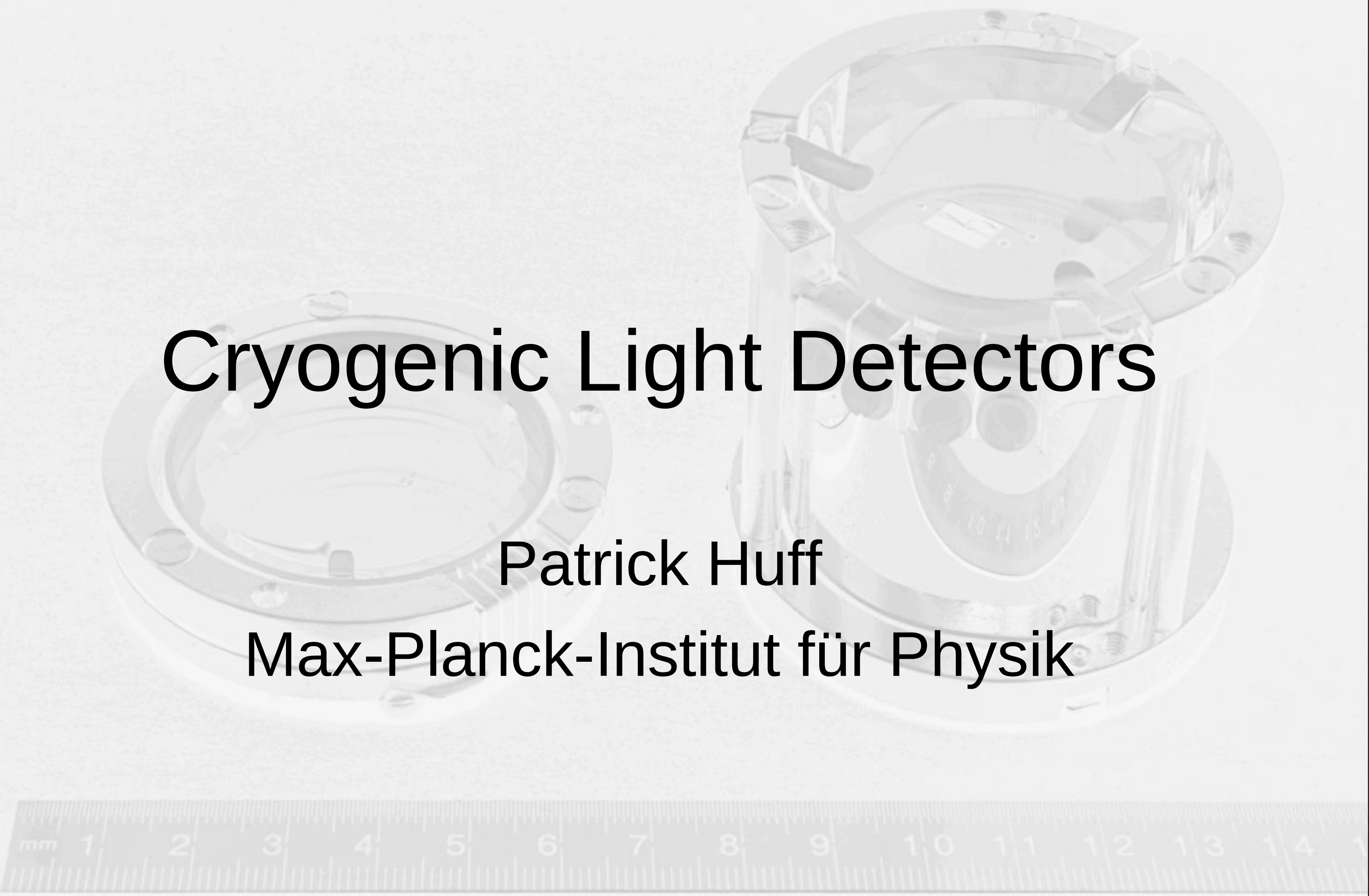


# Cryogenic Light Detectors

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# Applications of cryogenic LDs

Detection of the

- …energy of electromagnetic radiation
- …kinetic energy of a particle
- …biomolecules
- …single photons for quantum information

