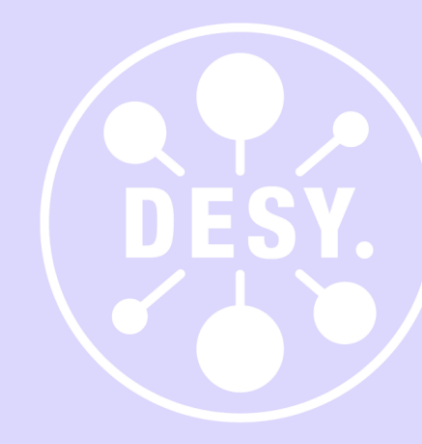


From Axion Searches

TES TECHNOLOGY AT



To Direct Detection

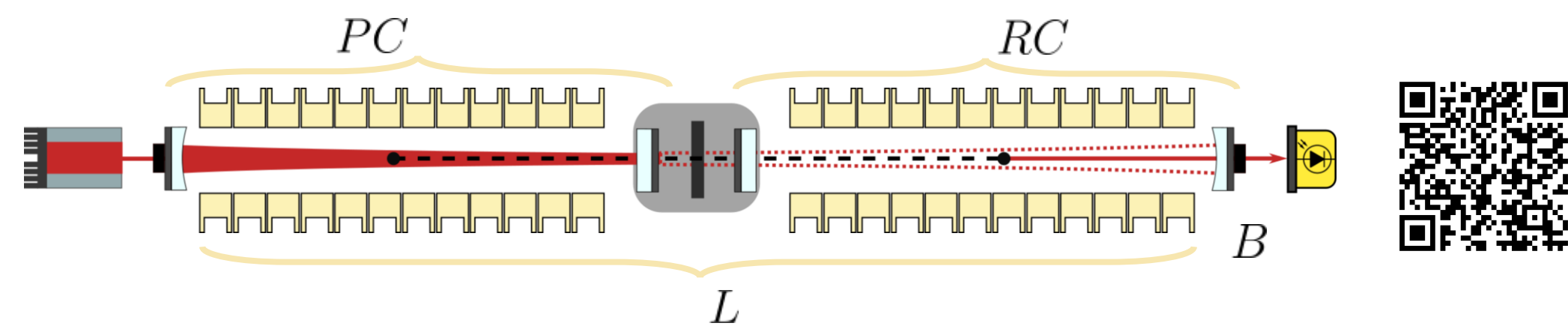
Christina Schwemmbauer¹, Katharina-Sophie Isleif²,
Friederike Januschek¹, Axel Lindner¹, Manuel Meyer³,
Gulden Othman⁴, Elmeri Rivasto³, José Alejandro Rubiera Gimeno²

¹Deutsches Elektronen Synchrotron DESY, Hamburg, Germany
²Helmut-Schmidt Universität, Hamburg, Germany
³CP3-Origins, University of Southern Denmark, Odense, Denmark
⁴Institut für Experimentalphysik, Universität Hamburg, Germany

THE ALPS II EXPERIMENT

ALPS II (Any Light Particle Search) is a **currently running** Light-Shining-through-Walls (LSW) experiment at DESY Hamburg, Germany. It exploits photon-ALP conversion in magnetic fields [1] to search for ALPs at an ALP-photon coupling down to $g_{a\gamma\gamma} = 2 \cdot 10^{-11} \text{ GeV}^{-1}$, independent of astrophysical and cosmological models.

