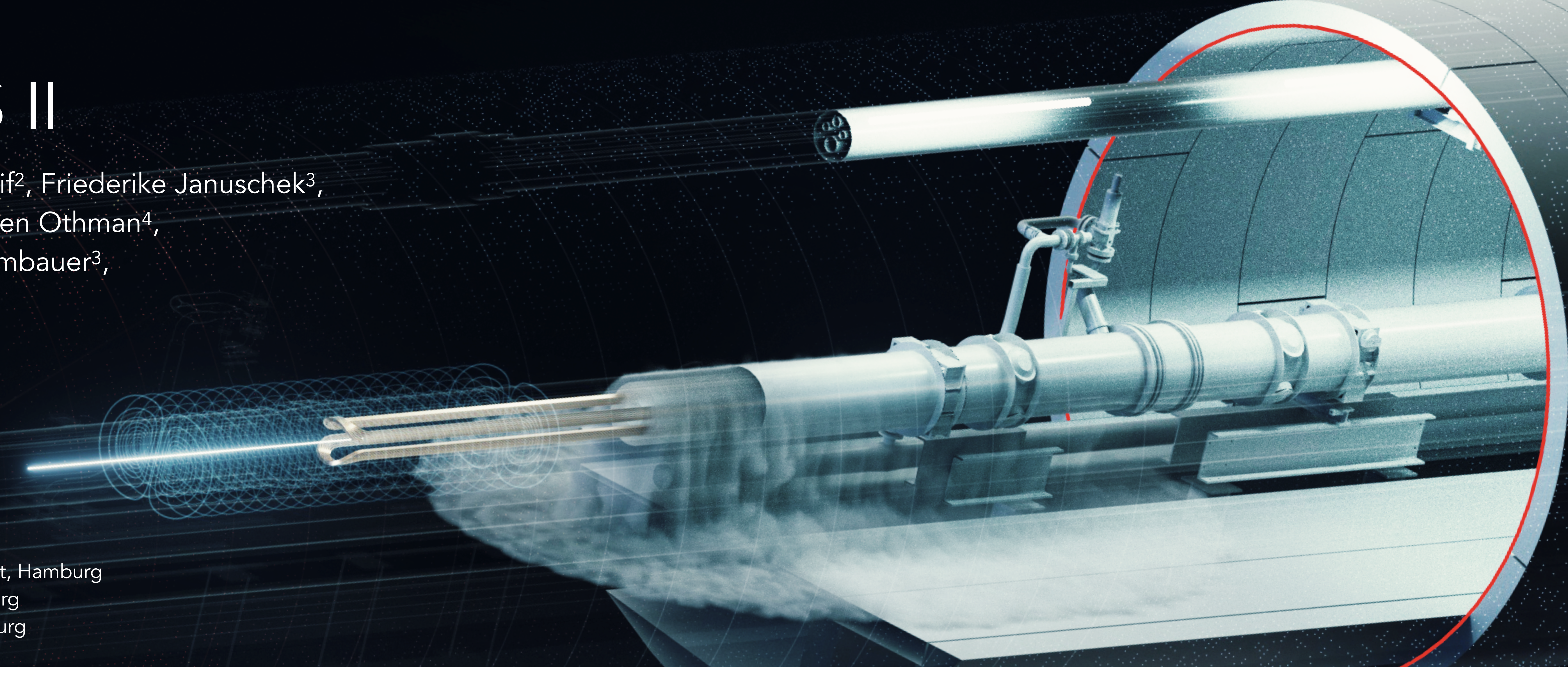

A TES for ALPS II

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Axions, ALPs, and the TES

- Axions and axion-like-particles predicted to solve strong CP problem in QCD [1] and are viable candidates for cold dark matter [2]
- Detection of these particles uses the Primakoff-like Sikive effect [3] with photon coupling
- ALPS II uses this to produce axions and ALPs (from photons) and subsequently detect them (Fig. 1)
  [ALPS II Overview talk by Gulden Othman, Tuesday 1130]
- Produced signals are single 1064 nm photons, expected at the low rate of ~1 photon per day
- Need a detector capable of low energy (~1 eV) photon detection with high energy resolution, high efficiency, and of achieving requisite low background rates $\leq 10^{-5}$ cps
- Can be realised using a Transition Edge Sensor (TES), a superconducting microcalorimeter (Fig. 2)