➢ Range: meV < E < MeV

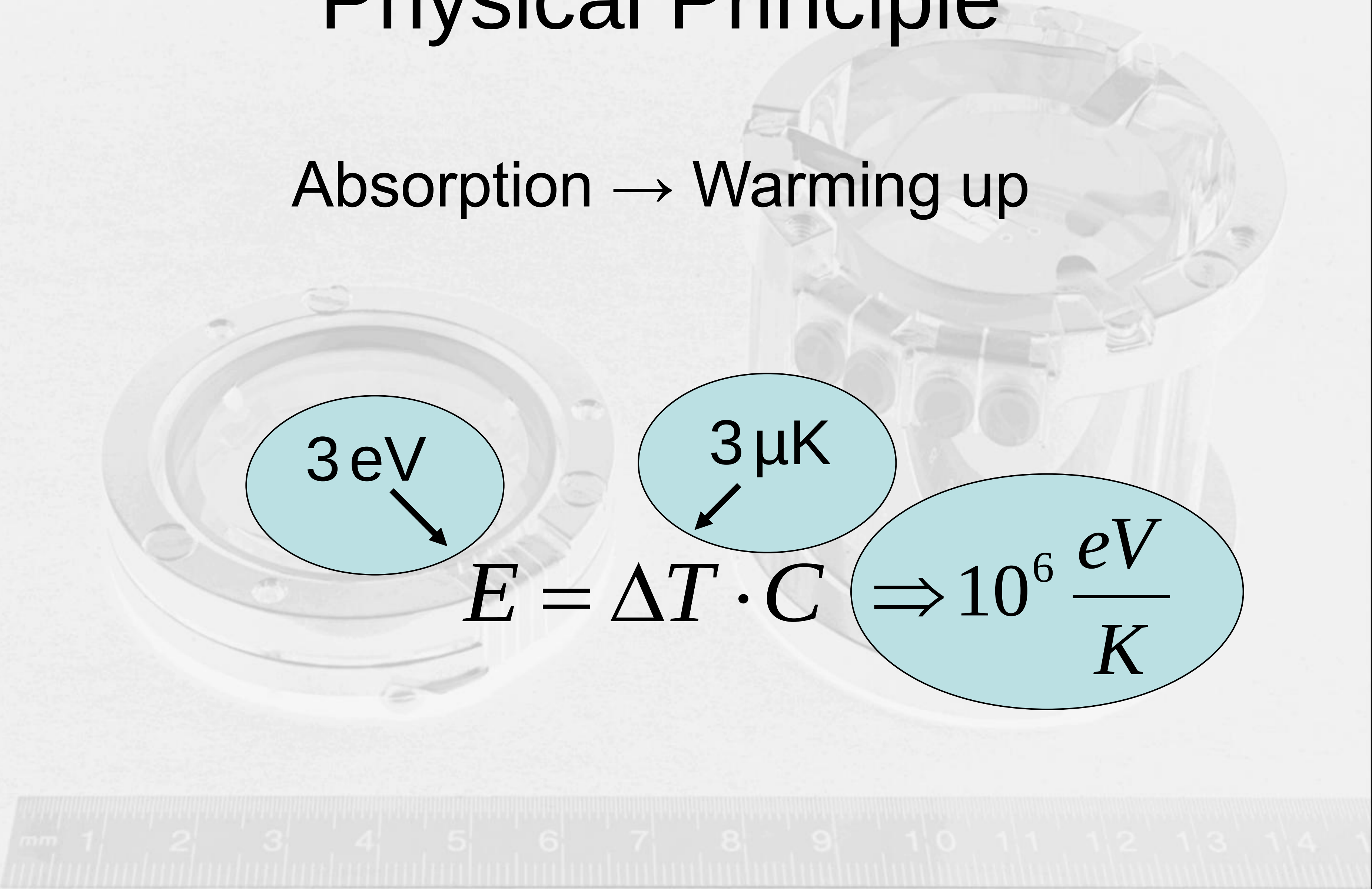
# Physical Principle

Absorption → Warming up

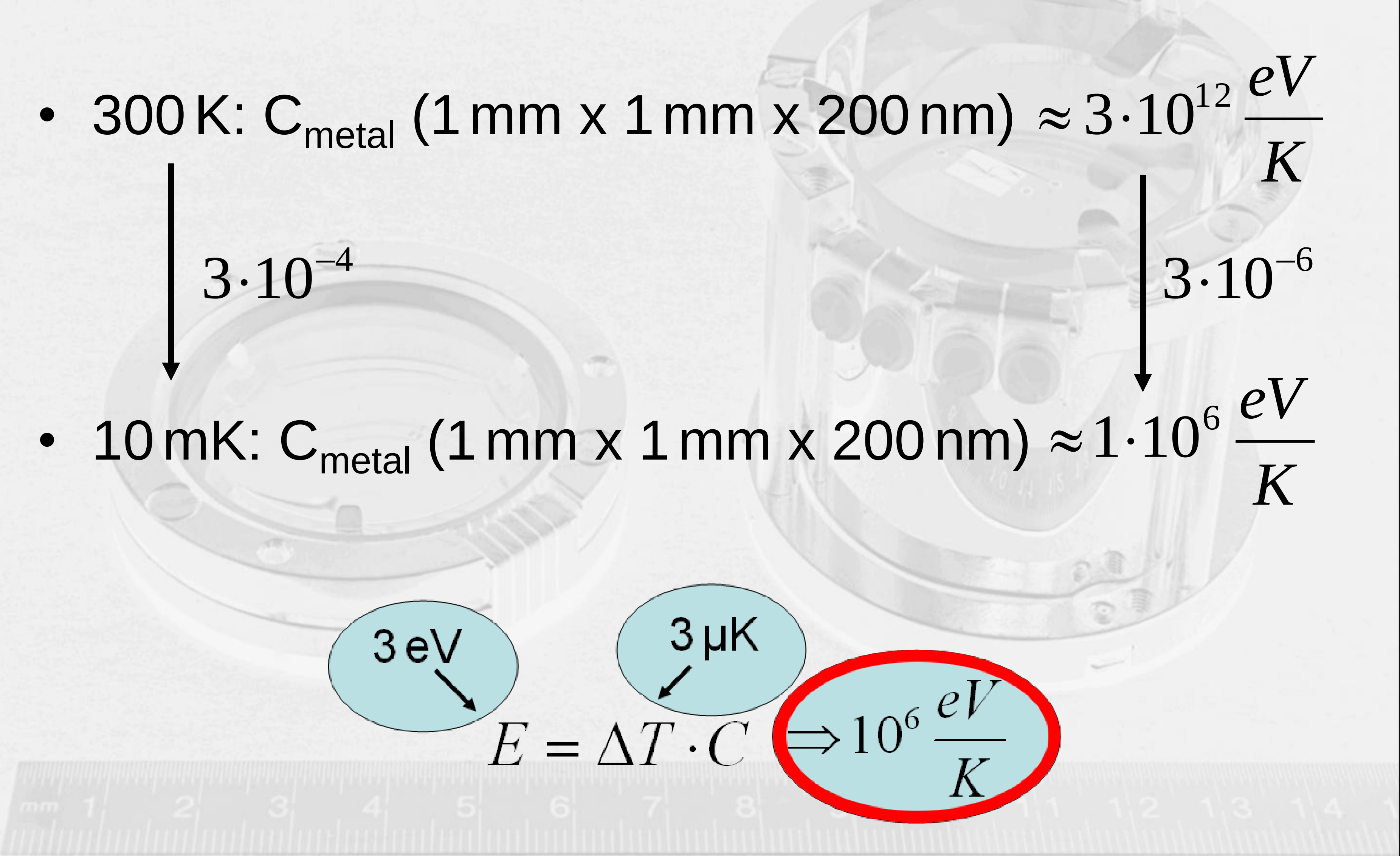
3 eV

3 µK

$$E = \Delta T \cdot C \Rightarrow 10^6 \frac{eV}{K}$$



# Physical Principle



- 300 K: $C_{metal}$ (1 mm x 1 mm x 200 nm) $\approx 3 \cdot 10^{12} \frac{eV}{K}$

$\downarrow 3 \cdot 10^{-4}$ $\qquad$ $\downarrow 3 \cdot 10^{-6}$

- 10 mK: $C_{metal}$ (1 mm x 1 mm x 200 nm) $\approx 1 \cdot 10^{6} \frac{eV}{K}$

3 eV $\qquad$ 3 µK

$$E = \Delta T \cdot C \Rightarrow 10^{6} \frac{eV}{K}$$

# Ultra-Low-Temperatures

- $T \approx 10\,\mathrm{mK}$
- macroscopic system
- arbitrary time period

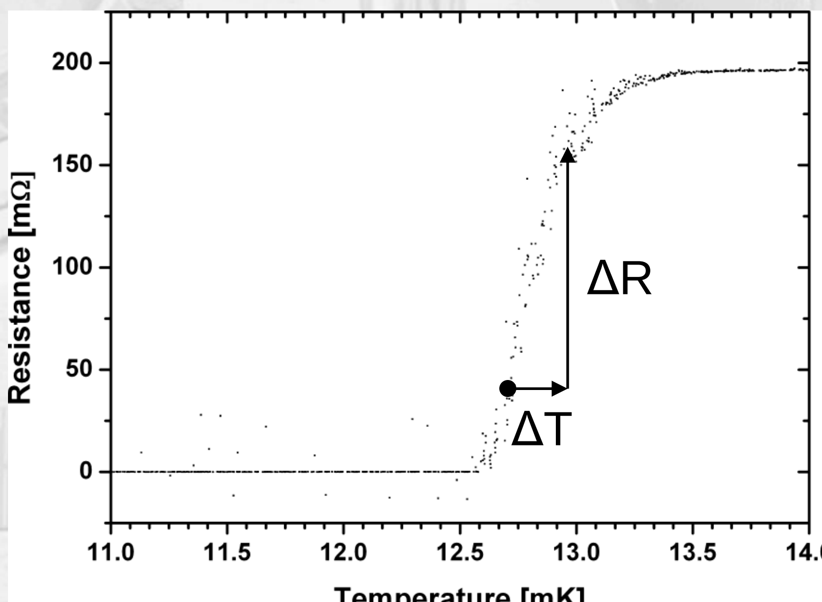
➢ $^3He/^4He$-Dilution Refrigerator
  - Light source in the cryostat
  - Light into the cryostat

