A TES for ALPS II
Status and Prospects

José Alejandro Rubiera Gimeno for the TES team in the ALPS collaboration

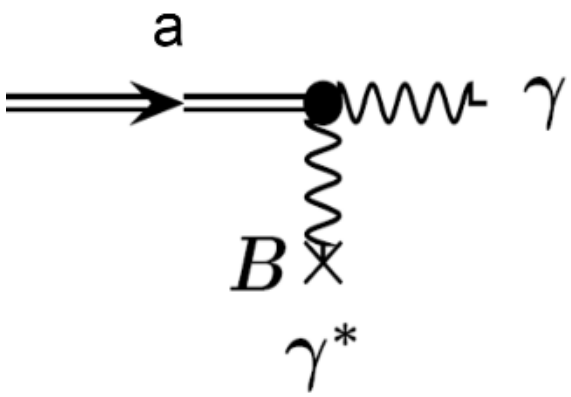
DPG Spring meeting 2023, 21.03.2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

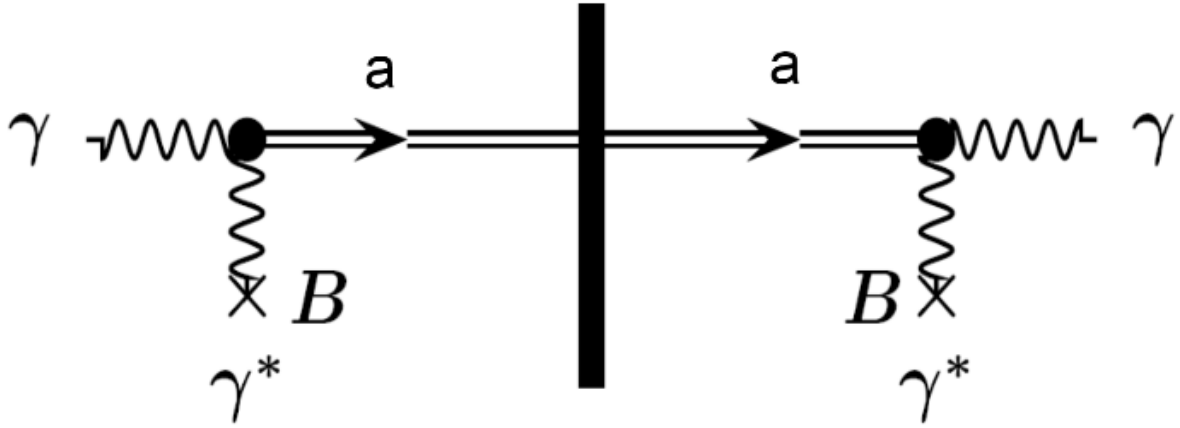
Leibniz Universität Hannover · UF University of Florida · JGU · Cardiff University · SDU University of Southern Denmark · UHH · DESY · NSF · Heising-Simons Foundation · Science & Technology Facilities Council · erc

Axion-like particles (ALPs)

- Pseudo-scalar bosons predicted by Beyond Standard Model Theories.
- Very weak interaction, makes it a good candidate for dark matter.
- The main mechanism for detection is its coupling to photons.



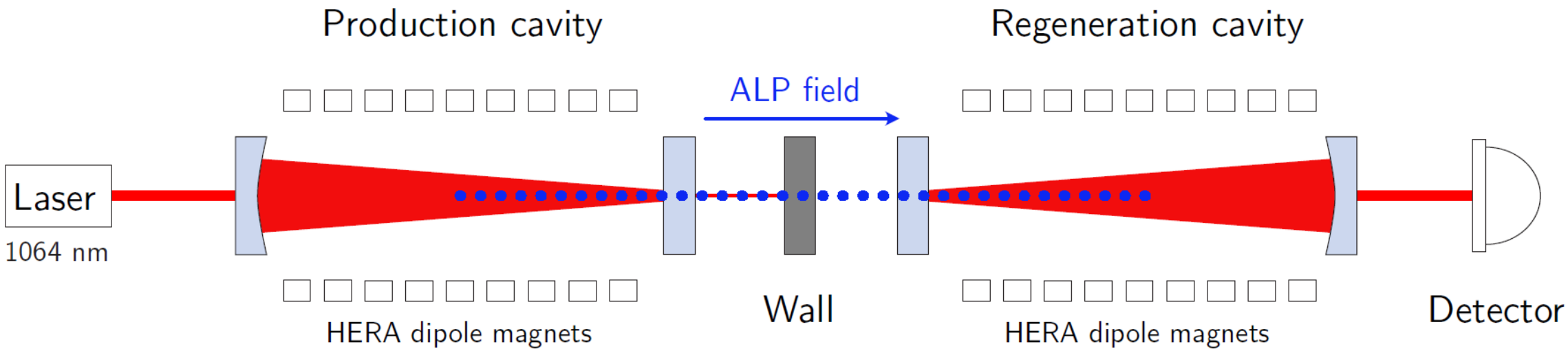
Helioscopes & Haloscopes



Light Shining through a Wall (LSW)

(Model independent approach)

Any Light Particle Search II (ALPS II)



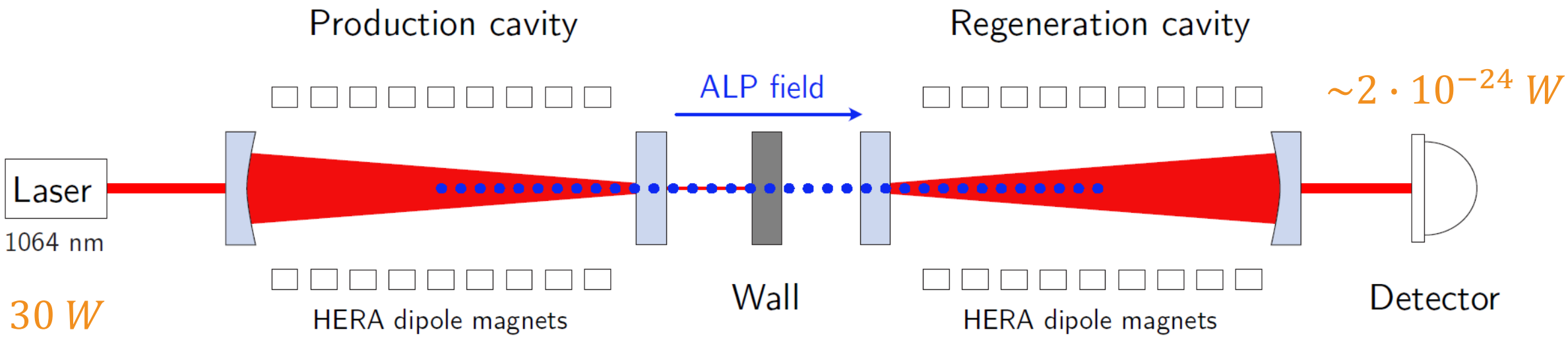
$$P_{\gamma \to a \to \gamma} = \frac{1}{16}\,\mathcal{F}_{PC}\mathcal{F}_{RC}\left(g_{a\gamma\gamma}Bl\right)^4$$

$$P_{\gamma \to a \to \gamma} = 8 \cdot 10^{-26}$$

$$P_{\gamma \to a \to \gamma} = 6 \cdot 10^{-38}\,\underbrace{\mathcal{F}_{PC}}_{5000}\,\overbrace{\mathcal{F}_{RC}}^{16000}\left(\frac{g_{a\gamma\gamma}}{\underbrace{10^{-10}GeV^{-1}}_{0.2 \cdot 10^{-10}GeV^{-1}}}\,\frac{\overbrace{B}^{5.3\,T}}{1T}\,\frac{l}{\underbrace{10m}_{105.6\,m}}\right)^4$$

Schematic adapted from Katharina-Sophie Isleif.