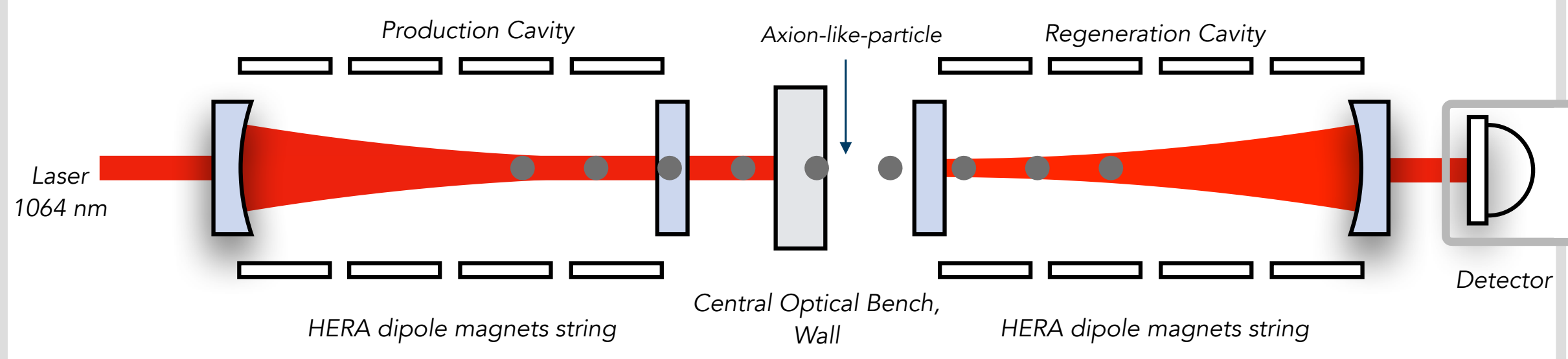


Fig. 1: Schematic of the ALPS II experiment.

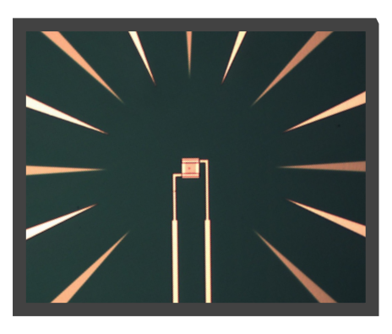


Fig. 2: Magnified view of the tungsten TES (25 μm x 25 μm) manufactured by NIST, USA.

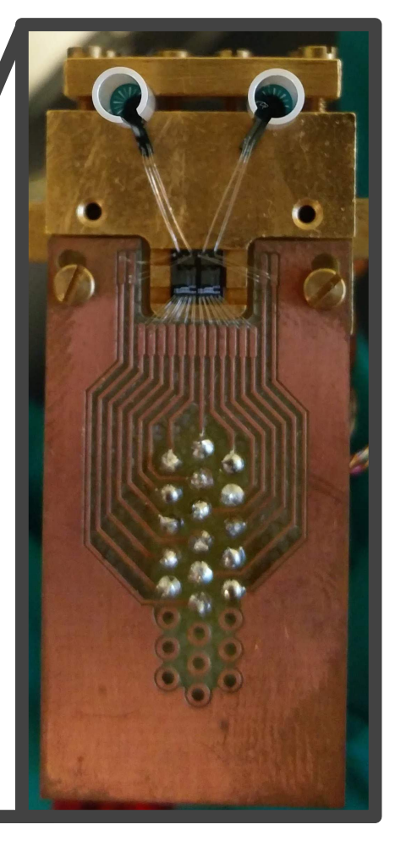


Fig. 3: TES Detector module, with the readout SQUIDs and fiber sleeves, assembled by PTB, Berlin.
Approx. 1 cm x 2 cm.

TES: Biasing

- The TES used is a tungsten microchip operated around its $T_c = 140$ mK, where a single photon can heat it by ~100 μK and increase resistance by $\sim 6\,\Omega$
- Corresponding change in current is picked up by SQUIDs (Superconducting Quantum Interference Devices), as a signal pulse (Fig. 5)
- Setup housed in dilution refrigerator capable of stable long-term operation at ≤ 30 mK
- TES is heated by biasing current to appropriate working region
- The biasing I-V curve, in Fig. 4, shows the possible working points, and the selected one where the pulse (Fig. 5) is acquired