# Low Temperature Measurement

3 eV → $E$, 3 µK → $\Delta T$

$$E = \Delta T \cdot C \quad \Rightarrow 10^6 \frac{eV}{K}$$

- Measurement of µK @ 10 mK
  → e.g.: Transition Edge Sensor (TES)



# Low Temperature Measurement

- material for TES:

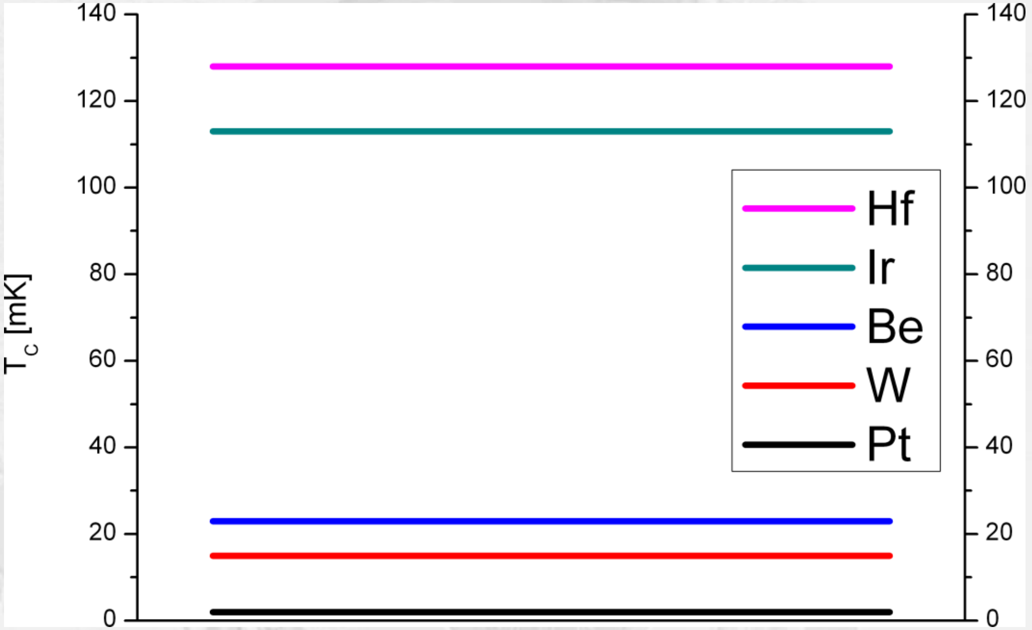
$\rightarrow T_C \approx 10\,\text{mK}$

  - pure metal
  - metal composition

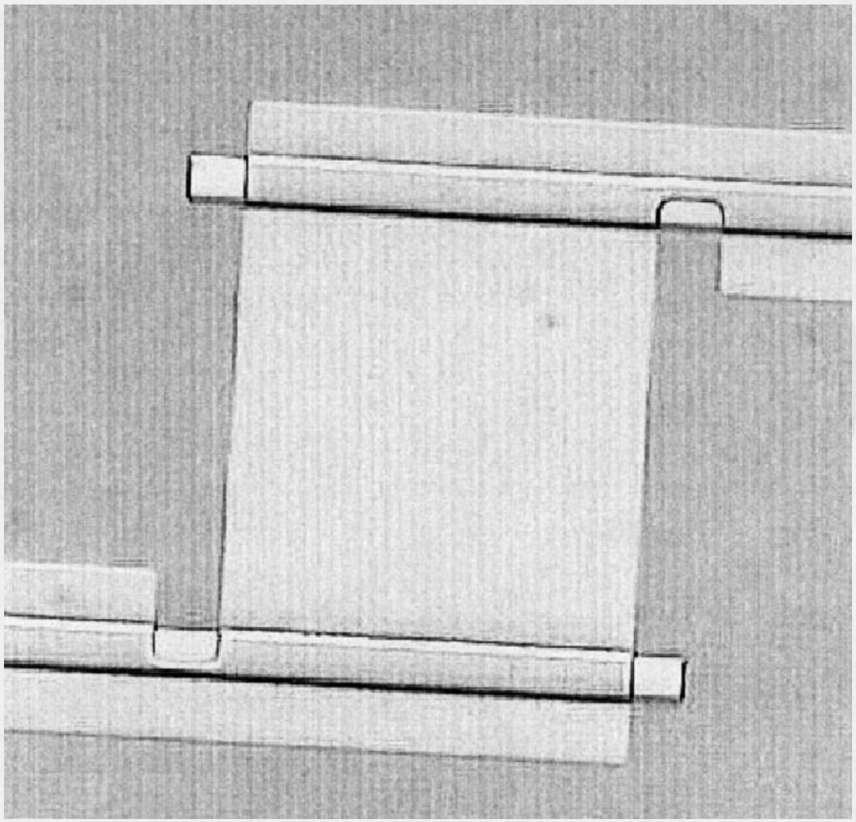
    $\rightarrow$ proximity effect:

    $T_C^1$ & $T_C^2 \Rightarrow T_C^1 < T_C^{12} < T_C^2$

    e.g.: Ir/Au
  - magnetically doped superconductors



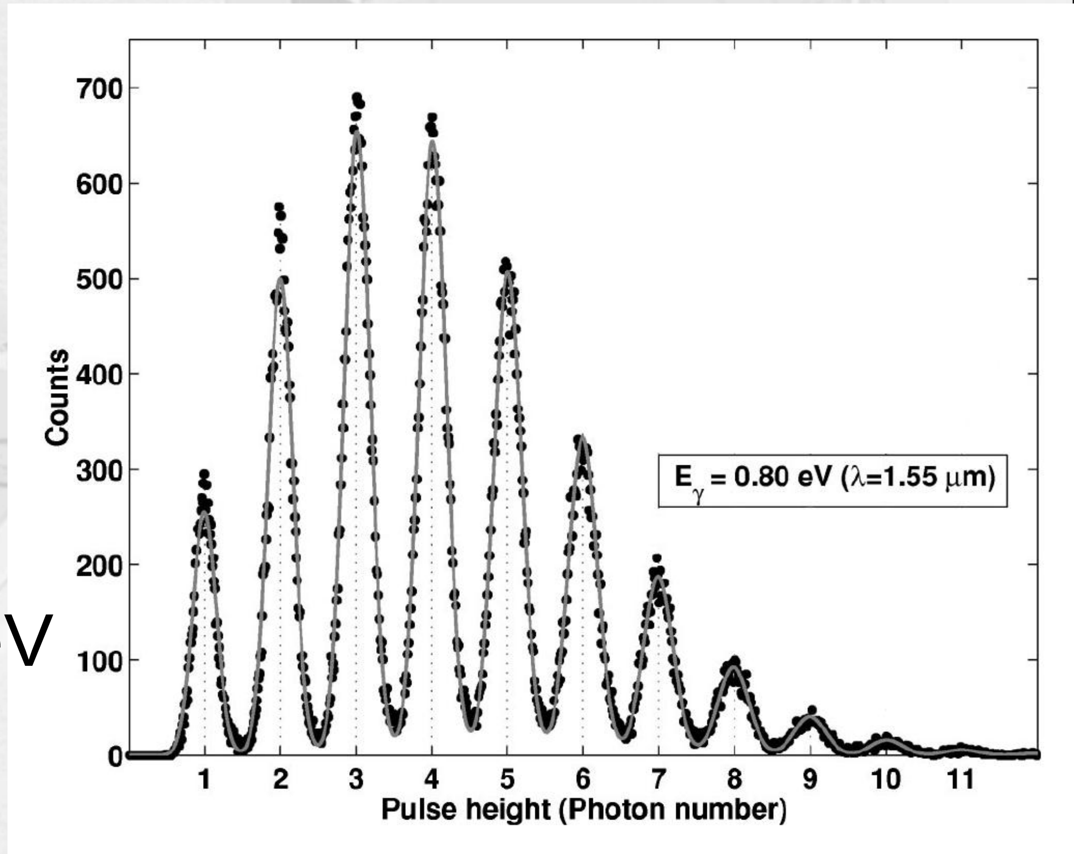
# TES as Light Detector



- tungsten W
- 20 µm x 20 µm x 40 nm
- absorption probability equal to PDE $\approx$ 50 % in the optical band
- $T_C \approx 80\,mK$
- FWHM = 0.15 eV @ 1 eV
- count rate: 30 kHz

# TES as Light Detector

- tungsten W
- 25 µm x 25 µm x 35 nm
- absorption probability equal to PDE ≈ 50 % in the optical band
- $T_C \approx 125$ mK
- FWHM = 0.28 eV @ 1 eV
- count rate: 20 kHz



