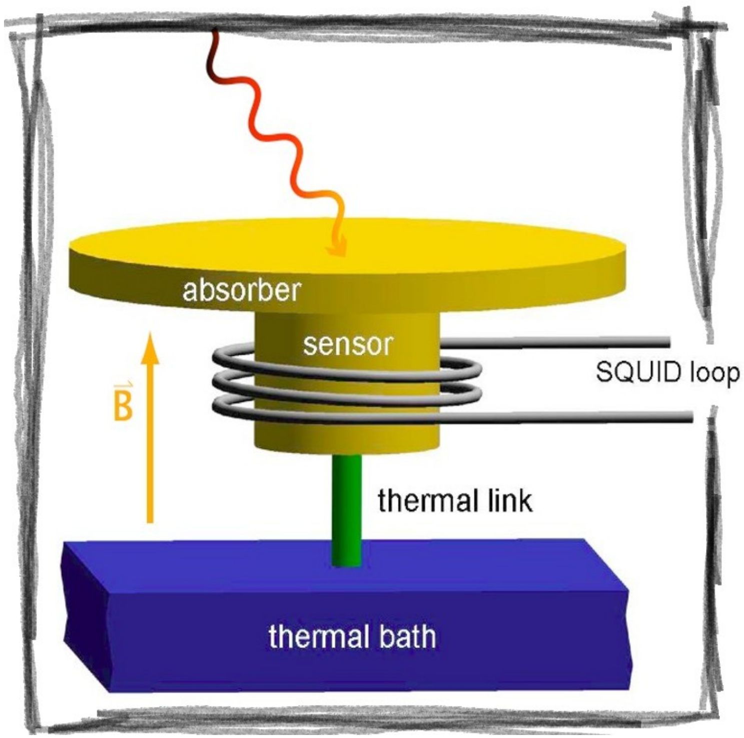
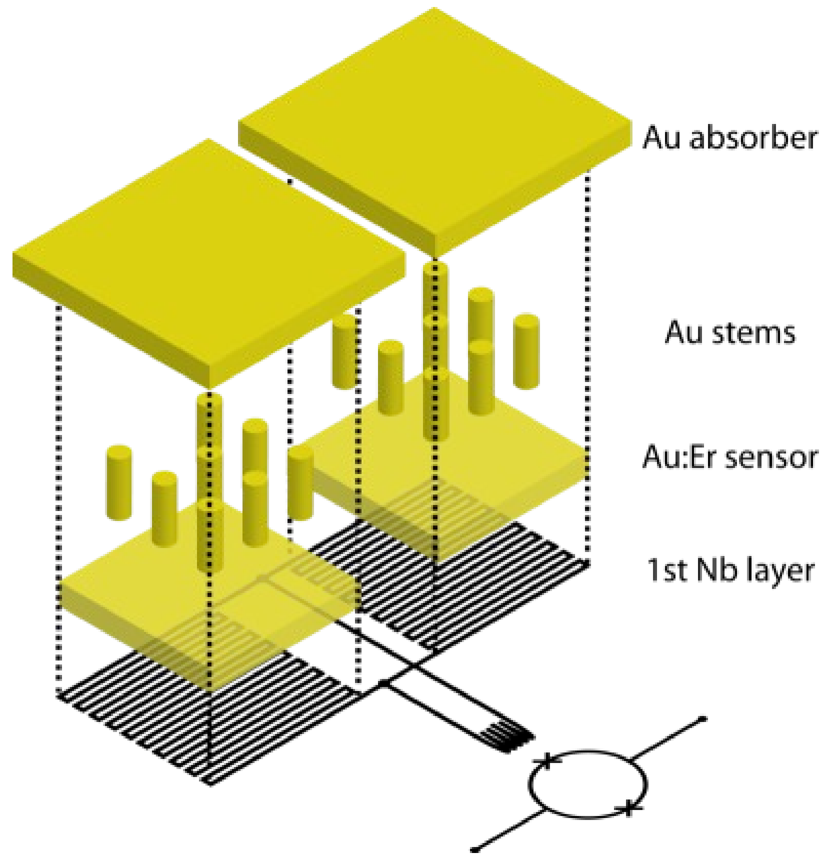
How MMCs <u>really</u> work

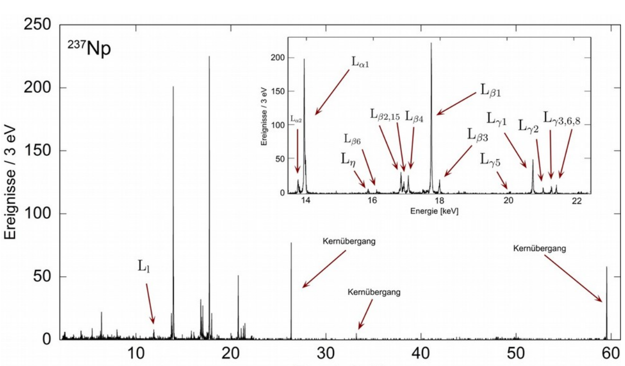
HighRR seminar
19.4.2017
D. Schulz

Metallic Magnetic Calorimeters





What for?