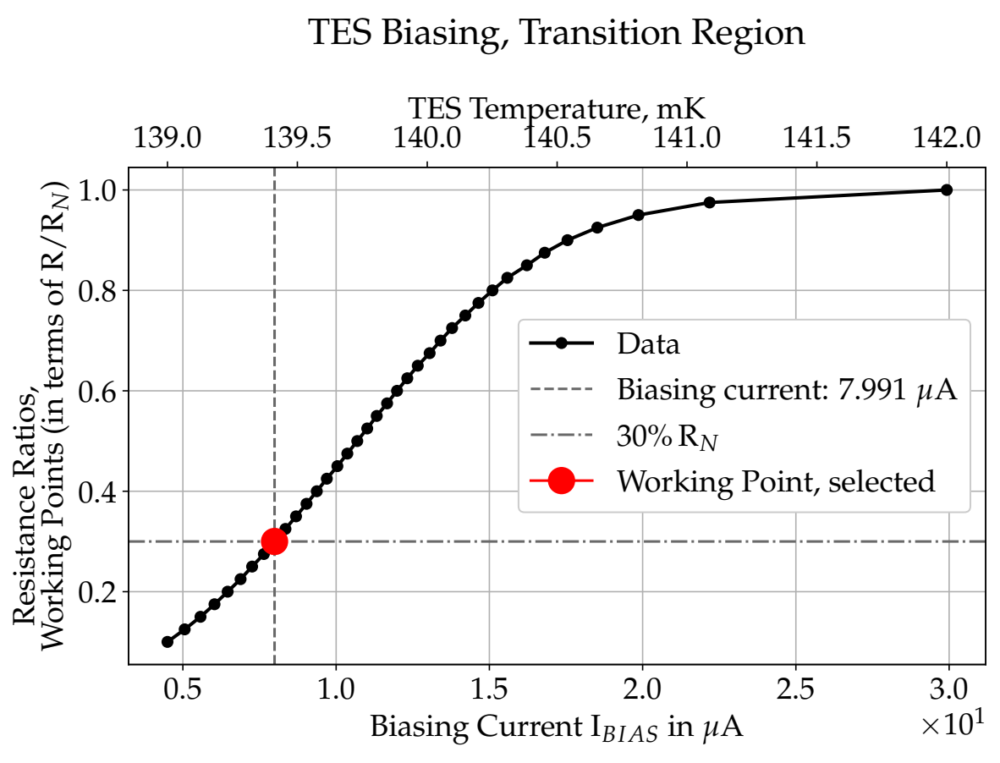


Fig. 4: The biasing curve for the TES, where the increasing current heats it to its normal conducting resistance from superconducting behaviour.

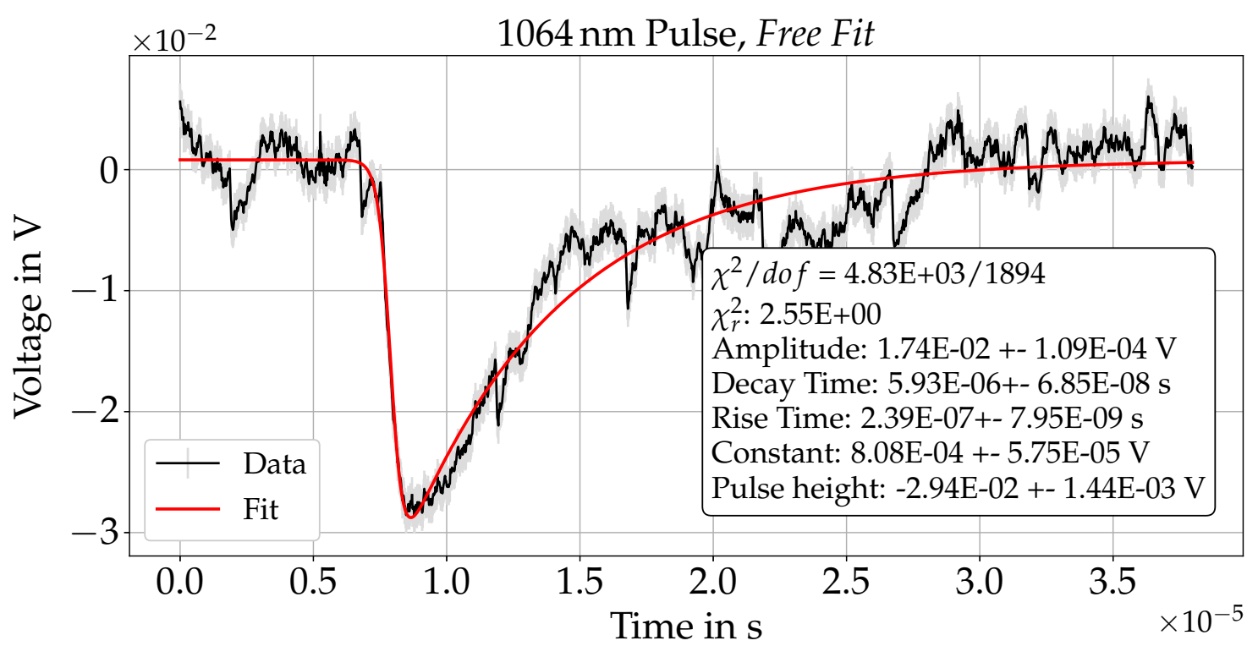


Fig. 5: Signal 1064 nm photon pulse, triggered in the acquisition scheme using an Alazar card and fitted with TES response function.

Pulse Characterisation

- Acquired TES pulses can be fitted with a response function, as in Fig. 5
- Yields characteristic fit parameters for pulse type, such as *pulse height* and *pulse integral*, the latter scales with the energy deposited in the TES
- An **energy resolution** $\Delta E/E \approx$ **8%** can be achieved [4] (depending on working point settings and choice of response function)
- Other analysis methods also used: PCA (Principal Component Analysis) [4]; and machine learning techniques
  [See poster: *Machine and Deep learning for background rejection in the ALPS II TES Detector, by Manuel Meyer*]
- Fit parameters used to compare signals to backgrounds and set up selection method(s), adopted as baseline approach