Any Light Particle Search II (ALPS II)



$$P_{\gamma \to a \to \gamma} = \frac{1}{16}\,\mathcal{F}_{PC}\mathcal{F}_{RC}\left(g_{a\gamma\gamma}Bl\right)^4$$

$$P_{\gamma \to a \to \gamma} = 8 \cdot 10^{-26}$$

ALPS II might produce a rate in the order of 1 reconverted photon per day

RECENT UPDATES ON THE ALPS II EXPERIMENT • GULDEN OTHMAN FOR THE ALPS COLLABORATION
HETERODYNE DETECTION OF WEAK FIELDS IN ALPS II • ISABELLA OCEANO FOR THE ALPS COLLABORATION

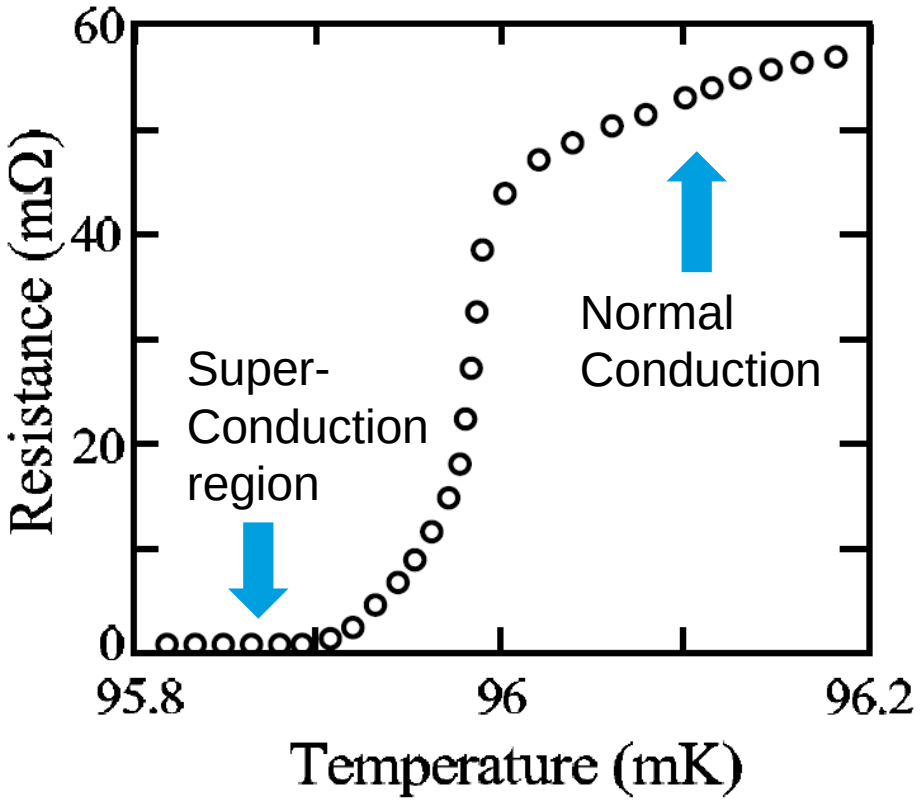
Single photon detector

Requirements:

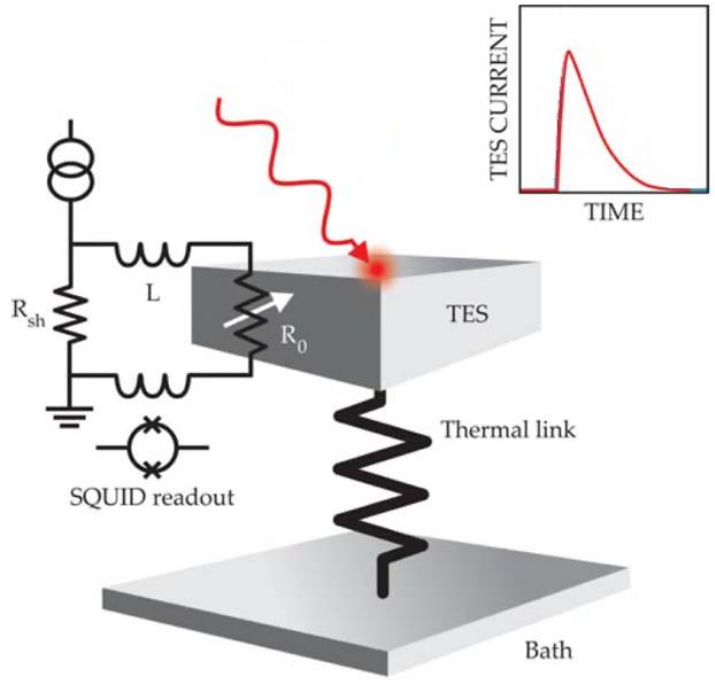
- Sensibility to very low rates (1-2 photons a day).
- Low energy photon detection (1064 nm equivalent to 1.16 eV).
- High detection efficiency.
- Low background rate: $< 7.7 \cdot 10^{-6}\text{cps} \sim 1\ \text{photon}\ (1064\text{nm} - \text{like})\text{every}\ 2\ \text{days}$
  - Good energy resolution (resolve 532nm)
- Long term stability ($\sim 20\ days$).

The Transition Edge Sensor (TES) could meet them!

Transition Edge Sensor

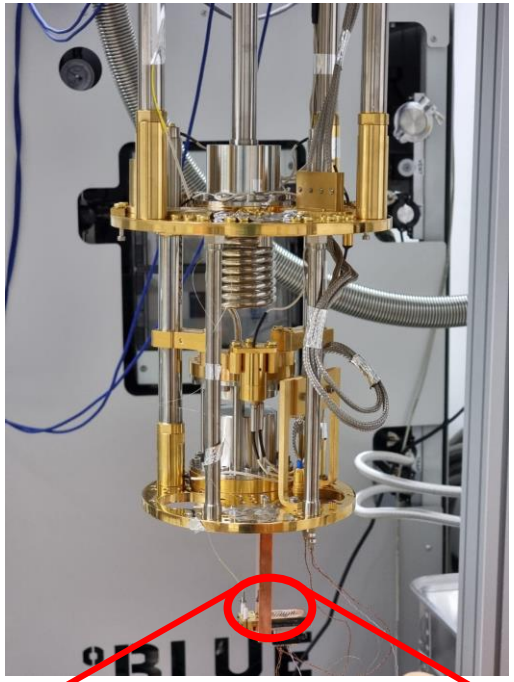


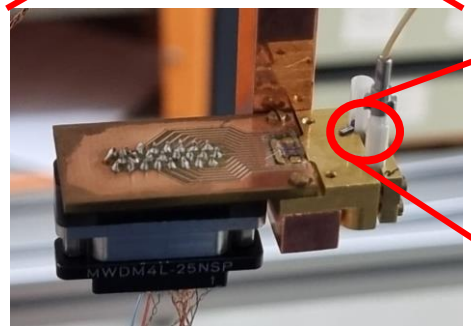
K. Irwin, G. Hilton, Transition-edge sensors, in: Cryogenic Particle Detection, Springer Berlin Heidelberg, Berlin, Heidelberg, 2005, pp. 63–150, http://dx.doi.org/10.1007/10933596_3.