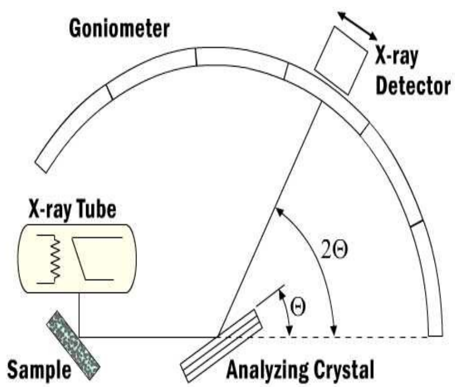


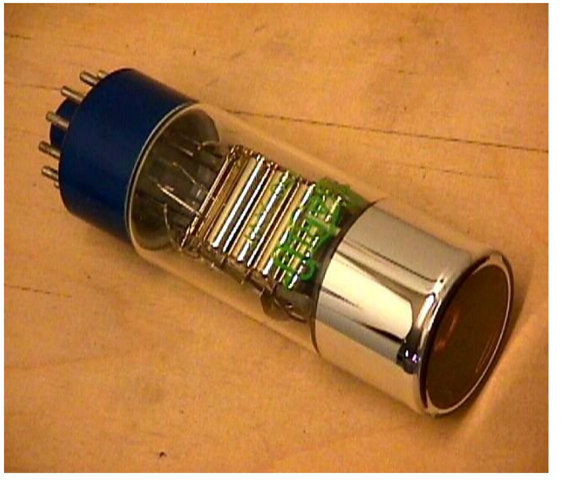
Applications for high-resolving broadband detectors:

- x-ray spectroscopy in astrophysics
- neutrino mass determination
- measuring particle spectra
- low energy massive particle detection
- ...

What for?

Crystal spectrometry vs. Ionisation Detectors





Crystal spectrometry:

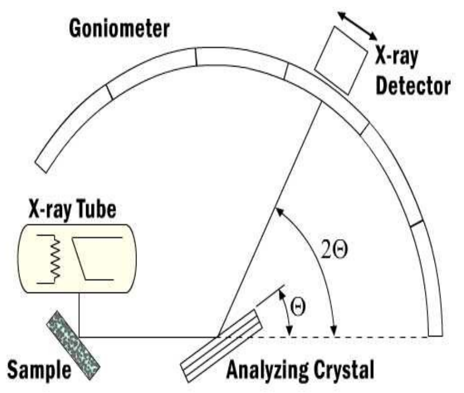
- low bandwidth
- high energy resolution

Ionisation Detectors:

- high bandwidth
- low energy resolution

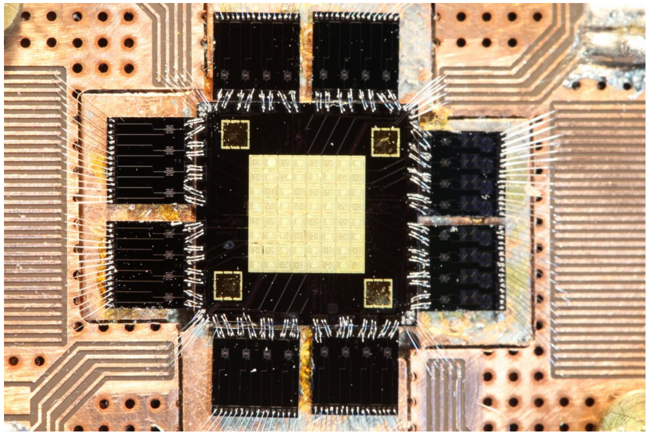
What for?