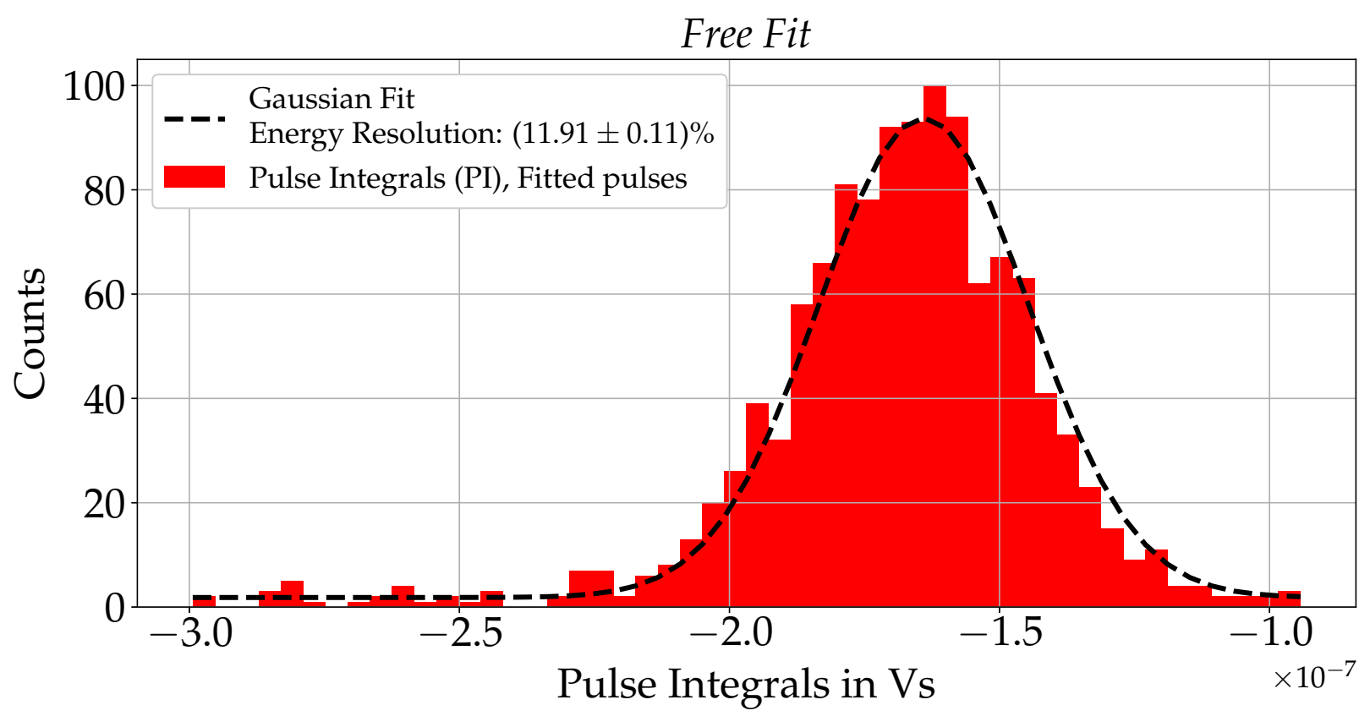


Fig. 6: The resolution for 1064 nm pulses in the TES, fitted with the response function seen in Fig. 5.

Backgrounds

Intrinsics

Events triggered in the TES without any optical fiber connected to it

Radioactivity, Cosmic rays, Electromagnetic interference

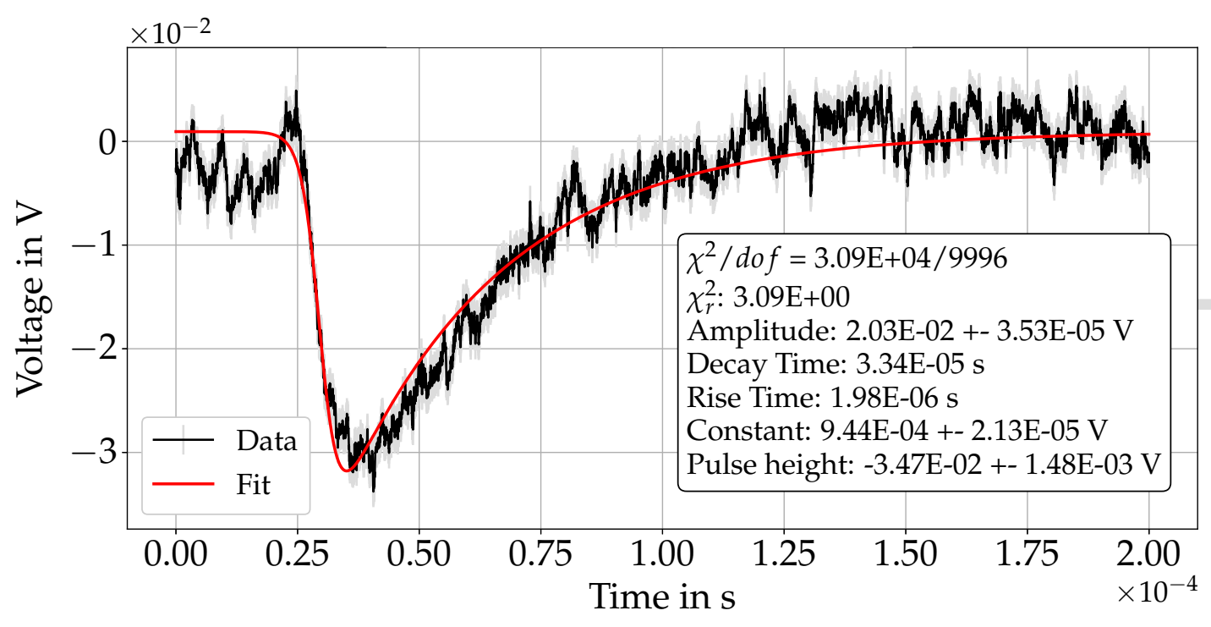


Fig. 7: Exemplary intrinsic background pulse, with fit parameters significantly differing from those in Fig. 5 for a 1064 nm pulse