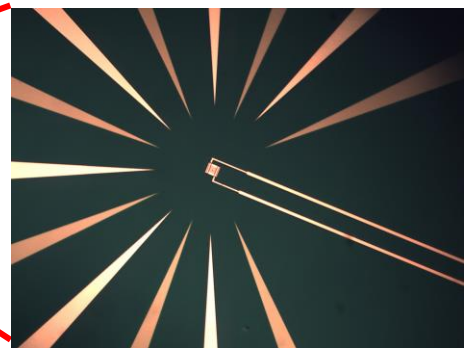


- Connected to a thermal bath
- Working point controlled by a current bias circuit.
- Change in resistance produced by energy deposition.
- Variations measured by Superconducting Quantum Interference Device (SQUID)

TES at DESY



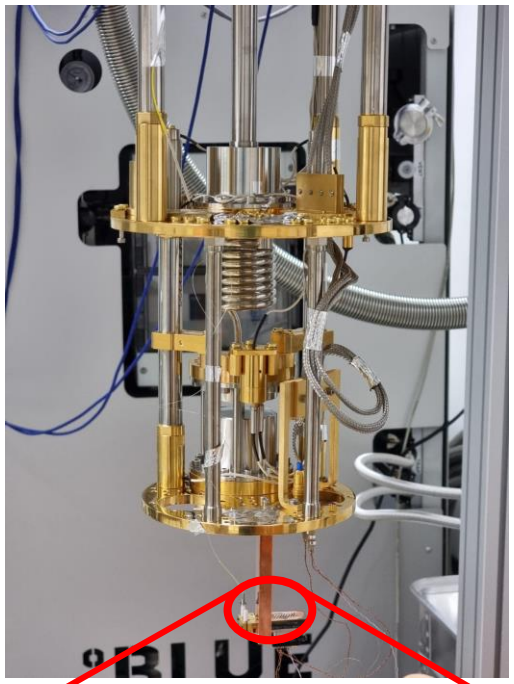


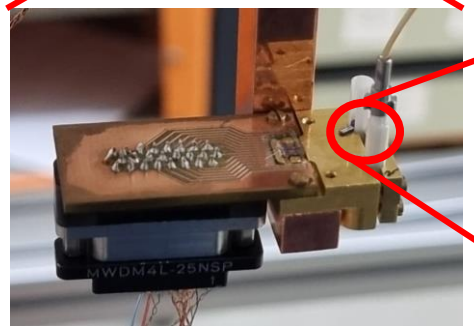


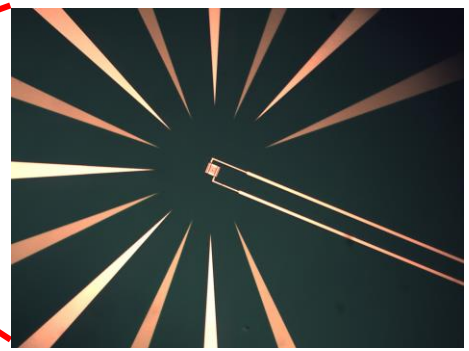
A tungsten microchip provided by NIST and PTB ($25\ \mu m \times 25\ \mu m \times 20\ nm$) operated in the transition region (~ 140mK)

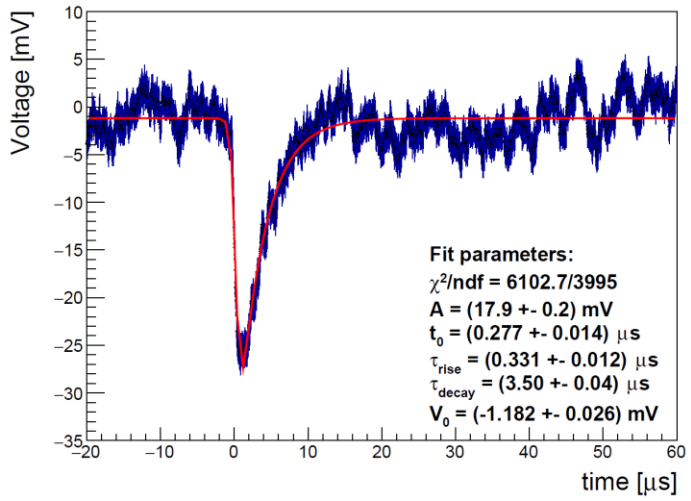
$1064\ nm$ photon ($\mathrm{E} \approx 1.16\ eV$)

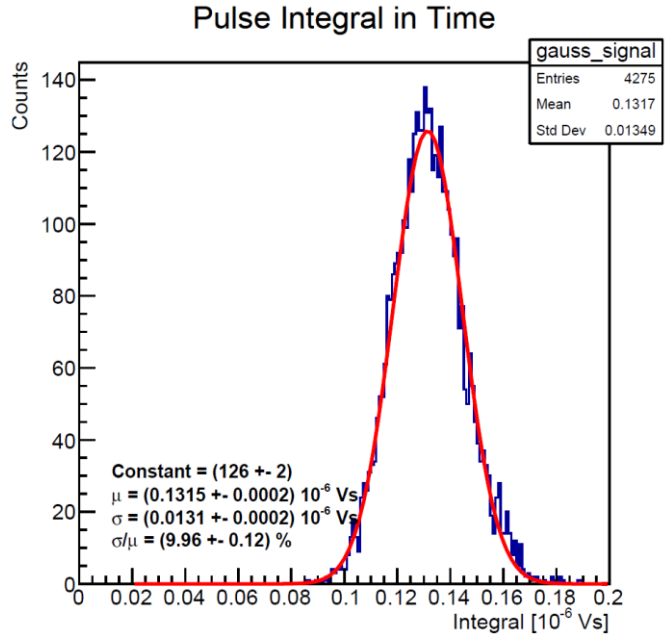
TES at DESY











$$E \propto \int_{t_1}^{t_2} [f(t) - V_0]dt$$

Energy resolution:

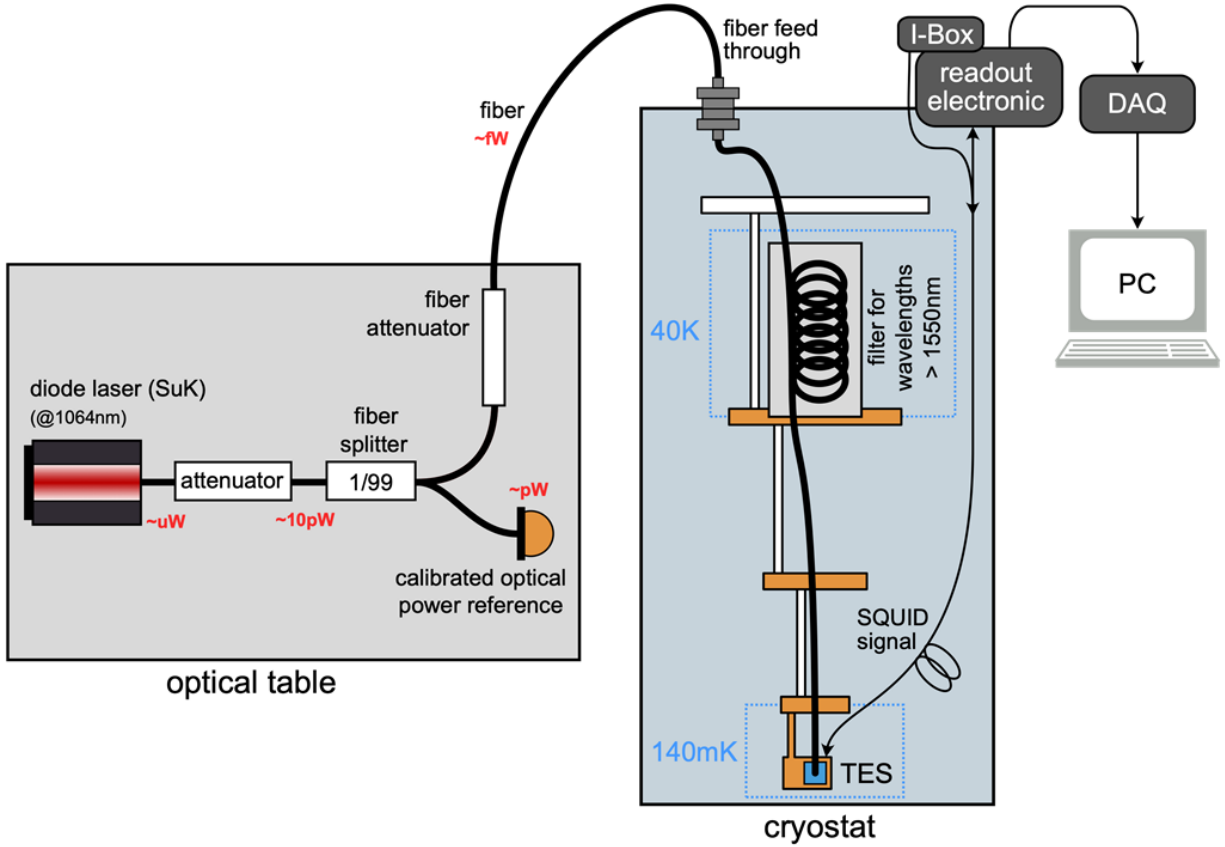
$$\Delta E = \frac{\sigma}{\mu} = (9.96 \pm 0.12)\%$$