Crystal spectrometry

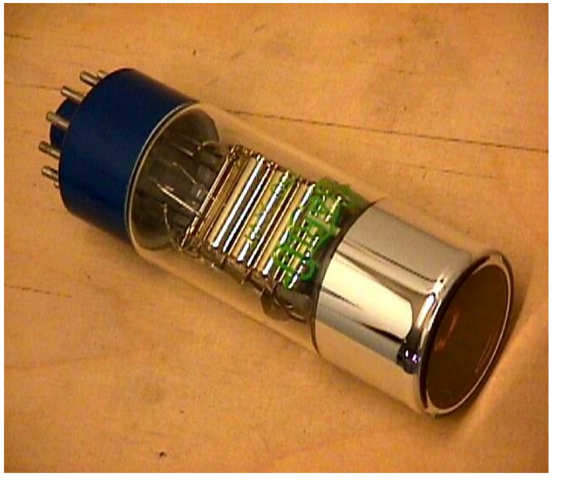


- low bandwidth
- high energy resolution

Low-T Calorimetry

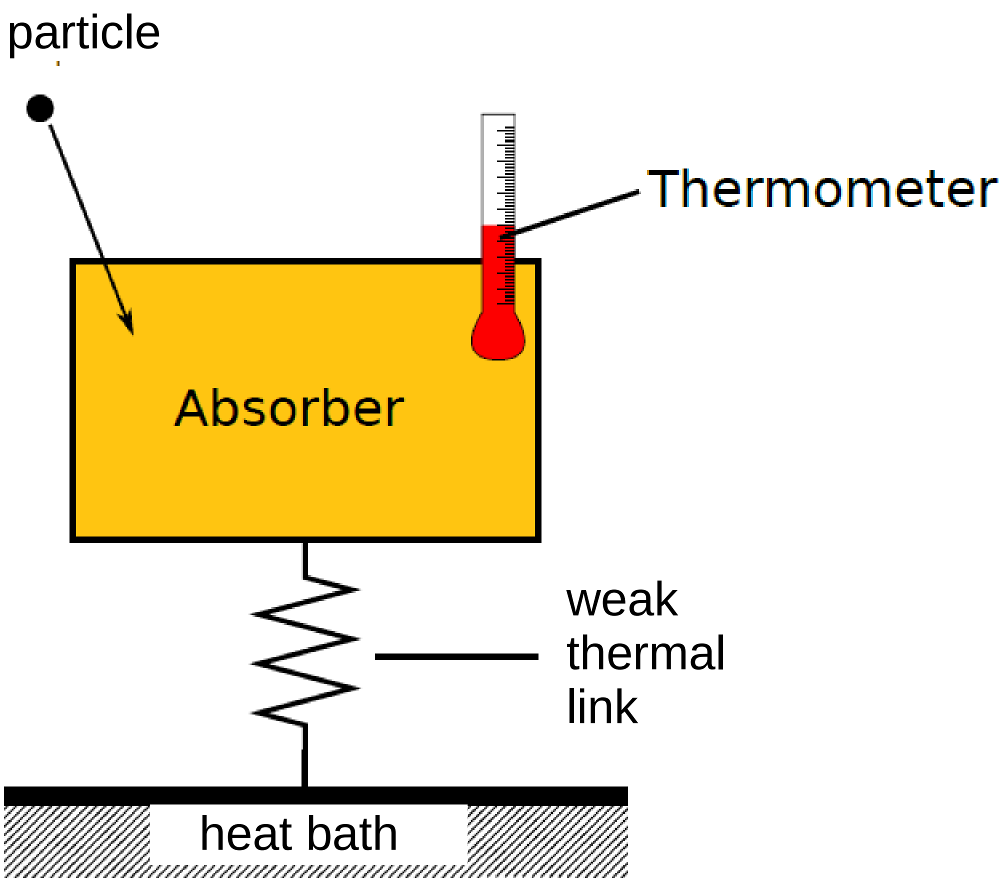


Ionisation Detectors

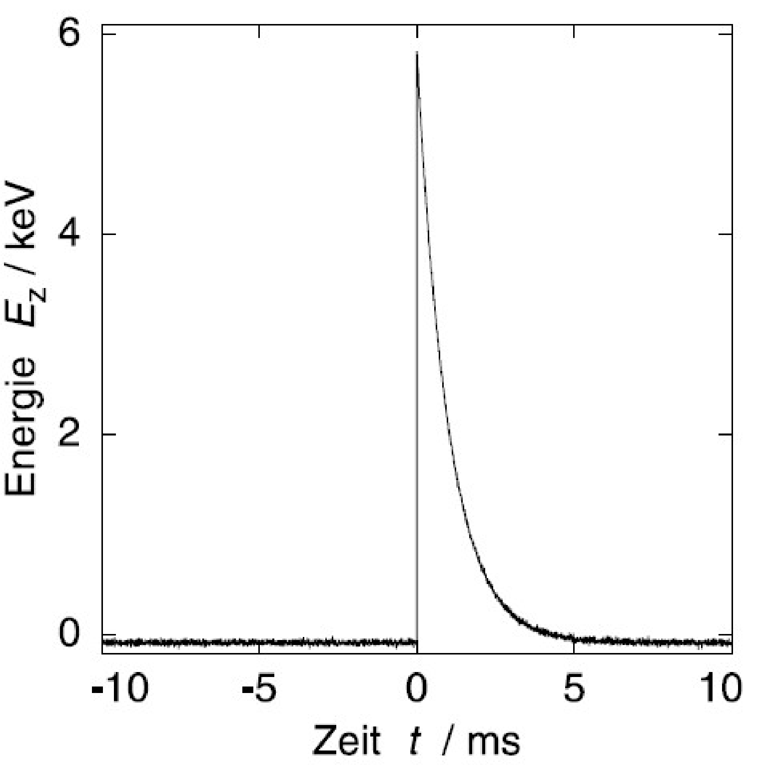


- high bandwidth
- low energy resolution

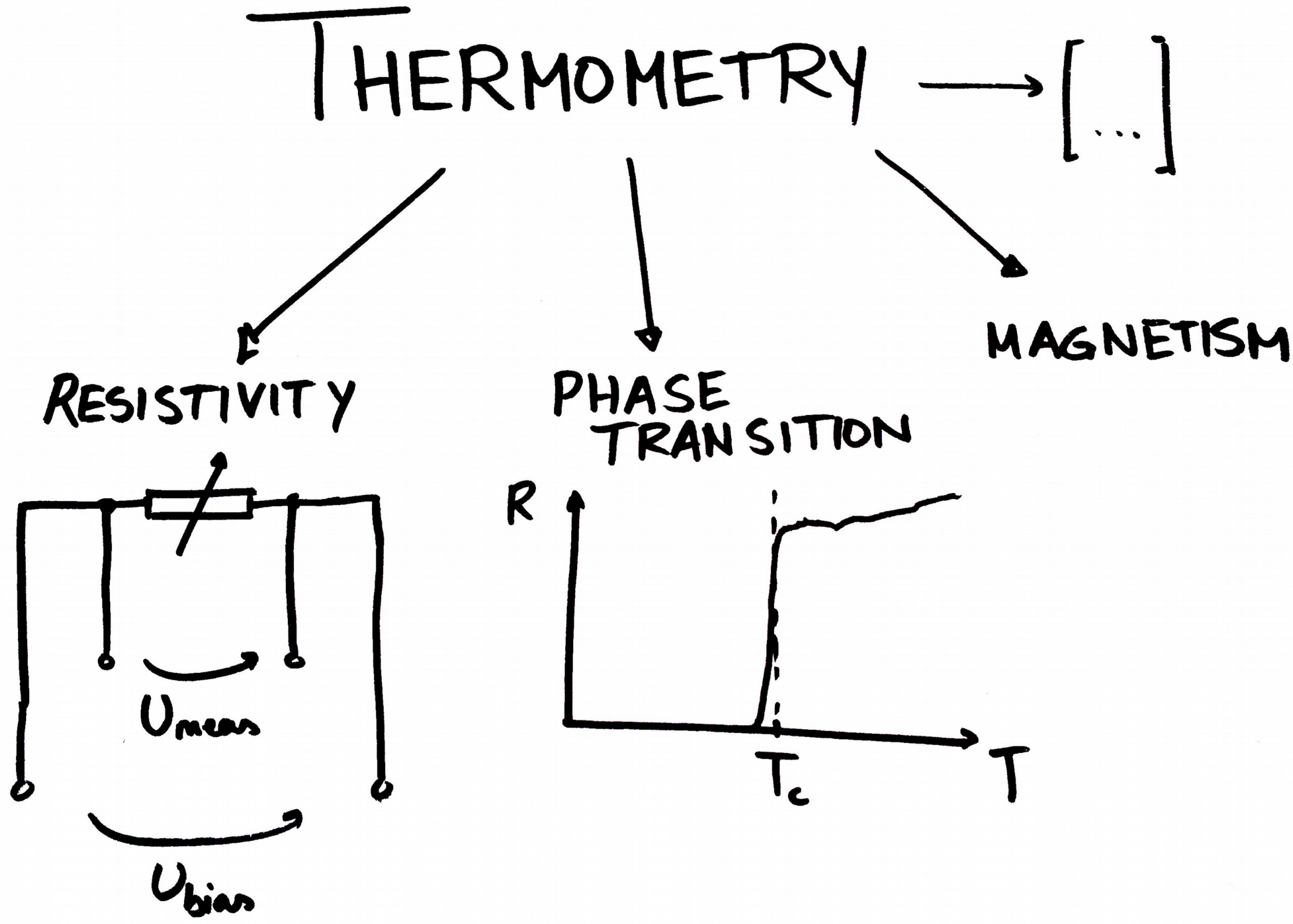
Low temperature detectors



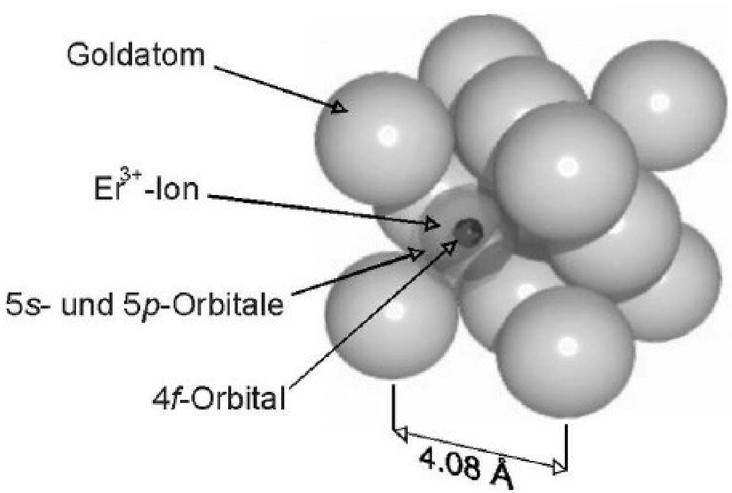
$$\delta T \simeq \frac{\delta E}{C_{\mathrm{tot}}}$$