Selection Scheme: Cuts

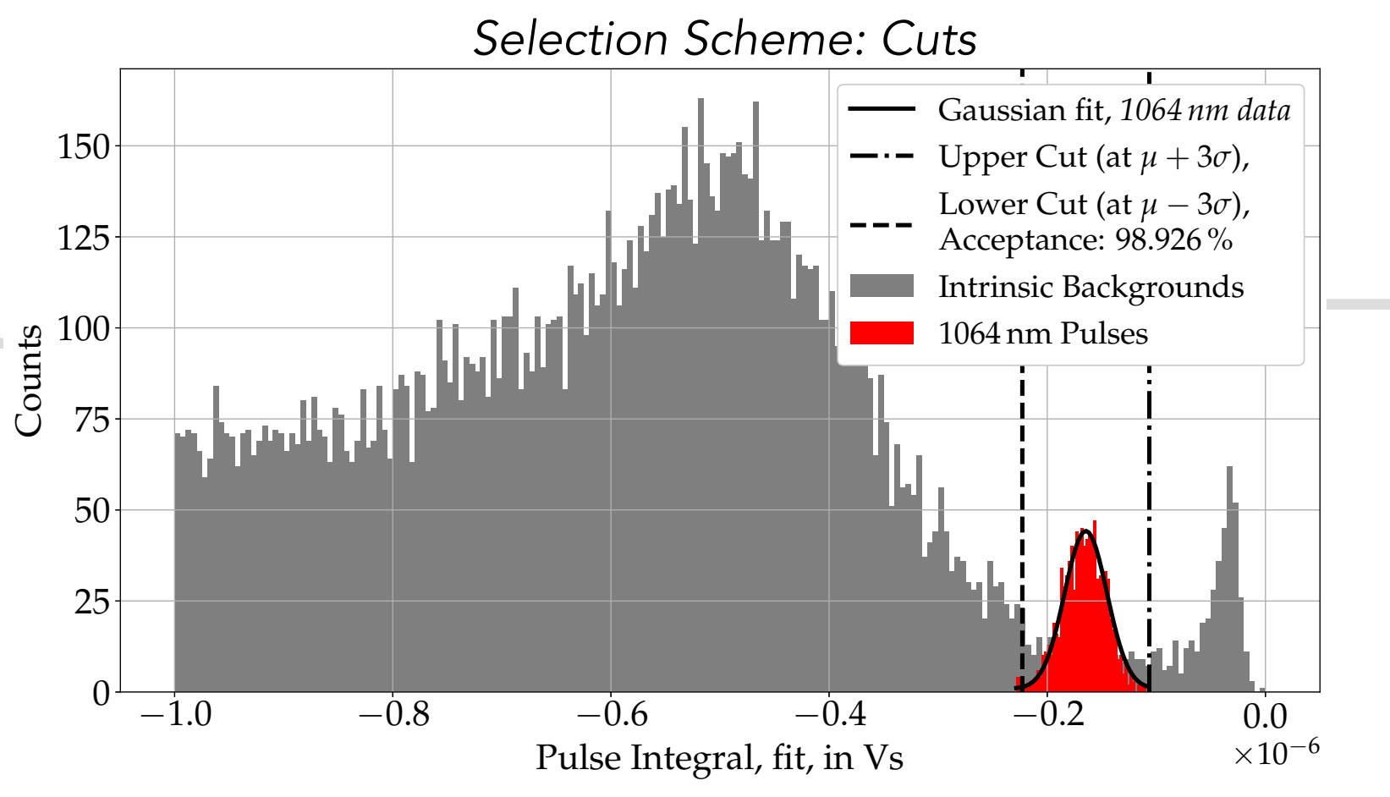


Fig. 9: Pulse Integrals of all intrinsic backgrounds collected over 20 days, compared to those of signal photons for selection from Fig. 6.