- ALPS II consists of two $L = 12 \times 8.8 \text{ m}$ magnet strings of $B = 5.3 \text{ T}$ dipole magnets
- A production cavity (PC i.e. Fabry-Perot resonator) increases probability for photon-ALP conversion of laser light in a magnetic field
- Generated ALPs can cross a light-tight wall between the cavities, which cannot be penetrated by the laser light
- ALPs are re-converted to photons by the inverse effect in the regeneration cavity (RC)



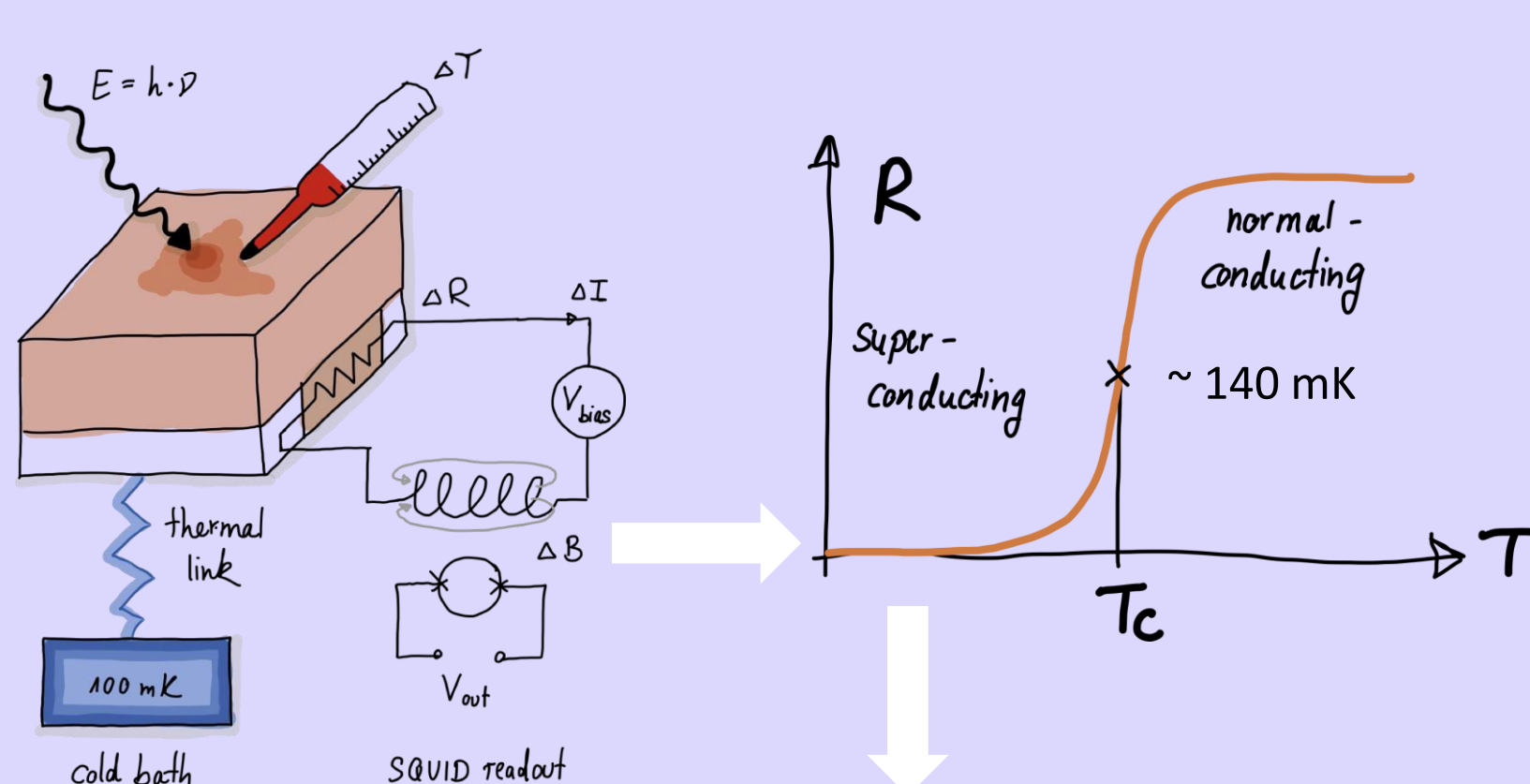
- With power build-up due to the optical cavities the probability to be able to detect a regenerated photon is

$$P_{\gamma \rightarrow a \rightarrow \gamma} \propto PC \cdot RC \cdot g_{a\gamma\gamma}^4 B^4 L^4 \rightarrow \mathbf{1 \text{ photon/day}}$$