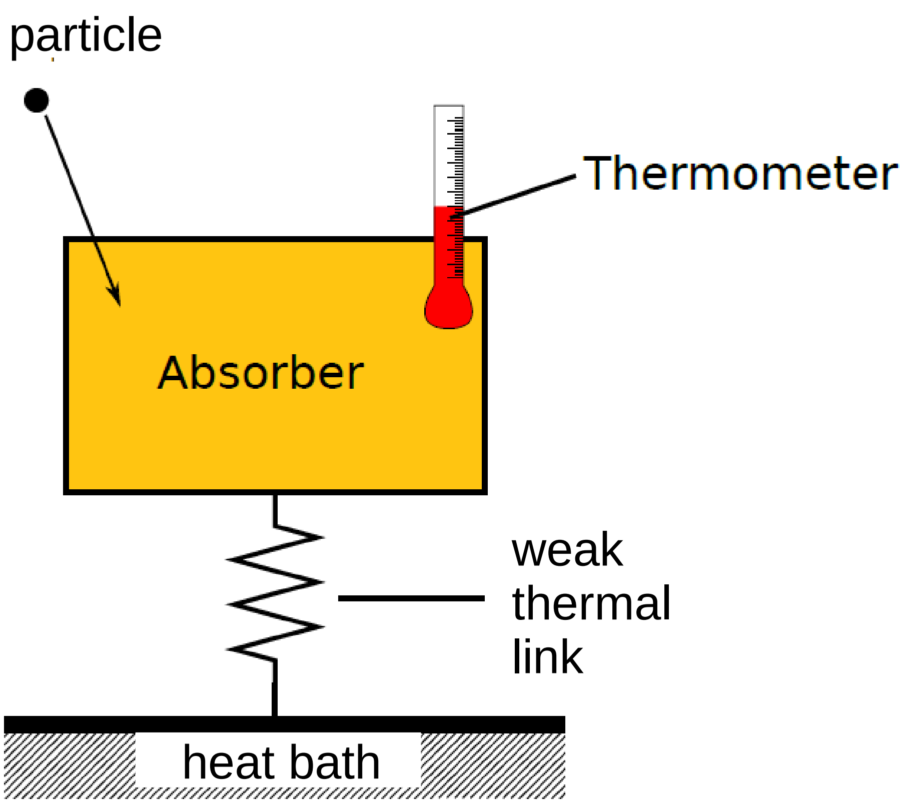
Thermometry at mK

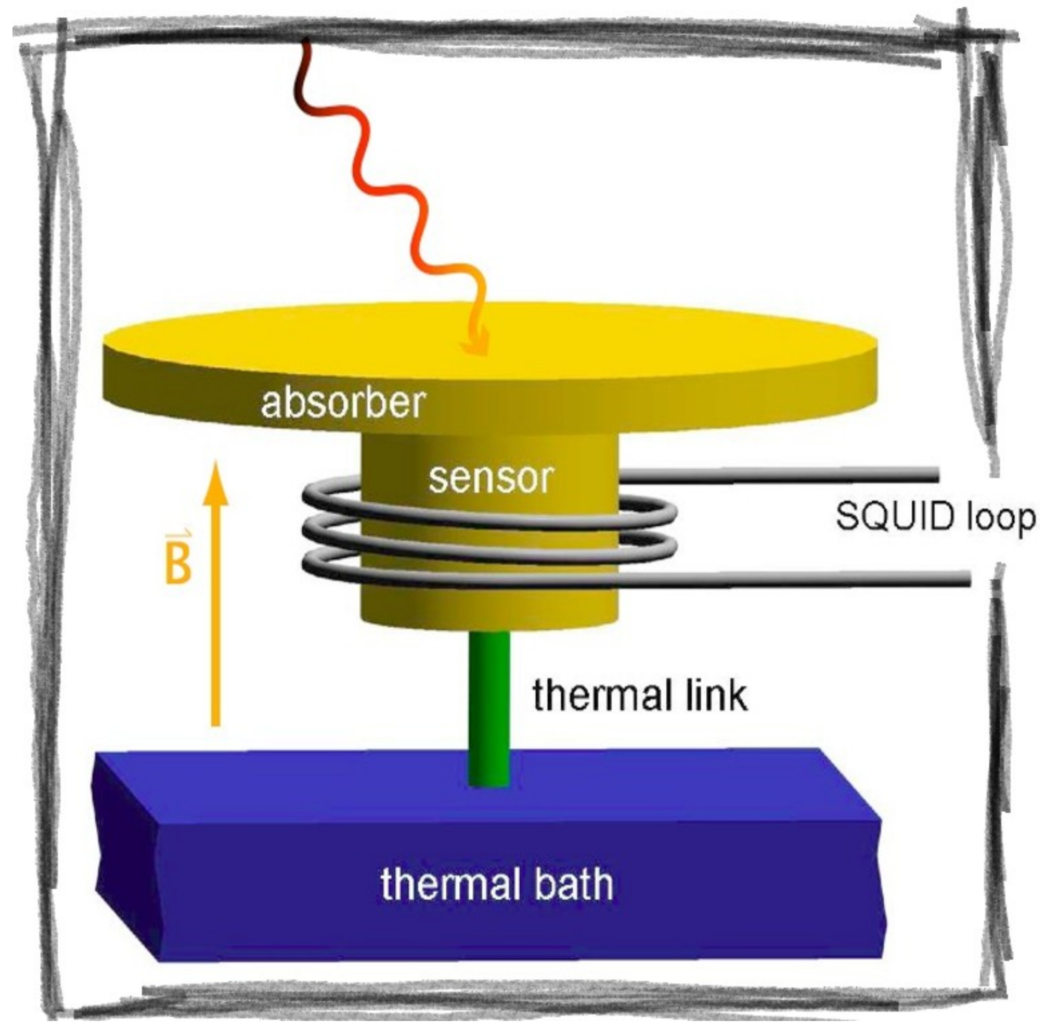


Magnetism as a thermometer



Metallic Magnetic Calorimeters