Performing for all fit parameters:
Measured background rate
$6.9 \cdot 10^{-6}$ cps [5]
over 20 days

Viable for use in ALPS II
considering intrinsic backgrounds

Extrinsics

Events triggered in the TES with an optical fiber connected to it, but no laser input

Black-body radiation (and pile-ups)

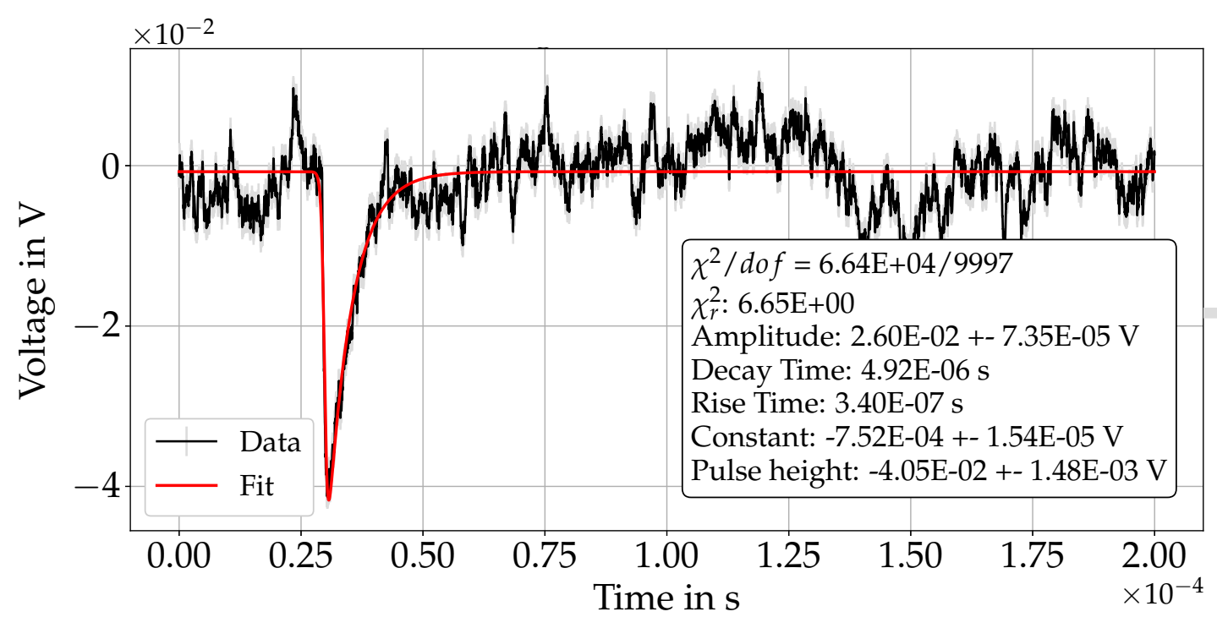


Fig. 8: Exemplary extrinsic background pulse

Must substantiate optical fiber coupling efficiency!

Ensure viability for use in ALPS II considering *all* backgrounds

Background suppression mechanisms include **in-cold filtering** and **fiber curling**

Efficiency

- Have achieved rates of intrinsic backgrounds down to $6.9 \cdot 10^{-6}$ cps, but depends on orientation of the detector module and can be irreducible
- The extrinsic backgrounds however, depend on the fiber coupling efficiency
- A measurement setup (adapted from [6], shown below) has to be optimised further with fiber connections, etc.