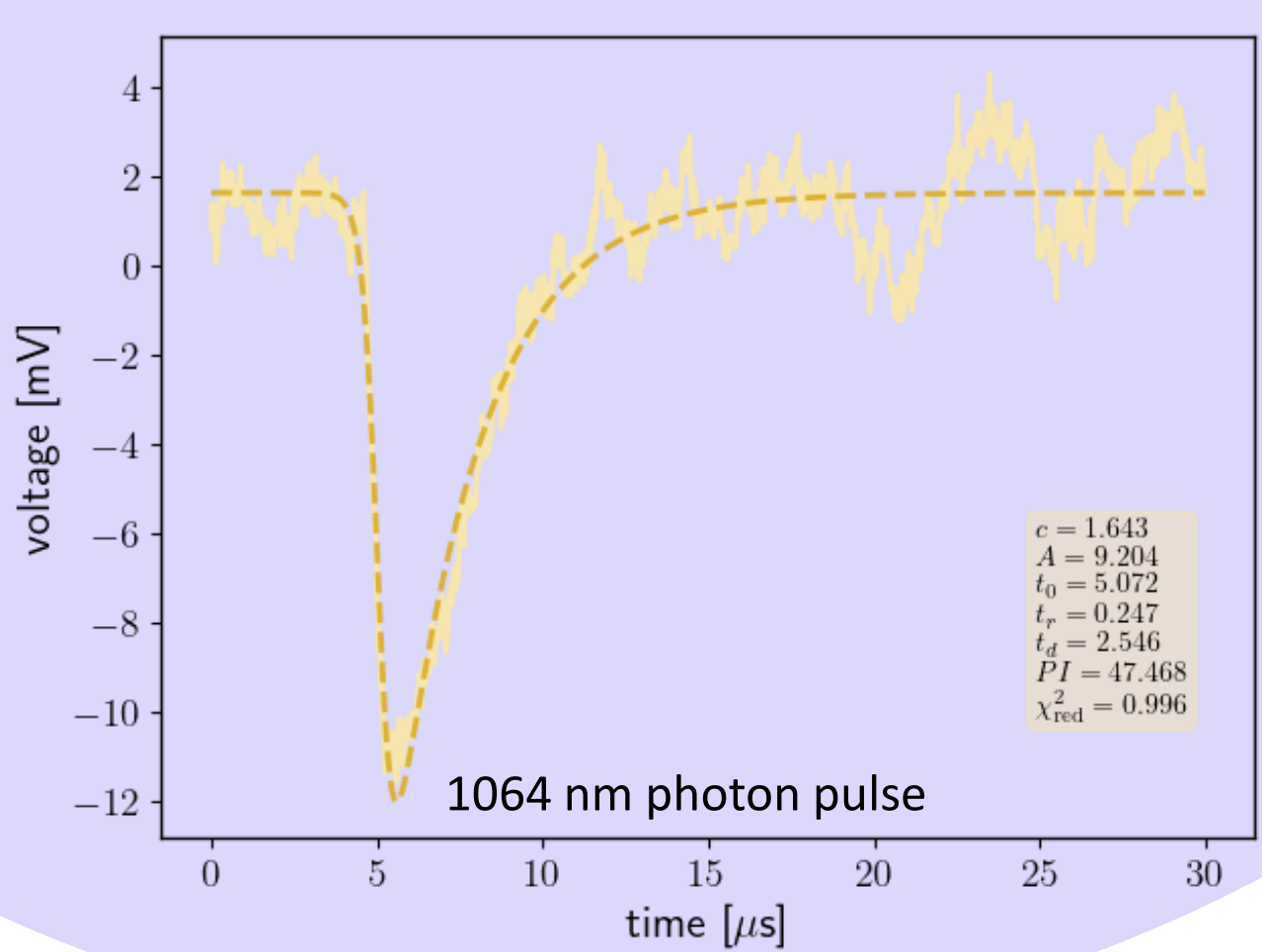
- Currently collecting data using the heterodyne sensing method, which involves mixing frequencies and analysis of the resulting beat note

In future upgrades of the ALPS II experiment, a cryogenic TES (Transition Edge Sensor) detector could be used for single-photon detection.