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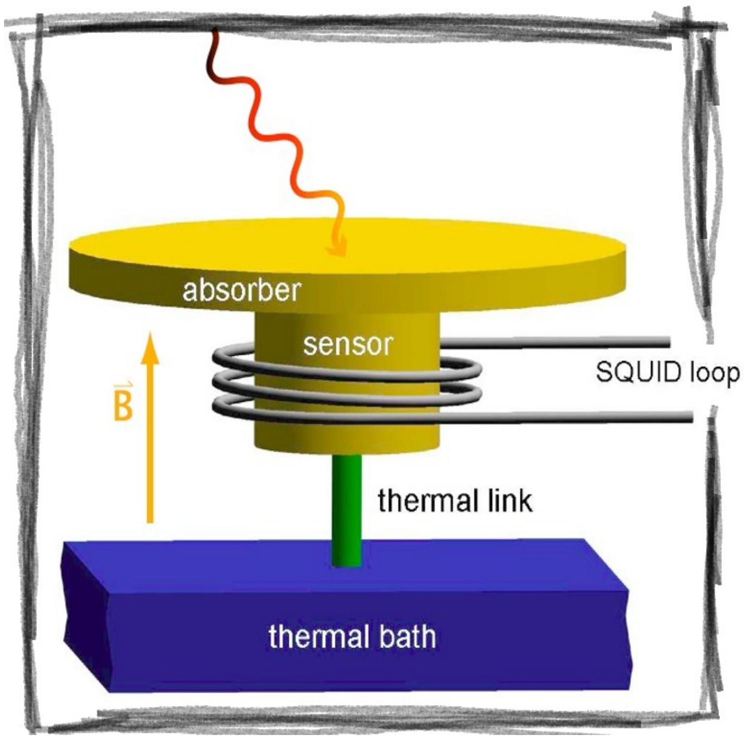
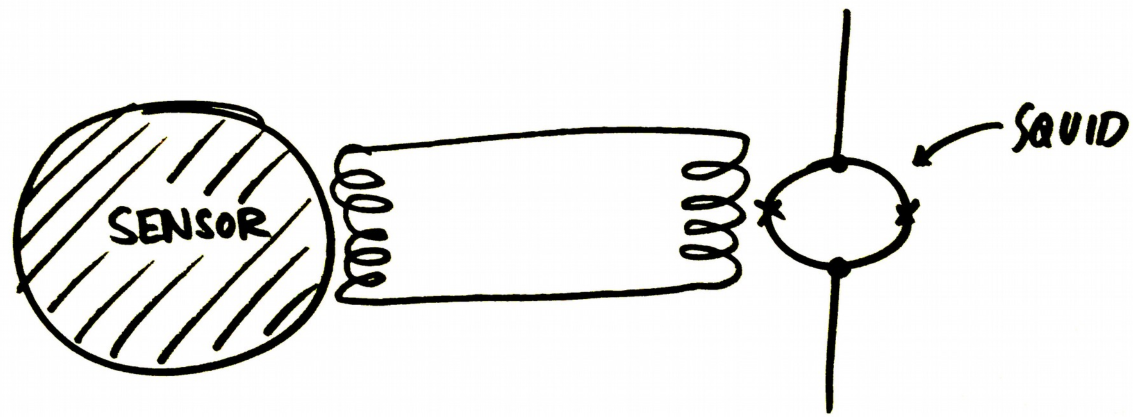
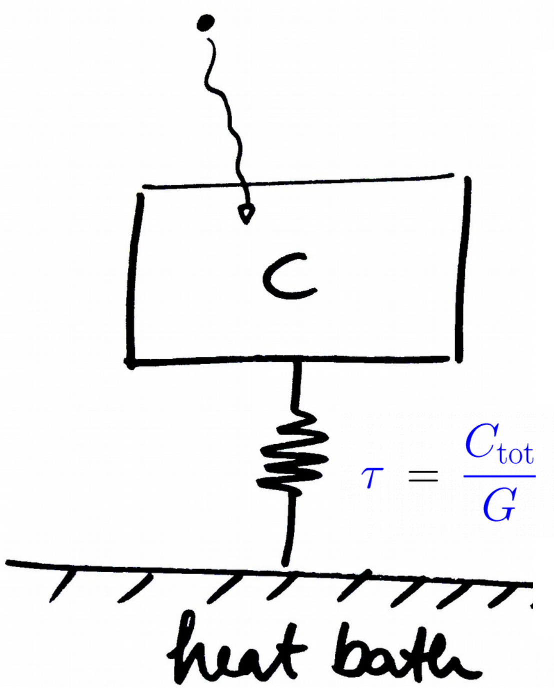
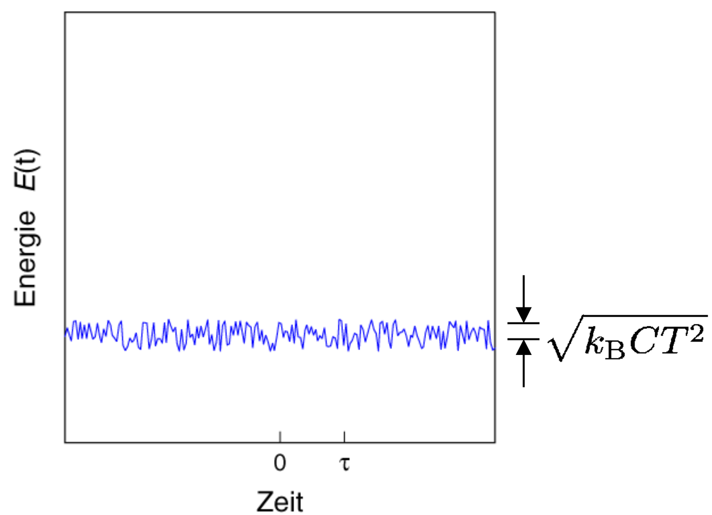