# TES as Light Detector

- 250 µm x 250 µm
- Mo/Cu
- 1.5 µm Bi absorber coating
- FWHM = 2.38 eV

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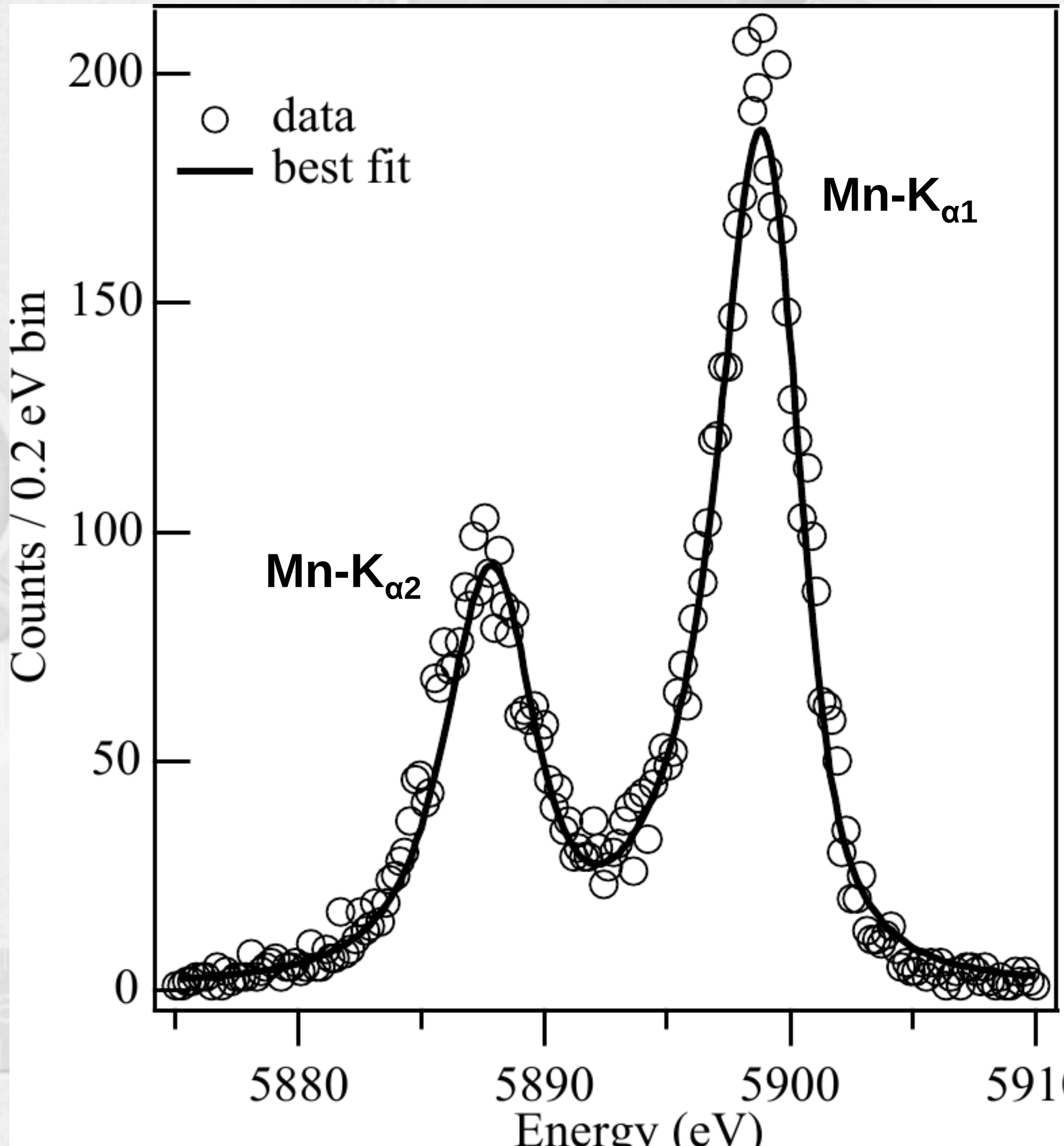
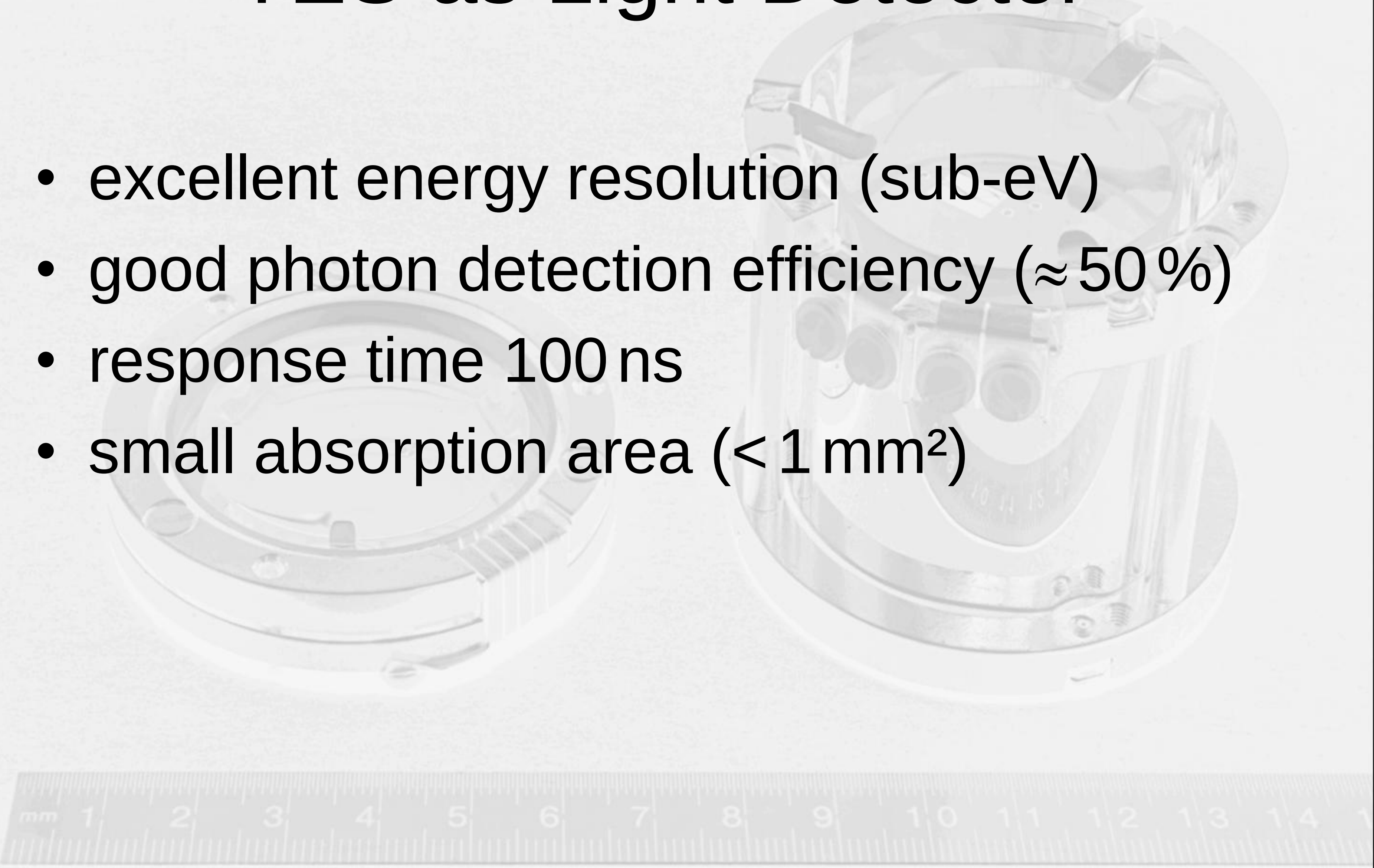
- 400 µm x 400 µm
- FWHM = 2.9 eV



# TES as Light Detector



- excellent energy resolution (sub-eV)
- good photon detection efficiency (≈ 50 %)
- response time 100 ns
- small absorption area (< 1 mm$^2$)

# TES with large absorption area

Enlargement of the absorption area:

→ Larger TES

⇒ sensitivity ~ 1/C

→ Array of TES

⇒ non active areas

⇒ # of wires and readout ~ # of TES

→ Multiplexing

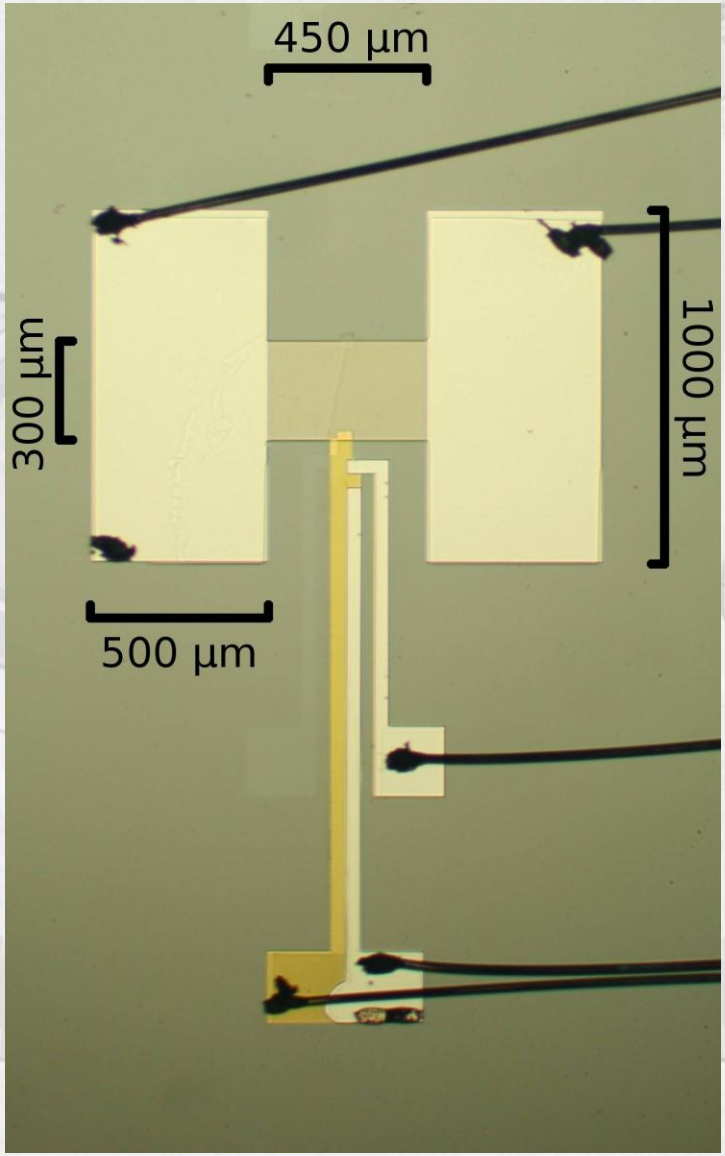
→ Additional absorber with small heat capacity