TES WORKING PRINCIPLE



$$U(t) = -\frac{2A}{e^{-\frac{t-t_0}{\tau_{\text{rise}}}} + e^{\frac{t-t_0}{\tau_{\text{decay}}}}} + V_0$$



A TES FOR ALPS II

Requirements for single-photon detection with a TES for ALPS II and recent updates from our optimized TES detector system:



Detection Requirements

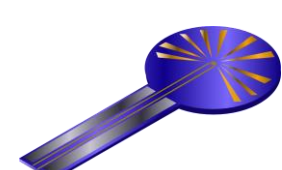
Low energy photon detection at ALPS II laser wavelength (1064 nm i.e. 1.165 eV) with high quantum efficiency

High system detection efficiency

Good energy resolution (at 1064 nm)

Low intrinsic background - no fiber (radioactive decays, cosmics, etc.)

Low extrinsic background - with fiber (mainly black-body radiation)



TES System Status

Optimized optical structure for **near unity quantum efficiency at 1064 nm**

Newest measurements: **> 90% efficiency**

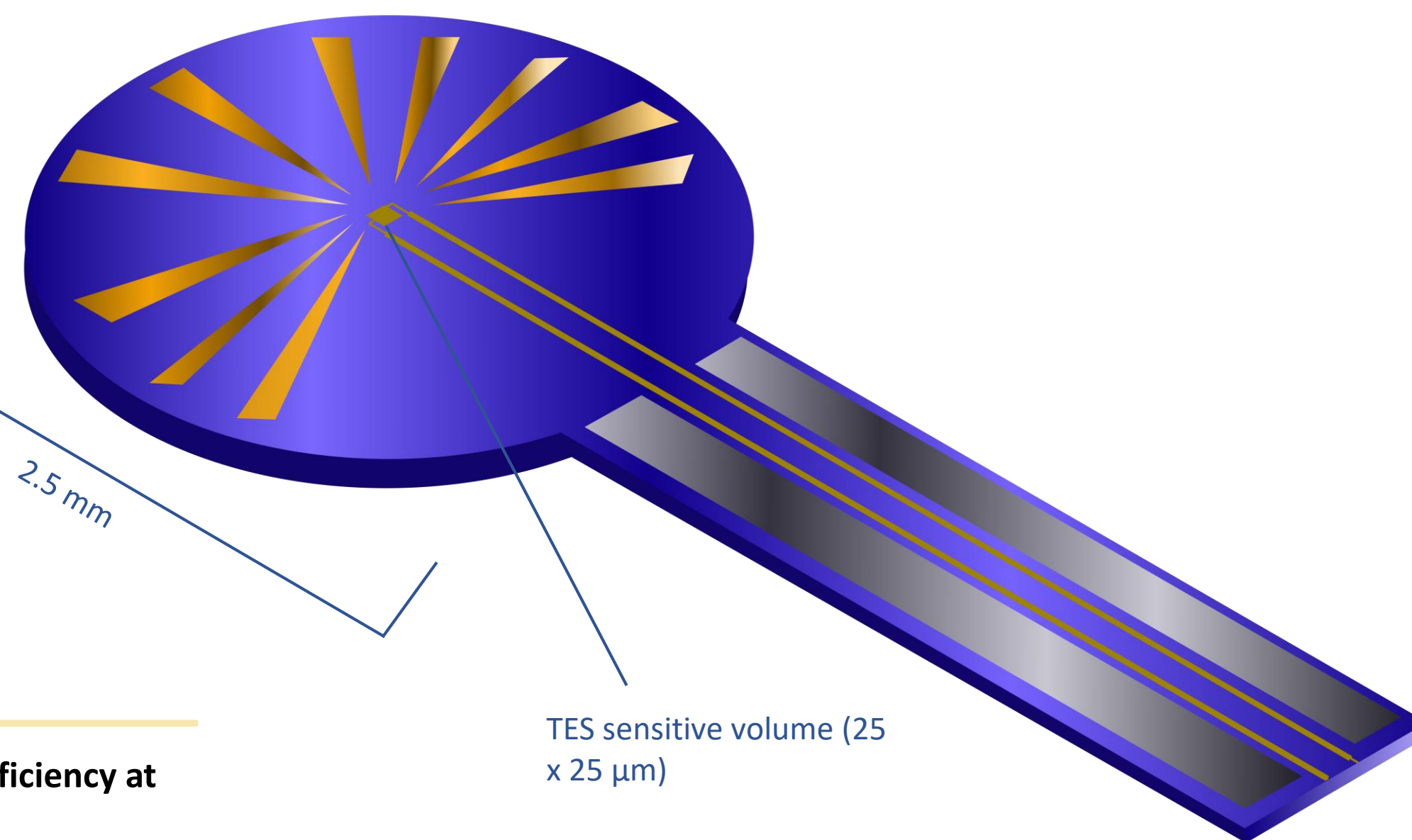
Enhanced analysis methods improve the (1064 nm) **energy resolution from 8% to 5.3%**