Energy resolution – ideal calorimeter





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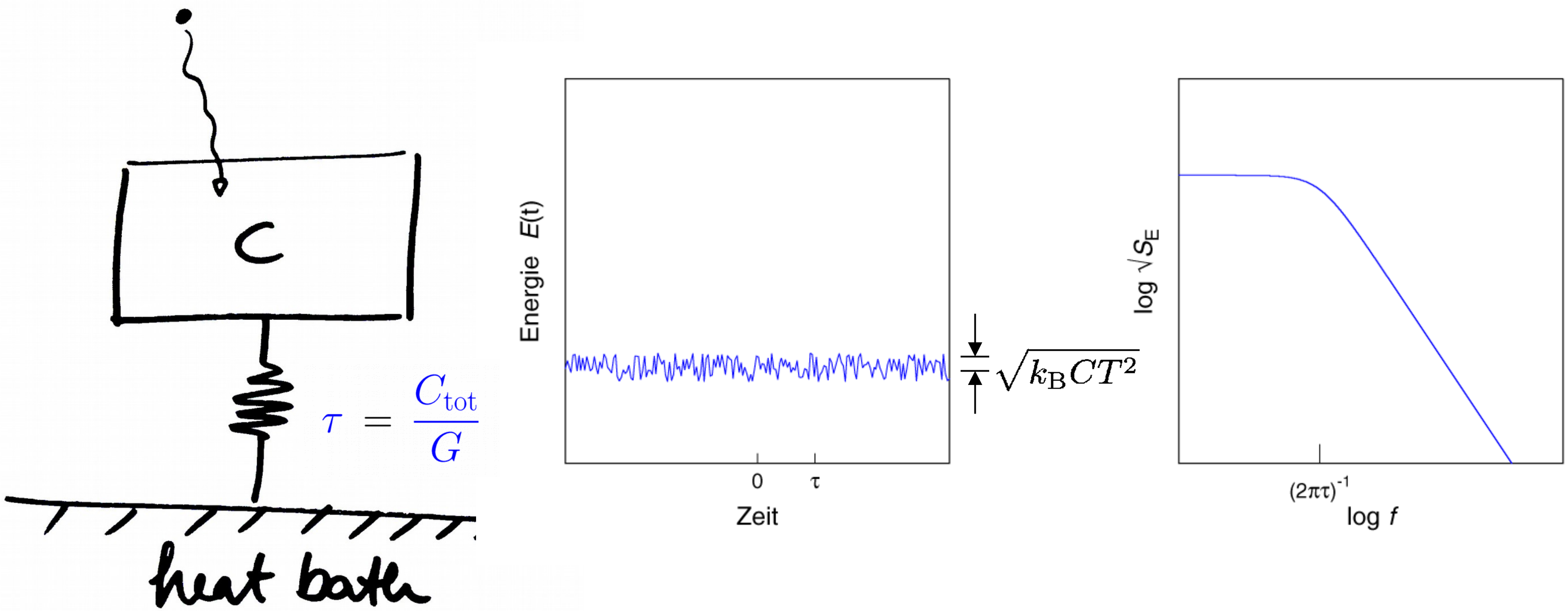