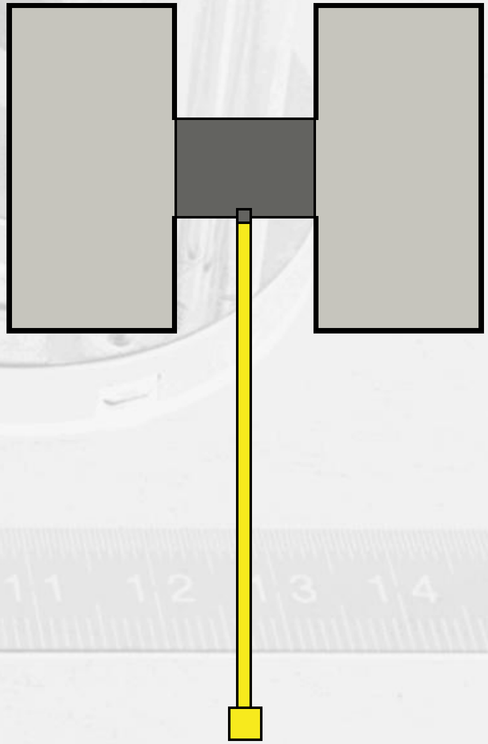
⇒ non-metal crystal, e.g.: Si, SOS, Ge, …

# TES on Absorber

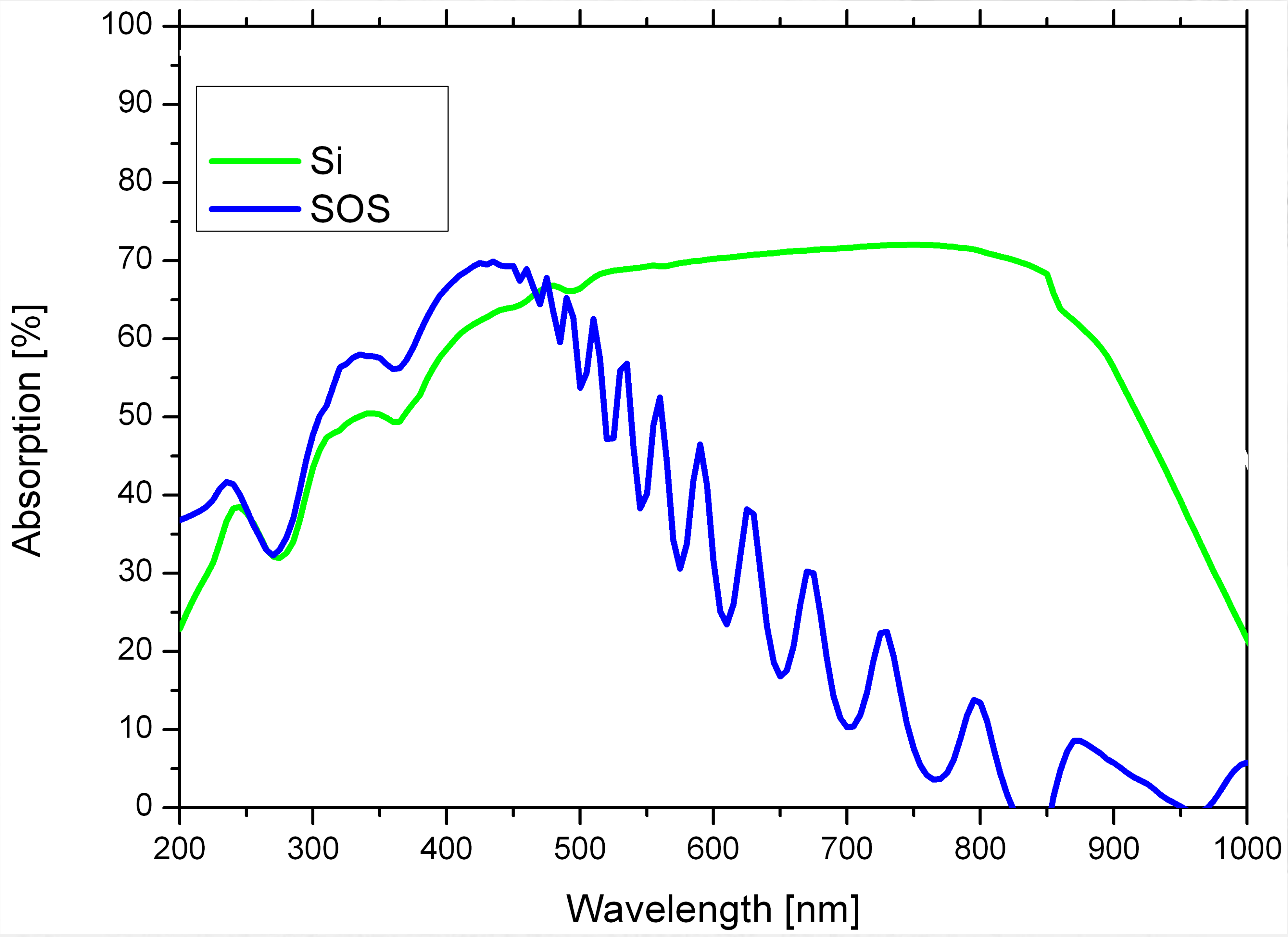

- diameter = 40 mm
- area increased by $10^4$
- thickness = 0.46 mm
- signal threshold
  ≈ 5 photons (3 eV)