Cryostat shielding and pulse shape analysis based background reduction yield a **background of 6.9×10^{-6} cps** [2] at high signal efficiency

Enhanced energy resolution improved the background reduction down to **10^{-5} cps**. Additional efforts:

- Currently building a setup to employ optical bandpass filters in the cold including cryo adjustment
- Fiber curling to cutoff higher wavelengths

Background requirements:
 $< 7.7 \times 10^{-6}$ cps



optical fiber
dilution refrigerator

TES detector module

SQUIDS



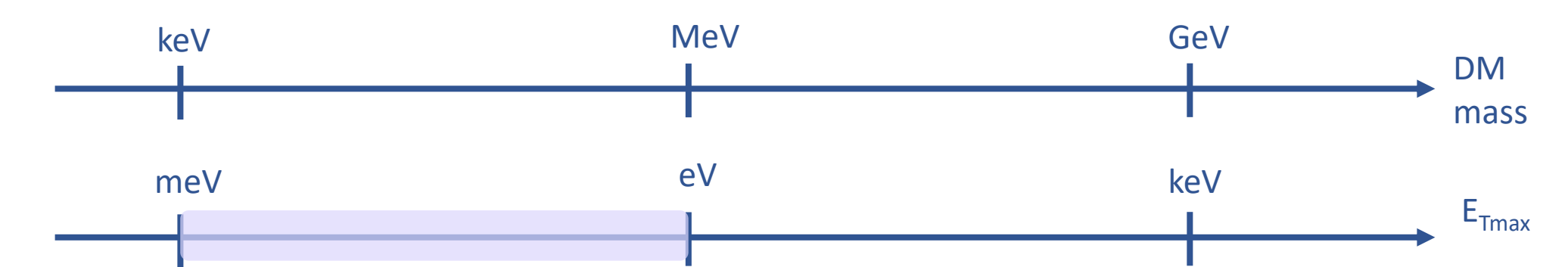
DM – ELECTRON SCATTERING

DM-electron scattering [3] is a promising approach for detecting WIMP-like light Dark Matter (DM) candidates with sub-GeV masses.

When probing these lower mass ranges, the maximum energy transferred in a scattering event is entire kinetic energy of incident DM particle:

$$E_{T_{\text{max}}} = E_{\text{kin}} \sim m_{\chi} v^2 \sim 10^{-6} m_{\chi}$$

where $v \sim 10^{-3}$ is the DM halo velocity.