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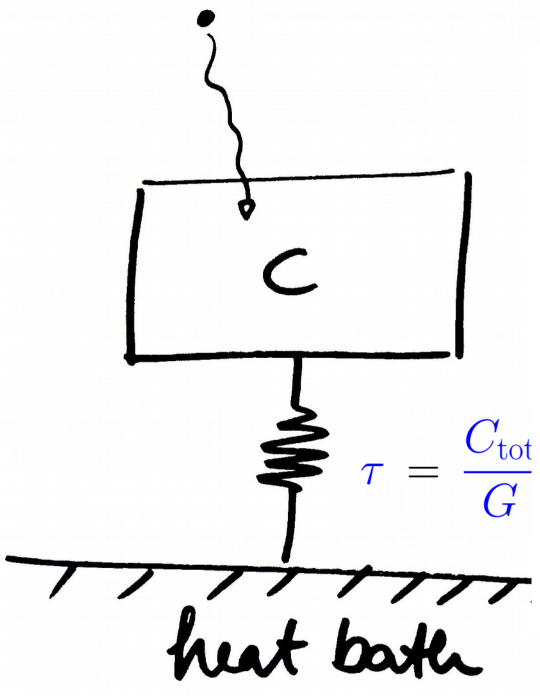
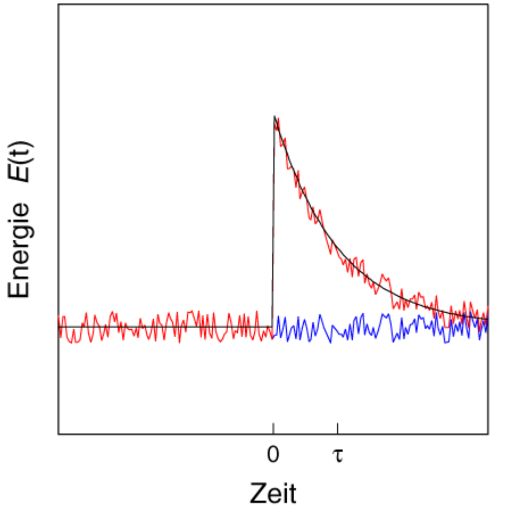
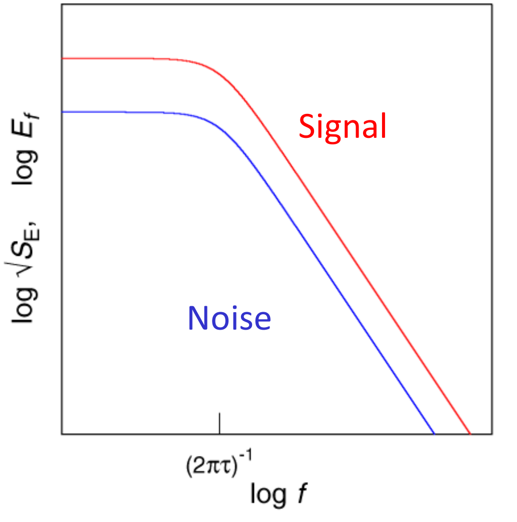
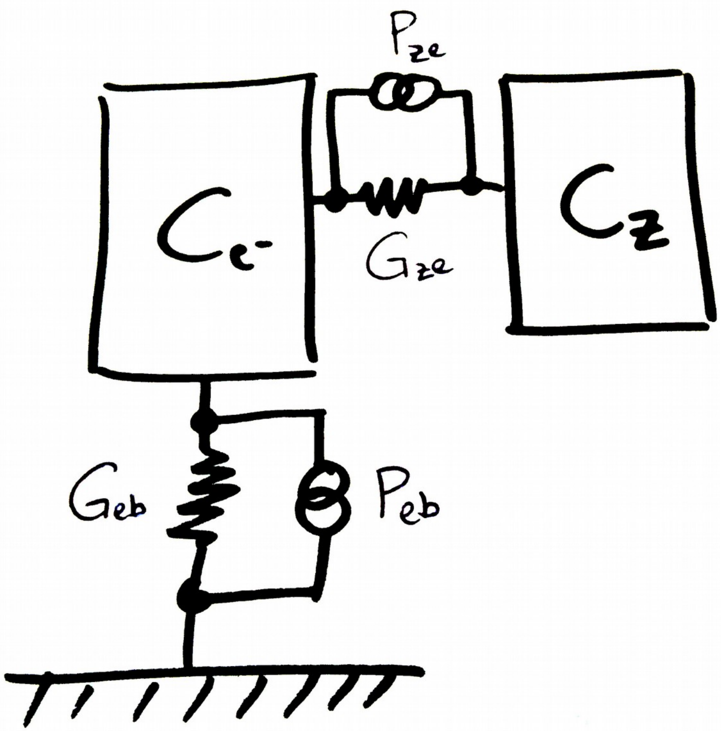