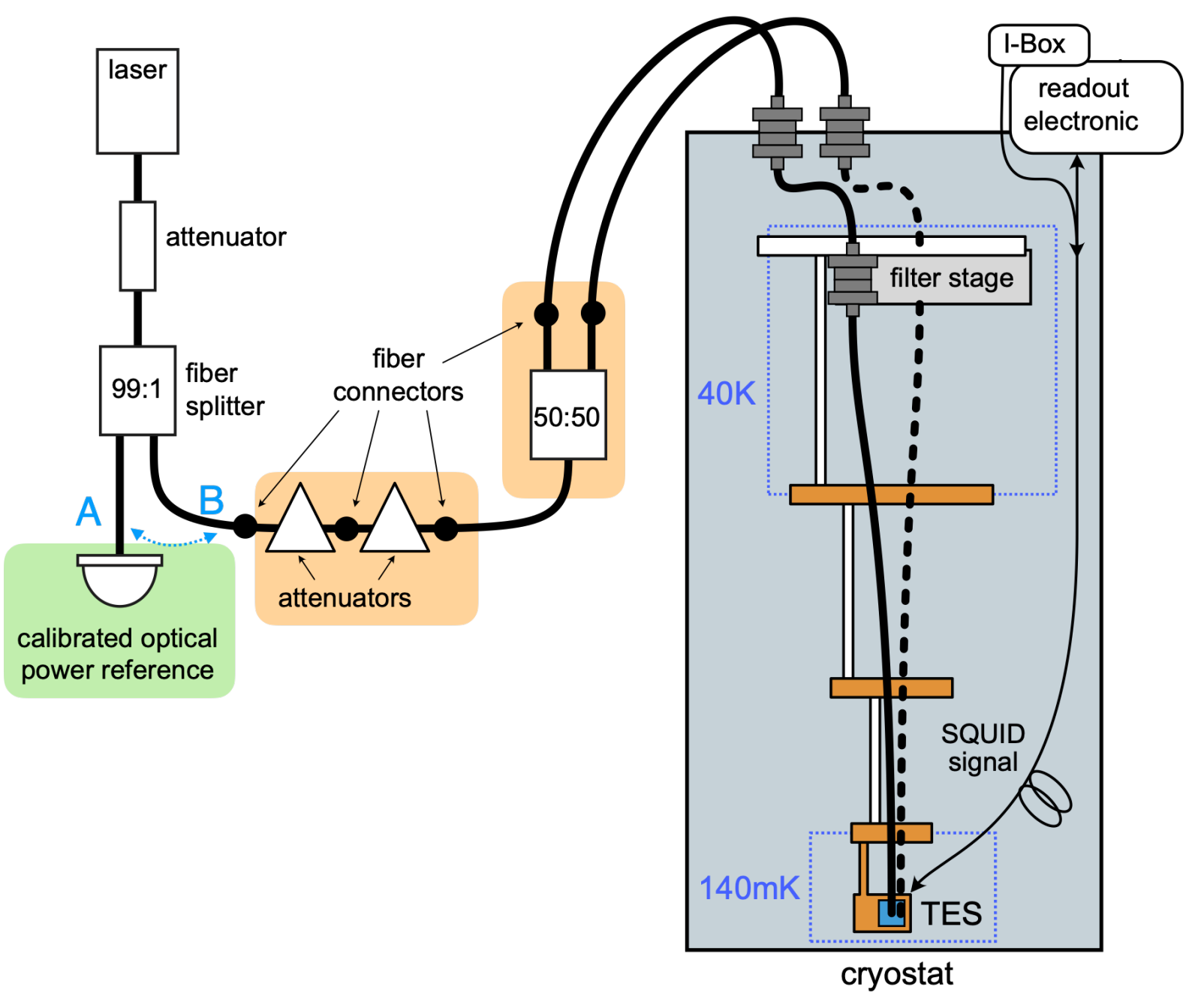


Fig. 10: In-situ efficiency measurement setup with a calibrated photodiode capable of sensing $\mathcal{O}(1)$ pW. Require $\sim 10^{-16}$ W at TES for accurate sensing.

Summary

- Detection of low-energy ~1 eV photons with resolution $\leq 10\,\%$
- Stable long-term operation of the detection system
- Reliable and robust pulse characterisation for all TES pulses with independent approaches
- Consequent fit parameters used for pulse selection algorithms
- Have demonstrated electrical-noise limited energy resolution
- Setup for background suppression and efficiency tests prepared and optimisation ongoing