This yields a relationship between DM mass and transferred energy in a scattering event, hinting towards possible detection schemes: Sub-MeV mass = Sub-eV energy **superconductors (TES)**

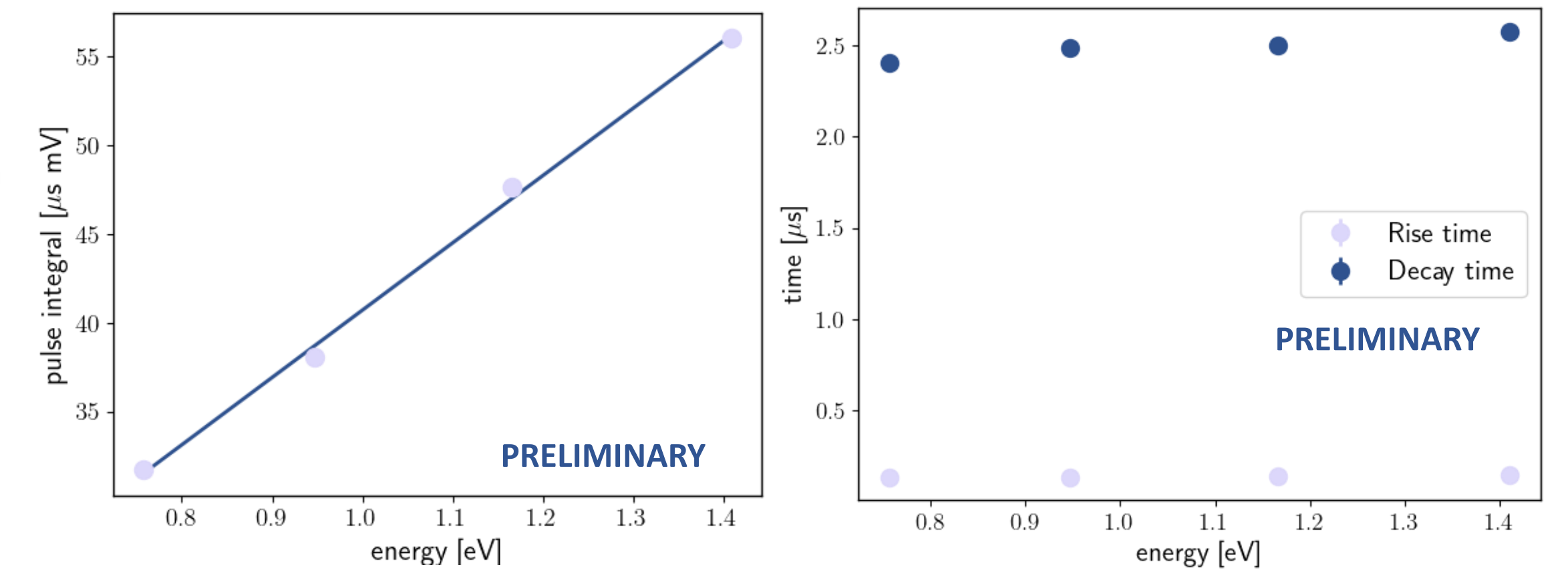
- No fiber connection needed for direct DM searches \rightarrow less background/noise
- First simulations showed promising results towards using ALPS II's TES for direct DM searches [4]

A TES FOR DIRECT DM SEARCHES

Broadband Low Energy Laser Calibration:

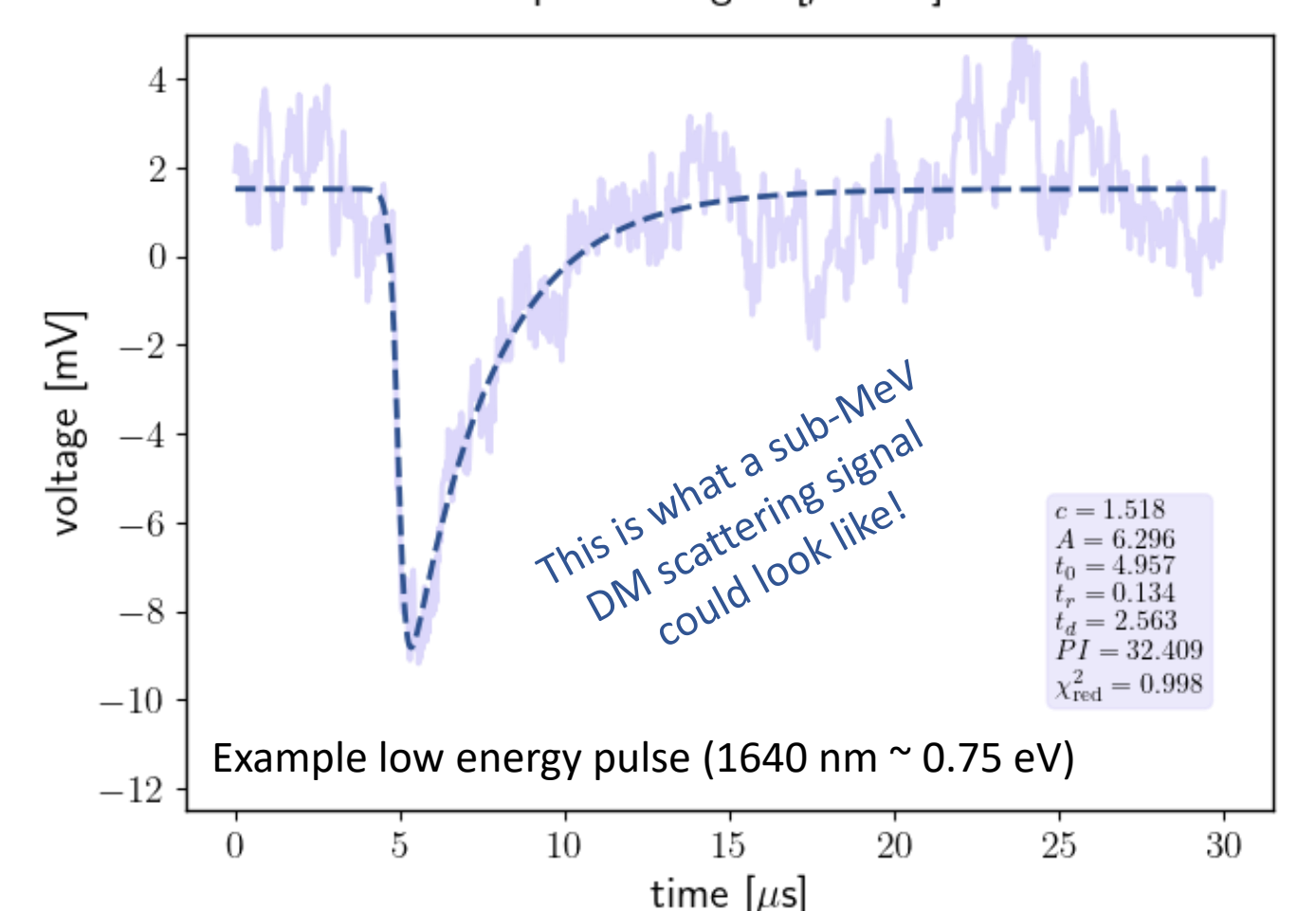
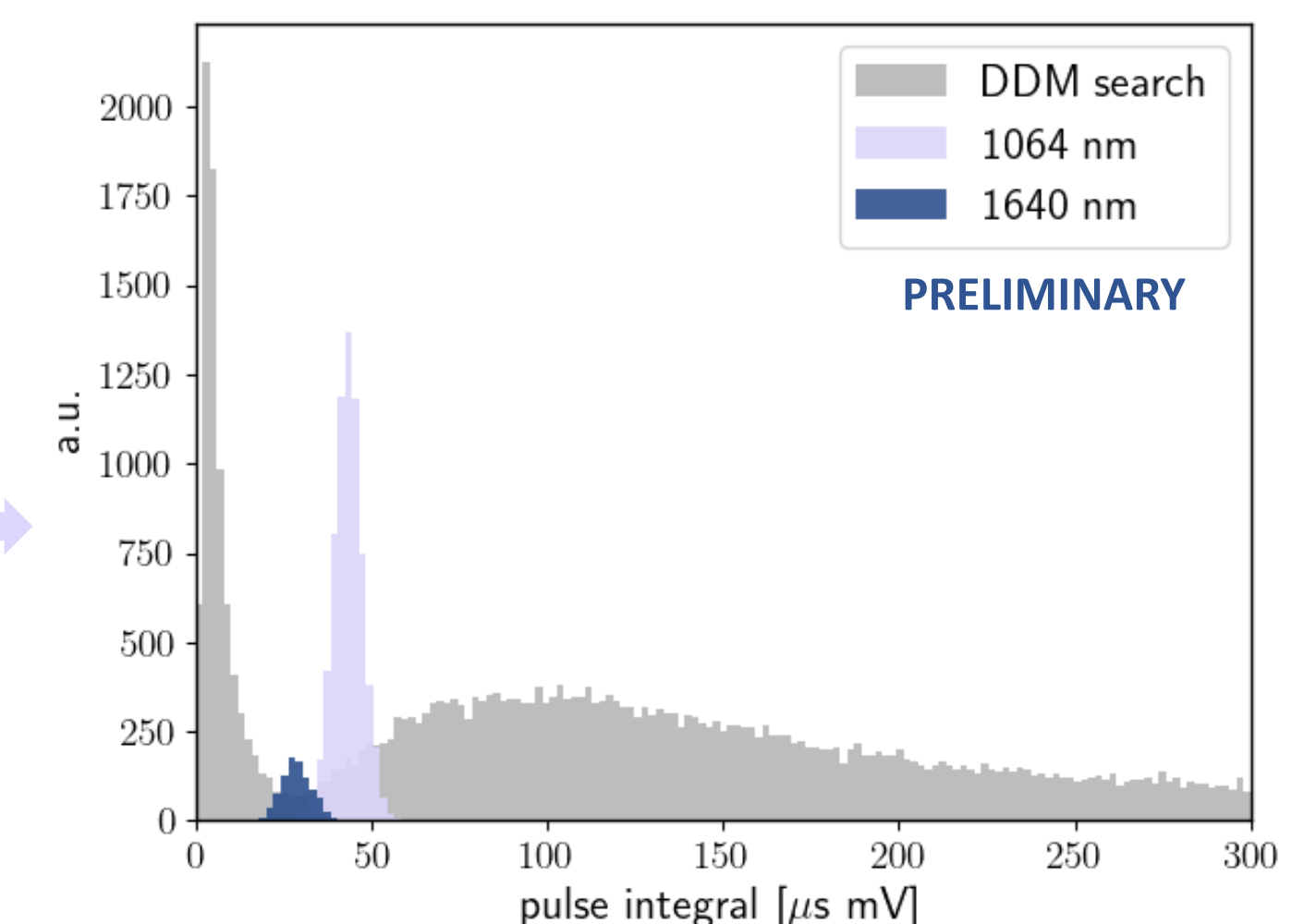
DM signals are expected to look like photons in the TES

- Pulse integral vs. Photon energy: Linear low energy TES response
- Rise and decay time vs. Photon energy: Mostly constant over tested energy range
- Enables distinction between photon-like pulses and background signals



FIRST TES DM SEARCH

- First direct DM search (no-fiber mode) of more than 400 h conducted
- Raw spectrum of the pulse integral of triggered events compared to laser calibration (1064 nm & 1640 nm)
- Majority of background lies outside of the photon-like regions
- More data, including optimized sensor data, to follow soon



AT A GLANCE

- Future ALPS II upgrades may incorporate TES detectors for photon counting via ALP-photon conversion, with the system's intrinsic background and detection efficiency already meeting current requirements
- Methods to filter black-body photons and enhance analysis will further reduce extrinsic backgrounds for ALPS II
- The TES system is being explored for the independent detection of ~MeV dark matter
- Linear TES energy response allows for energy-resolved dark matter searches down to sub-eV energies, distinguishing photon-like pulses from background through fit parameters
- Analysis towards an energy spectrum with subsequent investigation of uncharted terrestrial light DM parameter space currently ongoing