Efficiency measurement

A high detection efficiency is required.

- Attenuated laser light.
- Using reference photodiode.
- Single photons reach the TES and are counted. The counts are converted to power and compared with reference. [2]

Setup is done. Further improvement and measurements in progress, expected efficiency around 80% [2].



[2] Setup adapted from Marco Schmidt et al., "Photon-number-resolving transition-edge sensors for the metrology of photonic microstructures based on semiconductor quantum dots," Proc. SPIE 10933, Advances in Photonics of Quantum Computing, Memory, and Communication XII, 1093305 (4 March 2019); https://doi.org/10.1117/12.2514086

Schematic adapted from Katharina-Sophie Isleif.

Intrinsics background

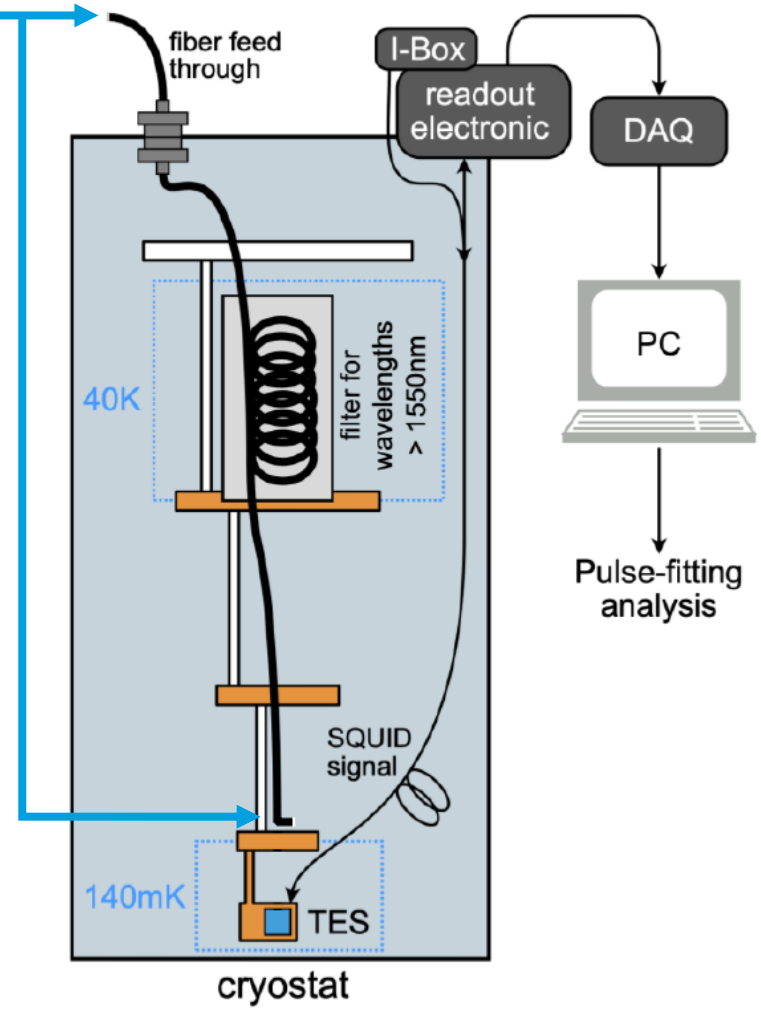
Intrinsics background (no fiber connected)

The accepted rate of events is in the order of $10^{-2}\ cps$ (same trigger as 1064nm data taking).

Evaluating backgrounds in 20 days.
ALPS II requirements:
$< 7.7 * 10^{-6}\ cps$, 1064 nm like events

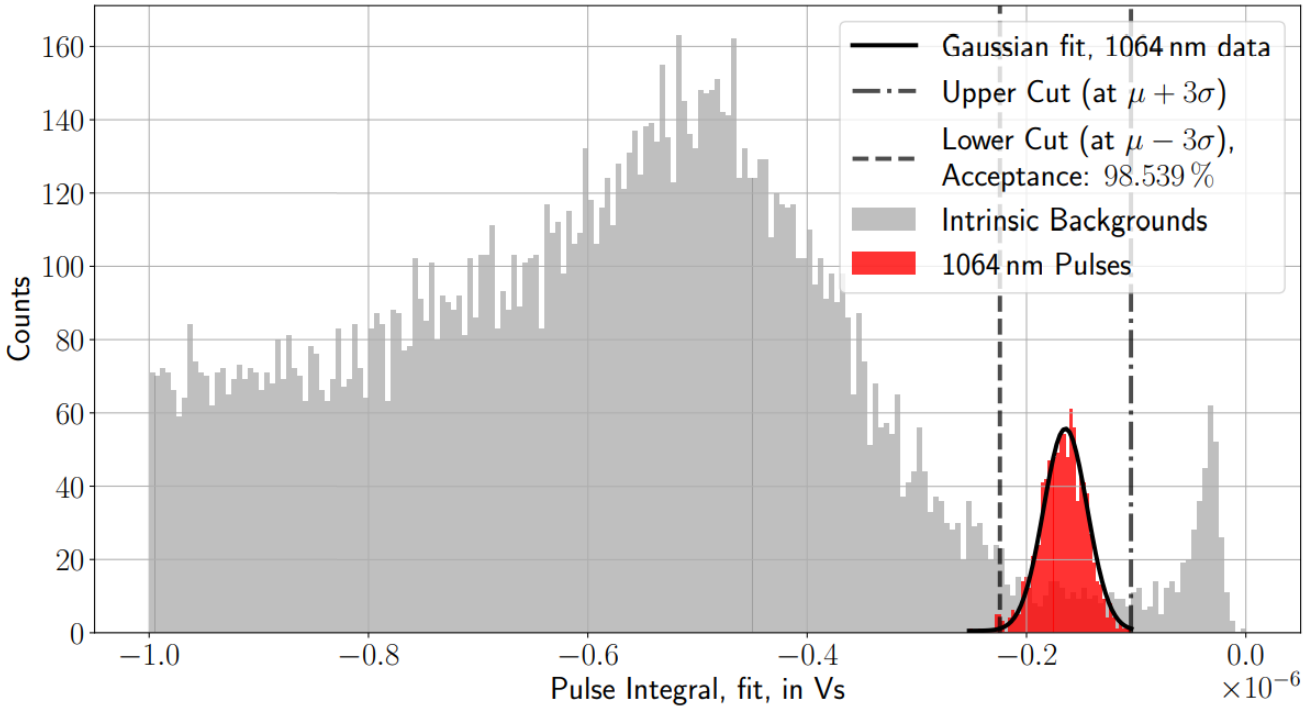
For example:

- Electronic noise
- Cosmic Rays (Muons)
- Radioactivity (Surrounding materials)



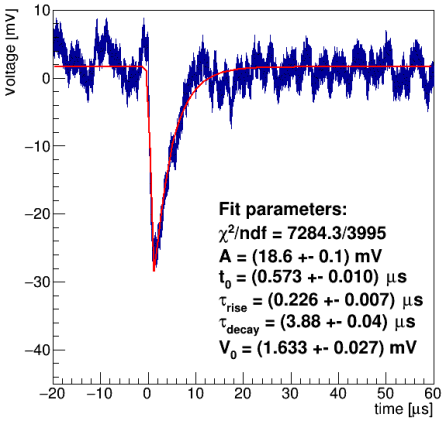
[1] Rikhav Shah, Katharina-Sophie Isleif, Friederike Januschek, Axel Lindner and Matthias Schott, “TES Detector for ALPS II”, Proceedings of The European Physical Society Conference on High Energy Physics, Volume 398, Page 801, (2022); https://doi.org/10.22323/1.398.0801

Intrinsics background



[1] Rikhav Shah, Katharina-Sophie Isleif, Friederike Januschek, Axel Lindner and Matthias Schott, "TES Detector for ALPS II", Proceedings of The European Physical Society Conference on High Energy Physics, Volume 398, Page 801, (2022); https://doi.org/10.22323/1.398.0801

Use of parameters from fitted $1064\ nm$ pulses, $A, \tau_{rise}, \tau_{decay}$, and Pulse integral



Cut-based analysis is able to exclude intrinsics backgrounds and maintain the acceptance for $1064\ nm$ pulses

ALPS II requirements:
$< 7.7 \cdot 10^{-6}\ cps$, 1064 nm like events

$6.9 \cdot 10^{-6}\ cps$ over 20 days was achieved with acceptance greater than 90% [1]

Extrinsics background

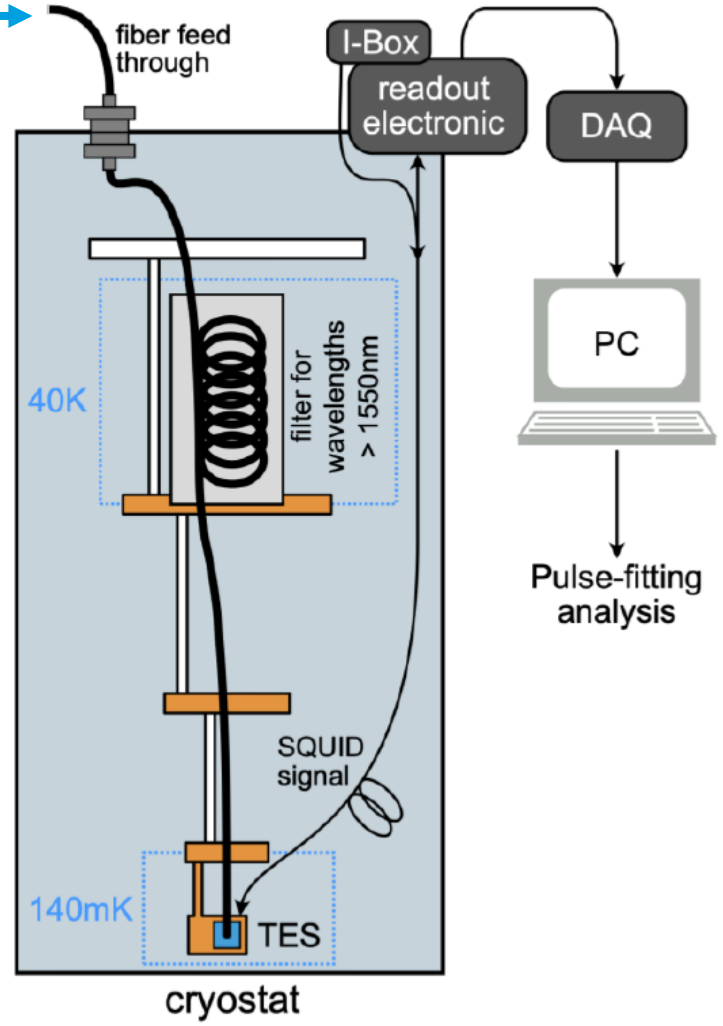
Intrinsics background (no fiber connected)

Extrinsics background (fiber connected)

Expected an additional contribution from laser for cavity locking (532nm) and Black Body Radiation in the form of:

- Direct photons -----> $\sim 1064\ nm$
- Pileup photons -----> looks like $\sim 1064\ nm$

