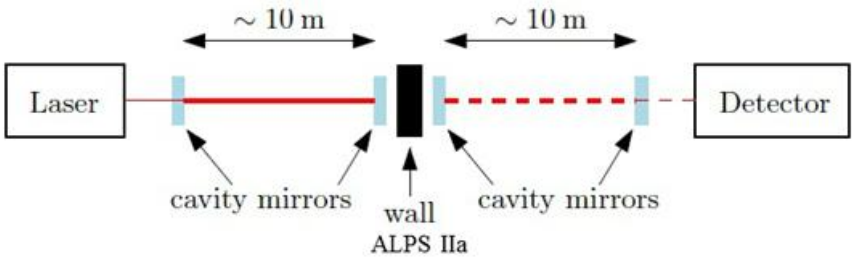
ALPS II TDR: arXiv:1302.5647
Characterization, 1064 nm photon signals and background events of a tungsten TES detector for the ALPS experiment: arXiv:1502.07878v1

Outlook

→ Finalizing characterization

→ Trying to reduce the background even further than what was already obtained (blackbody photons, intrinsic background,…).

→ First ALPS II data taking in 2016.



Thank you for your attention !