# TES on Absorber

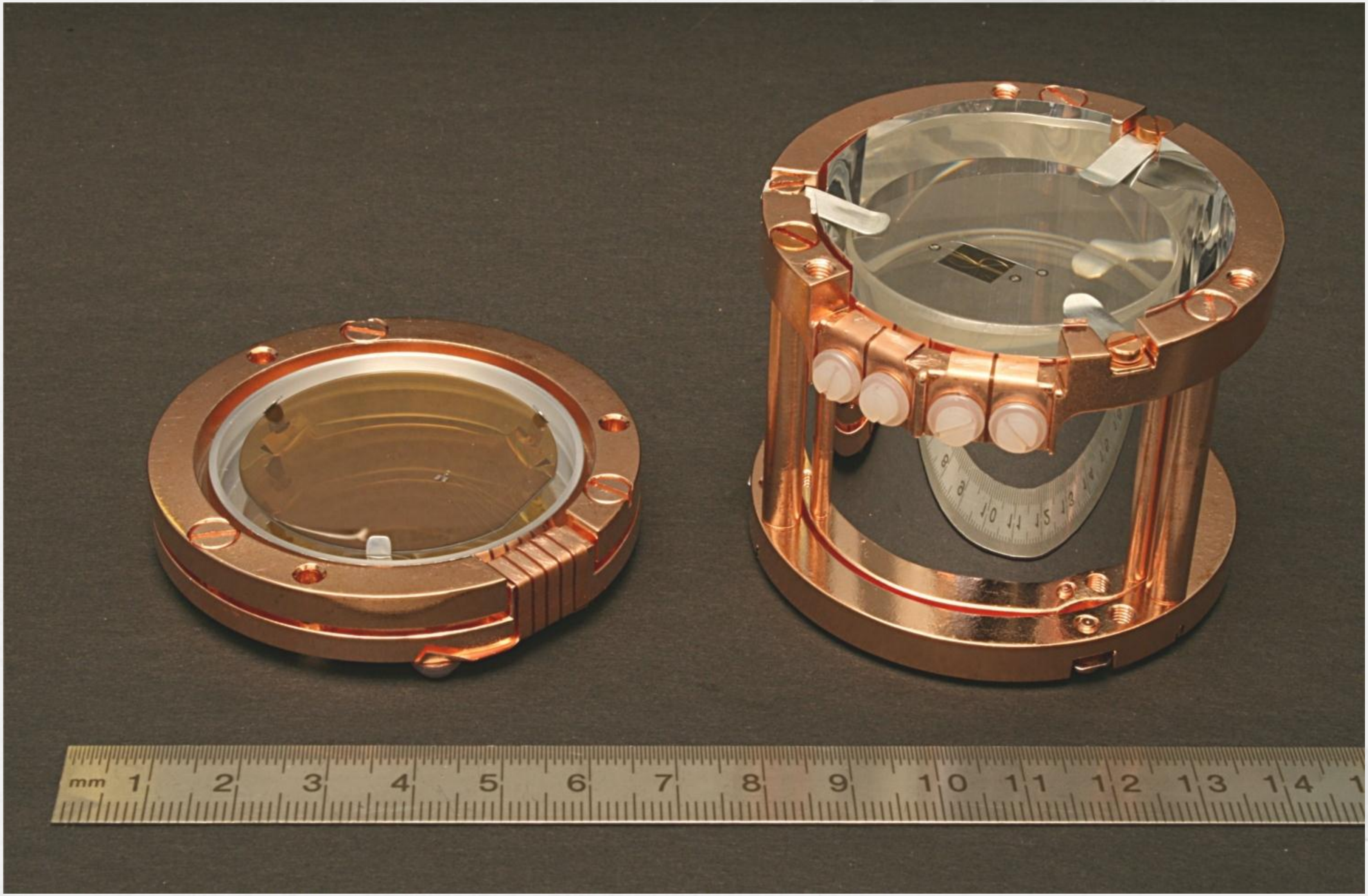


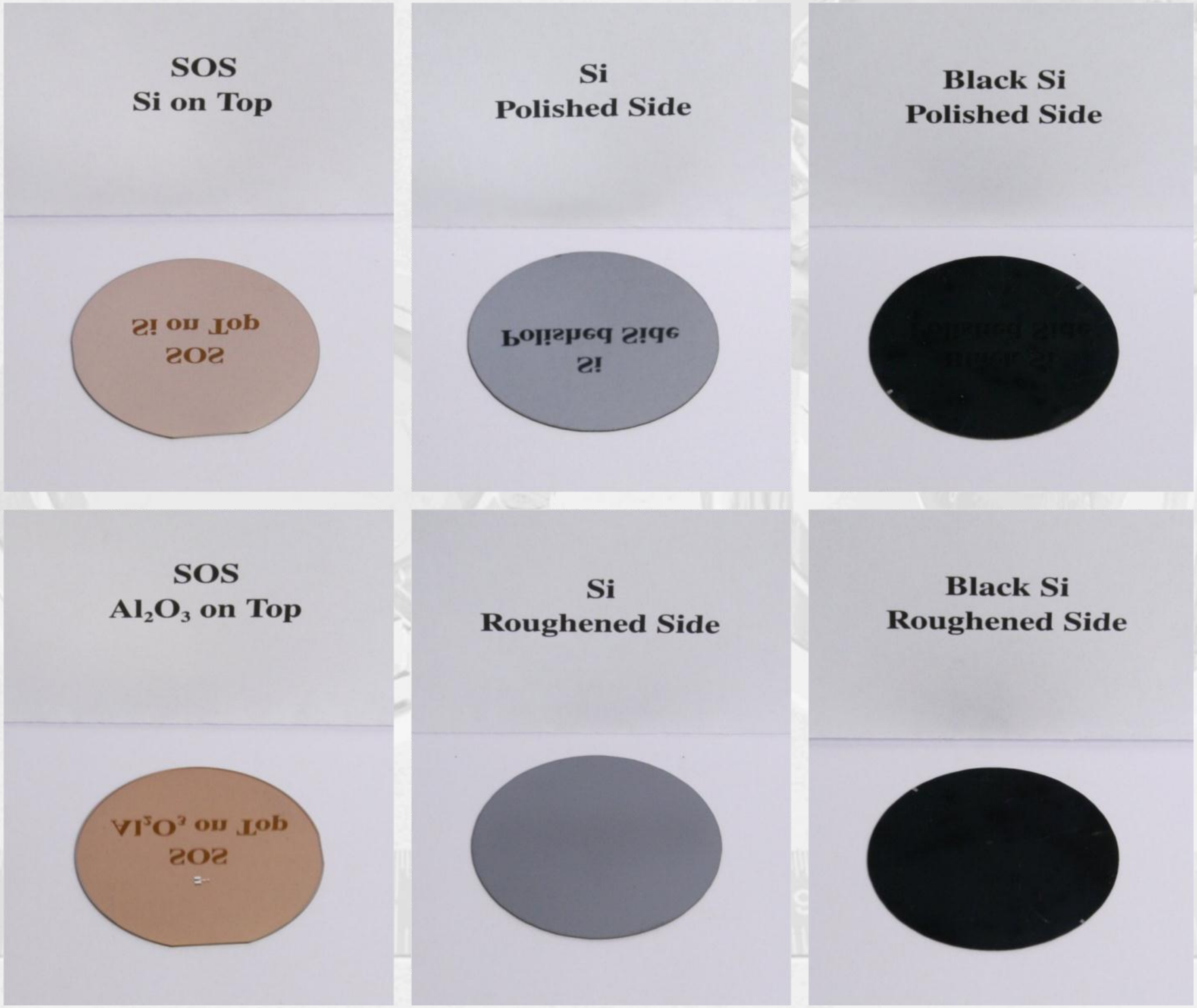
# TES on Absorber



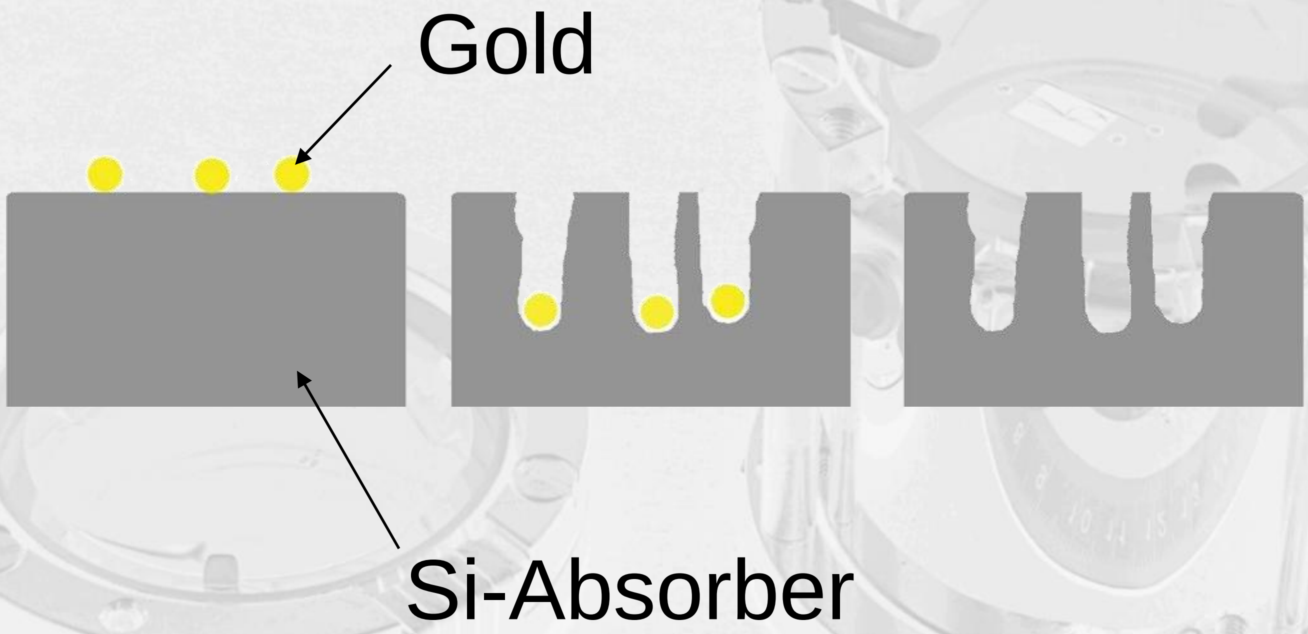
# CRESST Detector Module



# TES on Absorber

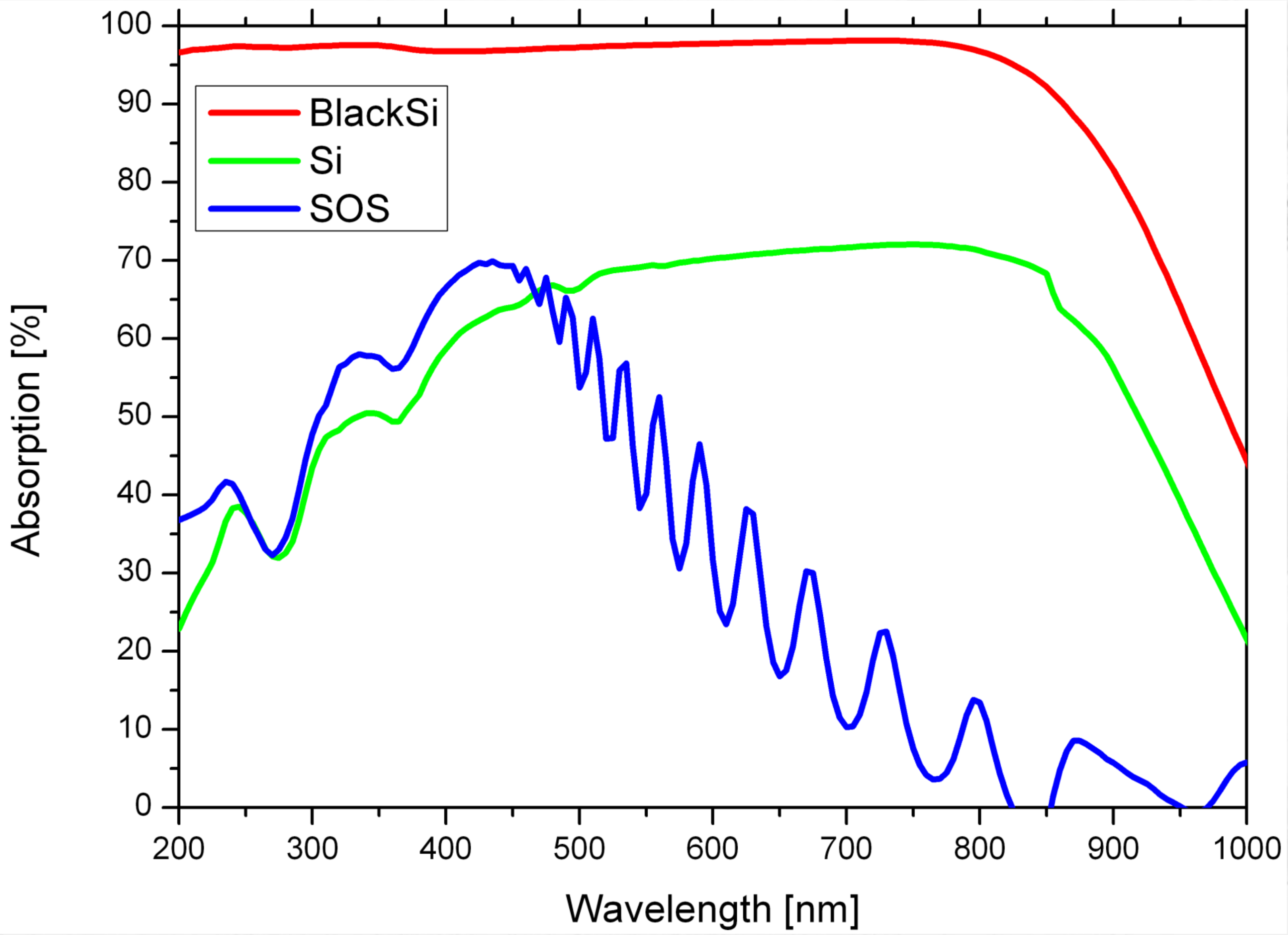


# TES on Absorber




- continuous change of the index of refraction due to the nano holes suppresses reflection

# TES on Absorber



# Summary

- Large PDE
- No dark counts
- No afterpulses
- Lower intrinsic radioactive background
- Not sensitive to overexposure
- Slow response time
- Not plug & play

  (ultra-low temperature & Thermometer)