Working on mitigating by filtering non-1064 nm photons in the cold



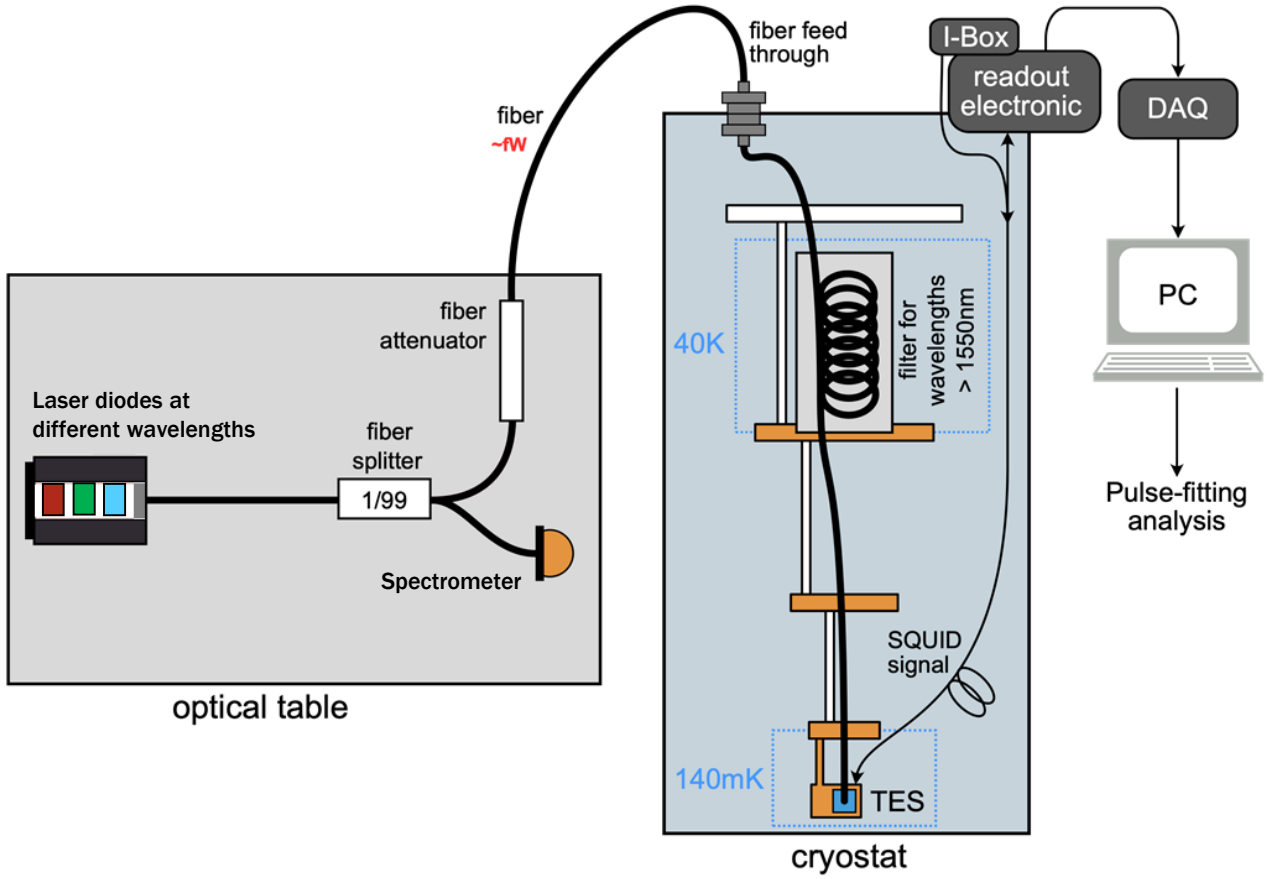
Linearity measurement

Measures the response of the TES to photons at different wavelengths.

- The ratios between different wavelengths are determined for the TES and the spectrometer.
- The comparison of the TES results with the spectrometer allows to evaluate its linear behavior.

ALPS II: 532nm ≠ 1064nm
Blackbody spectrum: λ < 532nm
Possible DM search: λ < 1064nm

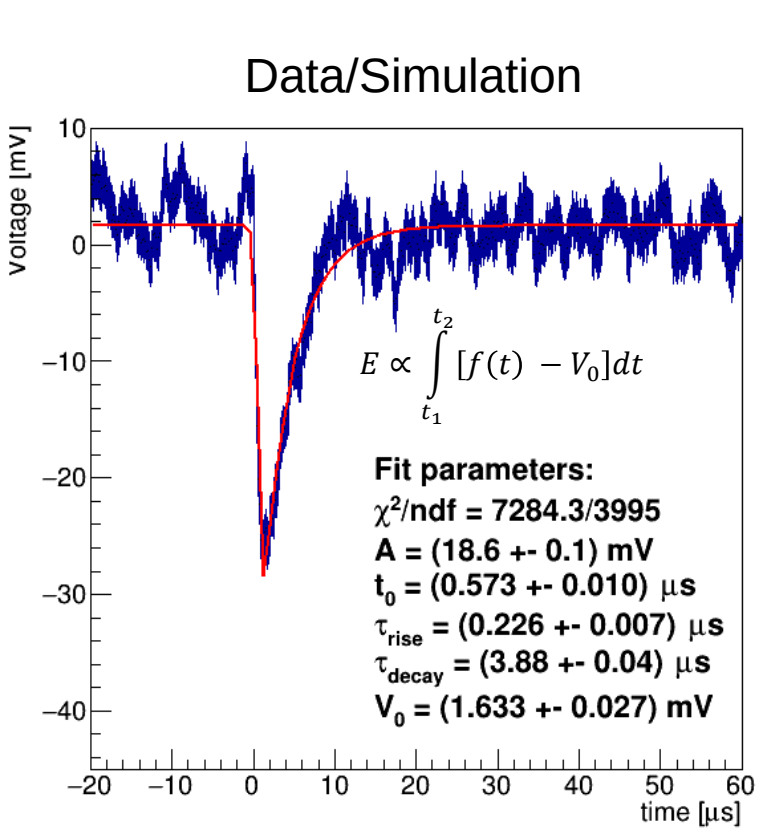
Good energy resolution is required.

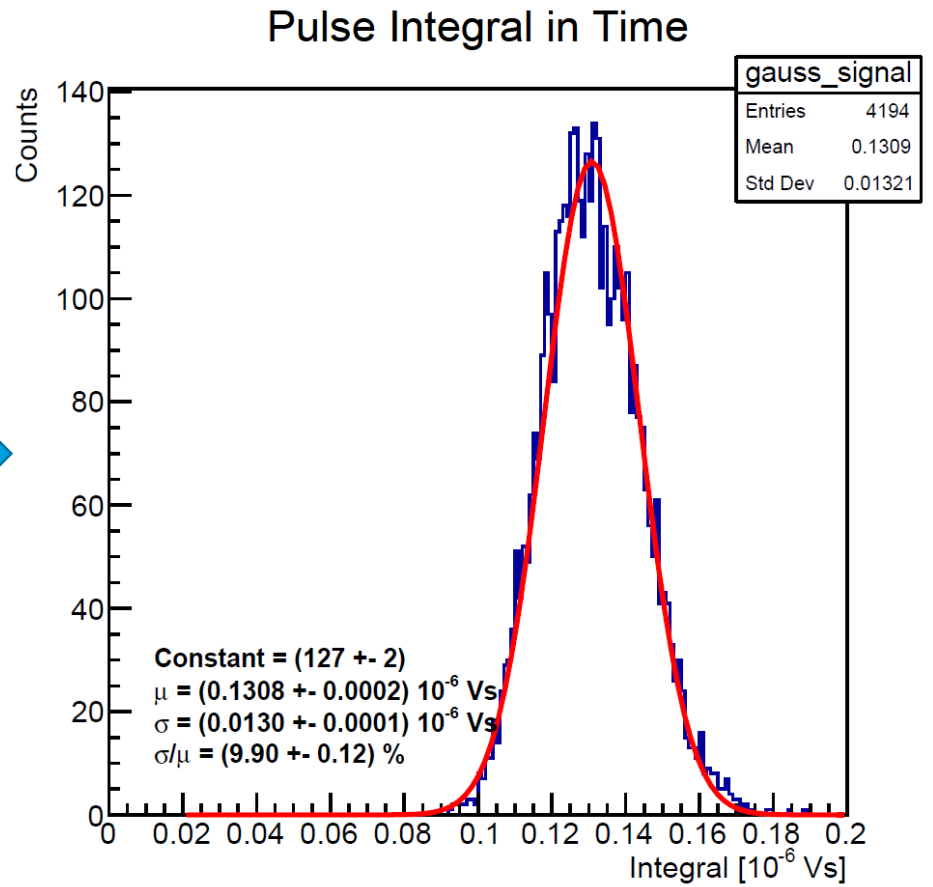


All equipment delivered. Measurements will start very soon.

Schematic adapted from Katharina-Sophie Isleif.

Towards the understanding of our system





Data Analysis:
Energy Resolution
$(9.96 \pm 0.12)\%$

Simulation:
Energy Resolution
$(9.90 \pm 0.12)\%$

Studying other phenomena
- Rejection of pileup
- DAQ trigger efficiency.

Simulation confirms energy resolution can be explained by the electronic noise.

Outlook

Requirements for ALPS II:

- Sensibility to very low rates (1-2 photons a day). ✓
- Low energy photon detection (1064 nm equivalent to 1.16 eV). ✓
- High detection efficiency. ✓
- Low background rate: $< 7.7 \cdot 10^{-6}\text{cps} \sim 1\ \text{photon}\ (1064\text{nm} - \text{like})\ \text{every 2 days}$ ✓
  - Good energy resolution ✓
- Long term stability ($\sim 20\ days$). ✓

And also … first steps on simulating our system
studying feasibility of the TES for direct dark matter detection

FURTHER DARK MATTER SEARCHES USING ALPS II'S TES DETECTOR • CHRISTINA SCHWEMMBAUER FOR THE ALPS COLLABORATION


High-power laser
HPL
Reference laser
RL
COB
Transition Edge Sensor
ALIPS

Thank you.