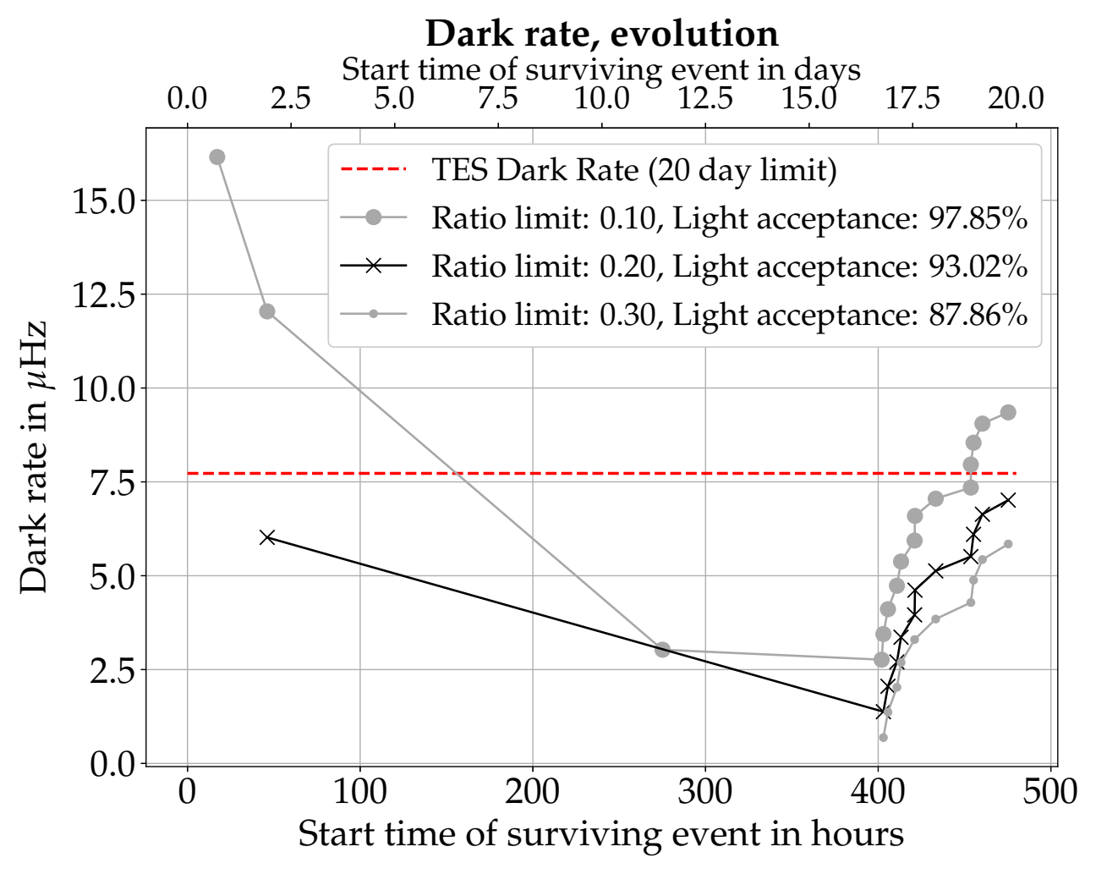
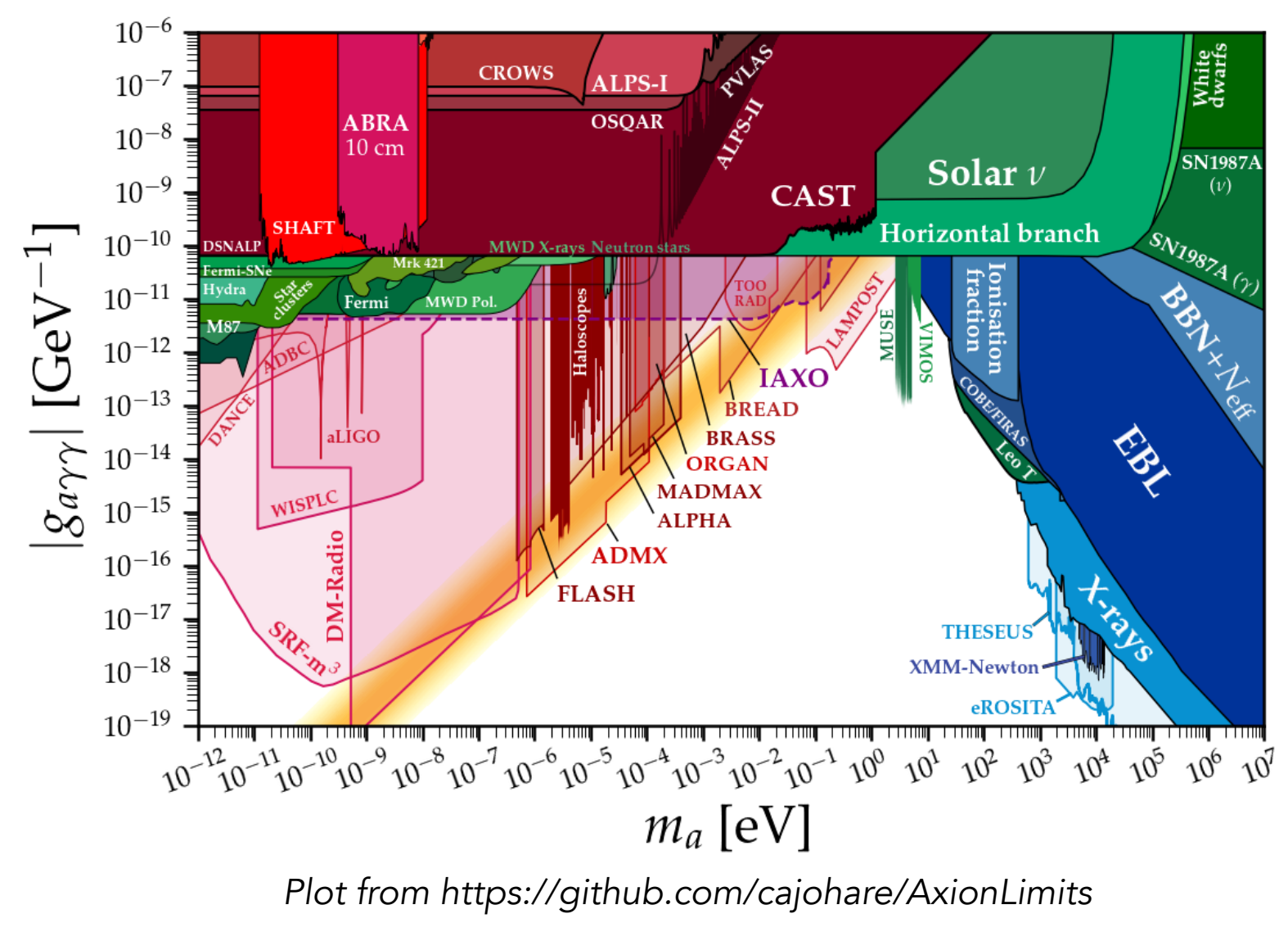


Fig. 11: The evolution of the dark rate over the 20 day period, for intrinsic backgrounds shown in Fig. 9, which survive the selection cuts.

Outlook

- Testing planned for characterisation of full background profile
- Designing TES implementation in ALPS II and TES Lab at experiment site
- Simulations of TES pulses and backgrounds also underway
- Expansion of working group with different collaborations to
  - Test new TESs and cryogenic single photon detectors
  - Understand scope for use of TESs in dark matter detection
- Moving and re-characterising system at ALPS II site
- Aim for DAQ in 2024



Plot from https://github.com/cajohare/AxionLimits

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