Contact

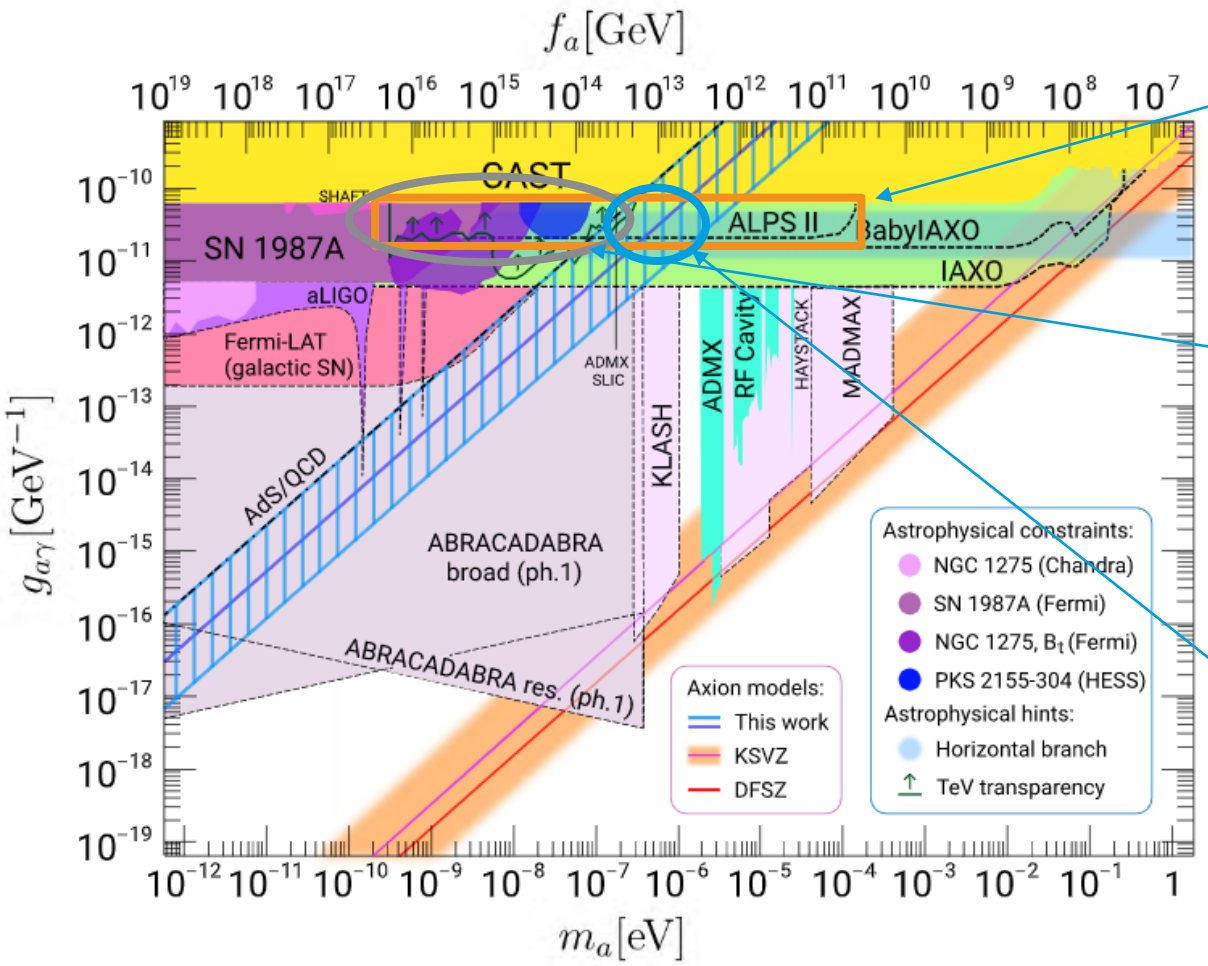
DESY. Deutsches Elektronen-Synchrotron

www.desy.de

José Alejandro Rubiera Gimeno
ALPS
jose.rubiera.gimeno@desy.de

Backup

Axion-photon coupling



ALPS II

Motivated by anomalies in the evolution of stars

$$10^{-11} GeV^{-1} \leq g_{a\gamma} \leq 10^{-10} GeV^{-1}$$

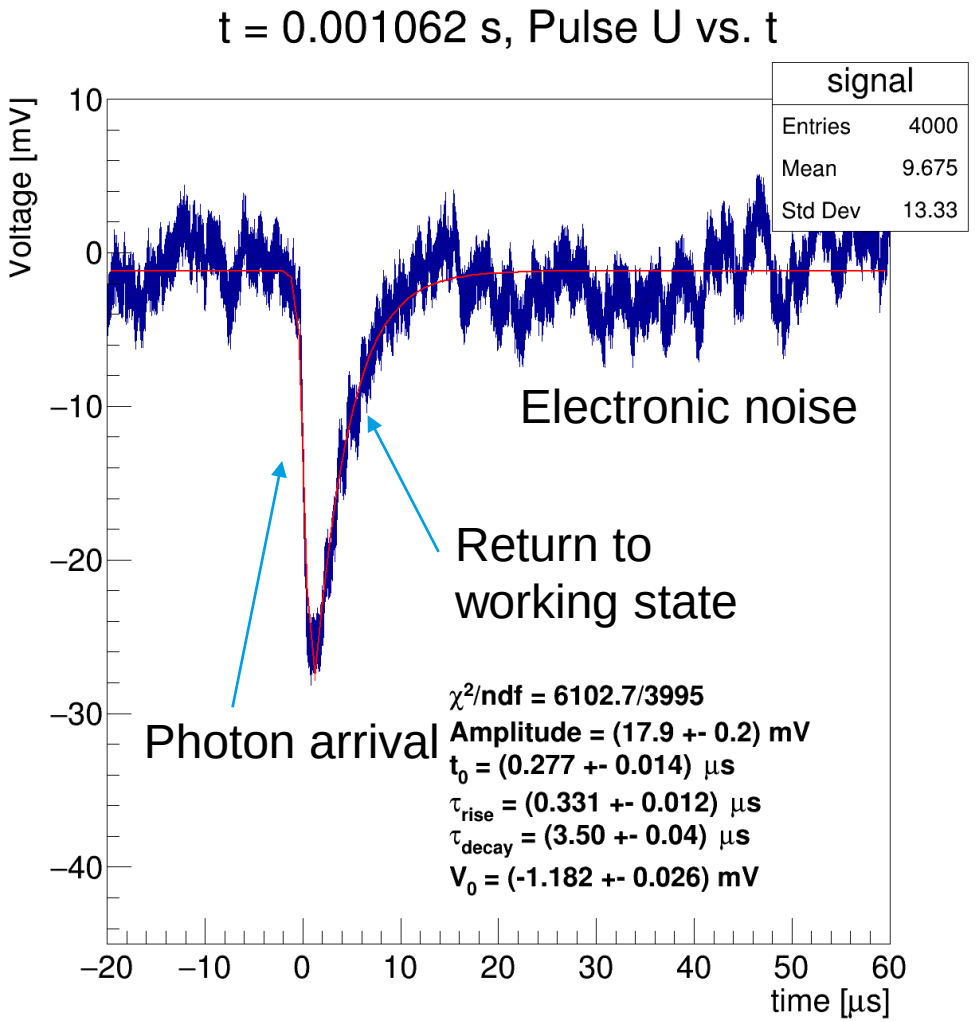
TeV Transparency

Best sensitivity among LSW experiments

New theory of QCD axion

[1] A. V. Sokolov and A. Ringwald, “Photophilic hadronic axion from heavy magneticmonopoles,” [arXiv:2104.02574 [hep-ph]].

Fitting procedure



From Small-Signal Theory:

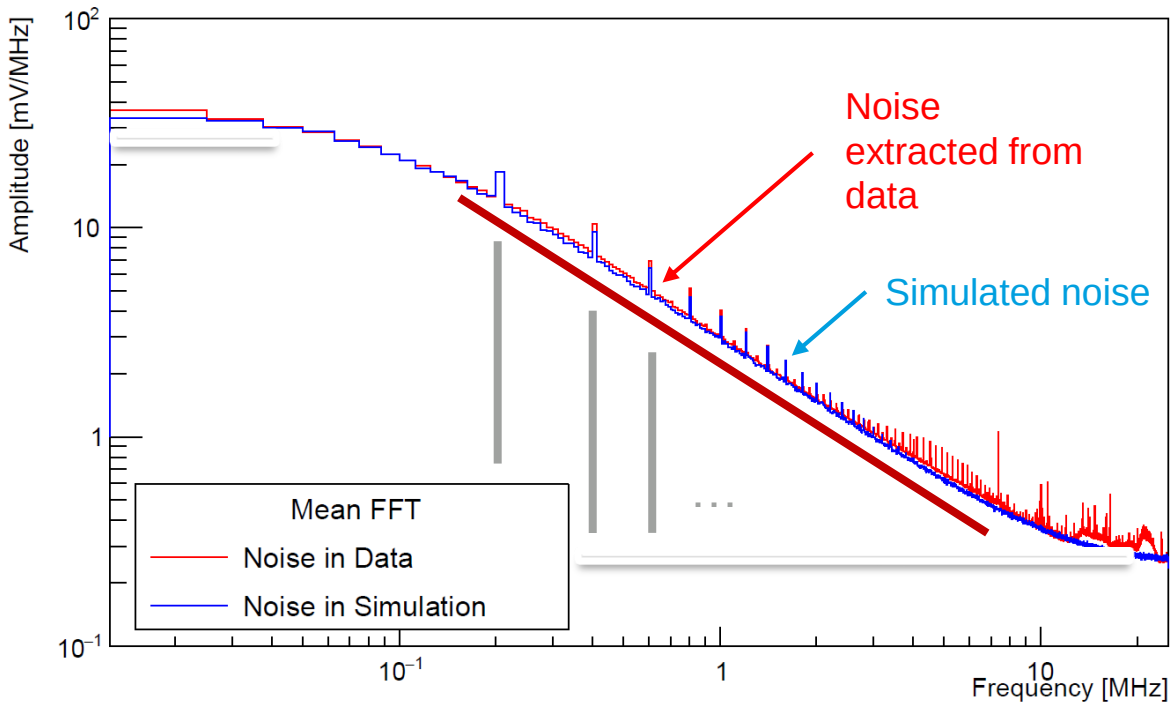
$$f_2(t) = \begin{cases} A\left(\underbrace{\exp\left\{-\frac{(t-t_0)}{\tau_+}\right\}}_{\text{Rise component}} - \underbrace{\exp\left\{-\frac{(t-t_0)}{\tau_-}\right\}}_{\text{Decay component}}\right) + V_0, & t \geq t_0 \\ V_0, & else \end{cases}$$

Piecewise function

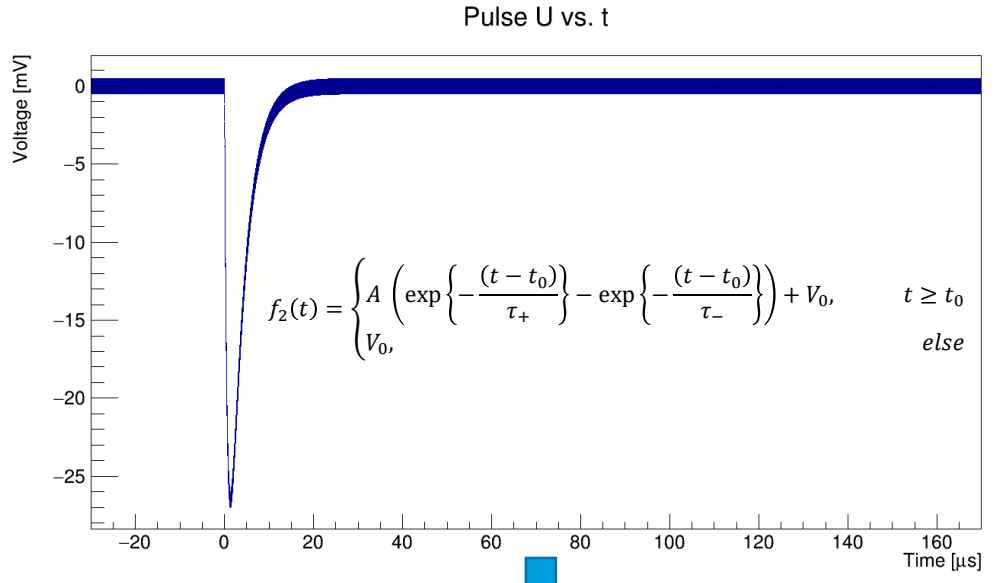
Phenomenological approach:

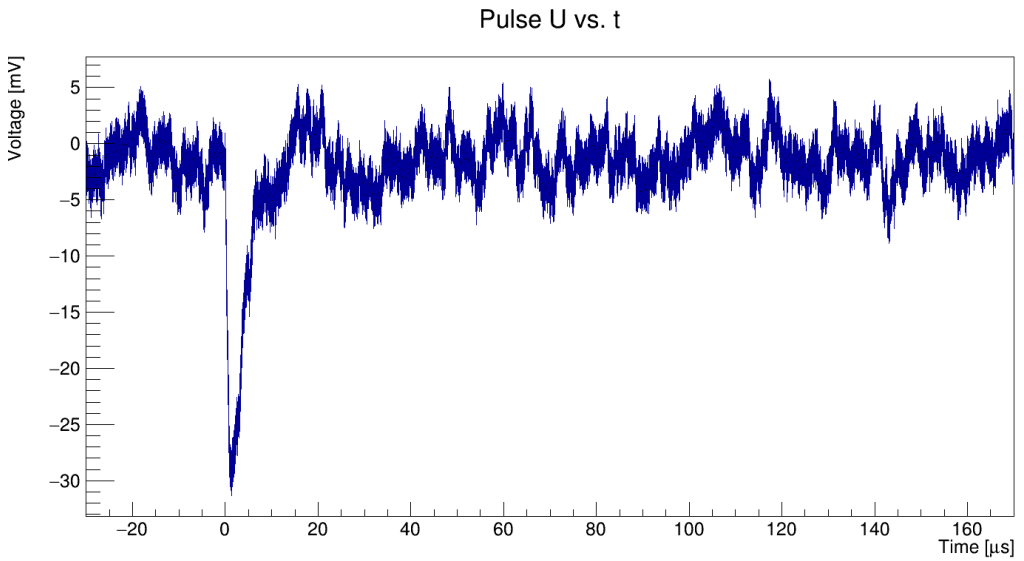
$$f_1(t) = -\frac{2A}{\underbrace{\exp\left\{-\frac{1}{\tau_{rise}}(t-t_0)\right\}}_{\text{Rise component}} + \underbrace{\exp\left\{\frac{1}{\tau_{decay}}(t-t_0)\right\}}_{\text{Decay component}}} + V_0$$

Simulation of electronic noise



+





- $200\ kHz$ harmonics
- White noise
- Brownian noise