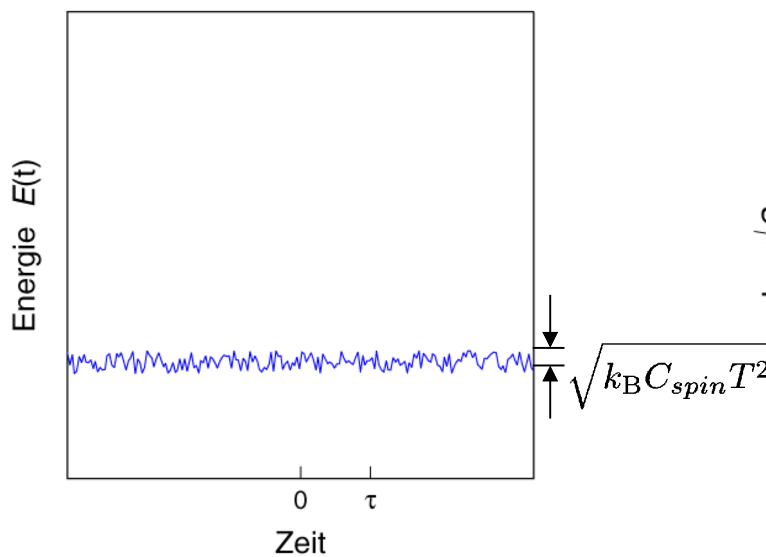


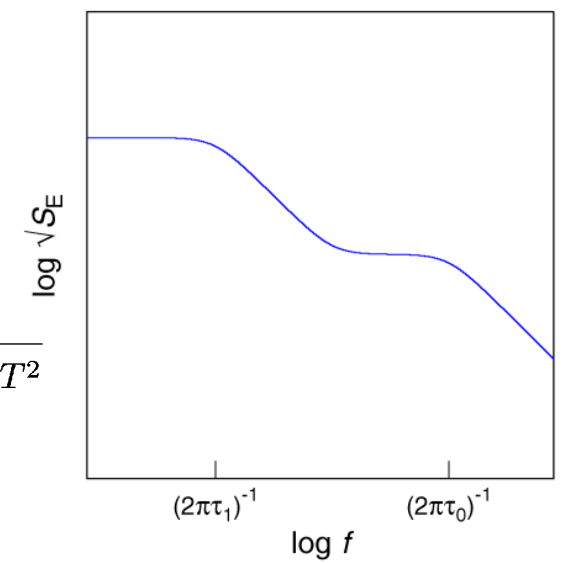


Energy resolution – subsystems

- absorber and thermometer are seperate systems
- thermalization in absorber is fast (t < 100ns)
- relaxation time absorber – thermometer finite







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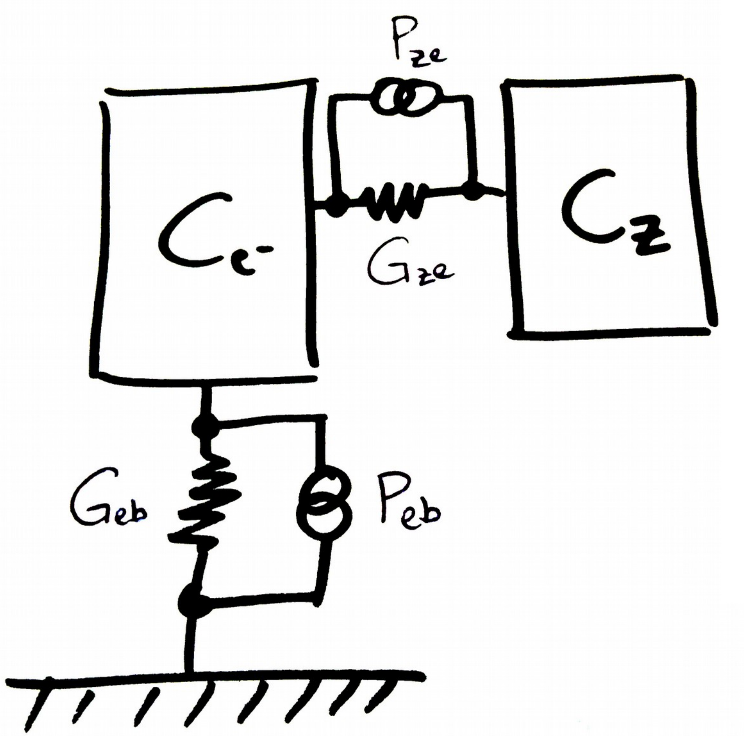

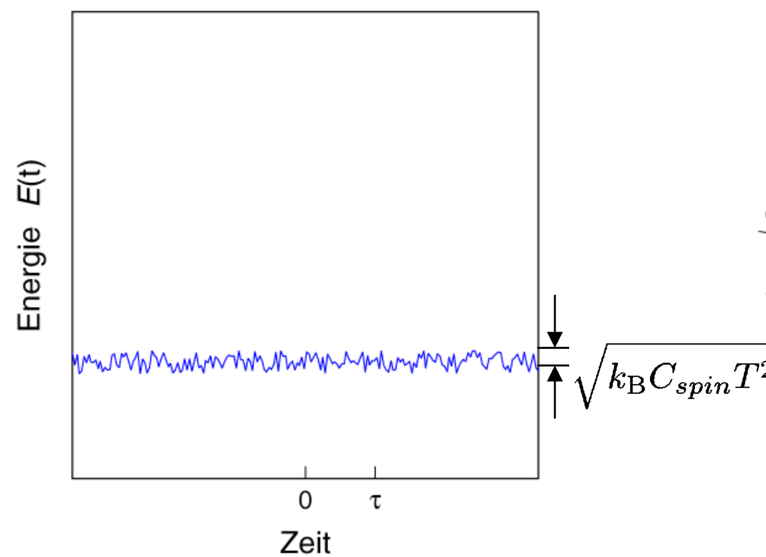

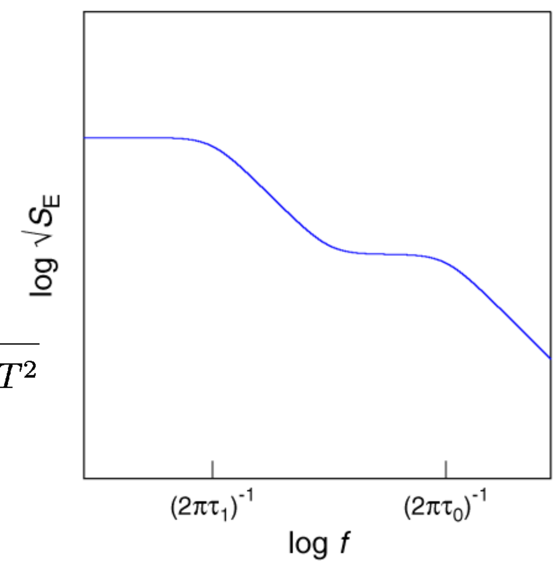

$$S_{\mathrm{Pze}}(f) = 4k_{\mathrm{B}}T^2G_{\mathrm{ze}}$$
$$S_{\mathrm{Peb}}(f) = 4k_{\mathrm{B}}T^2G_{\mathrm{eb}}$$

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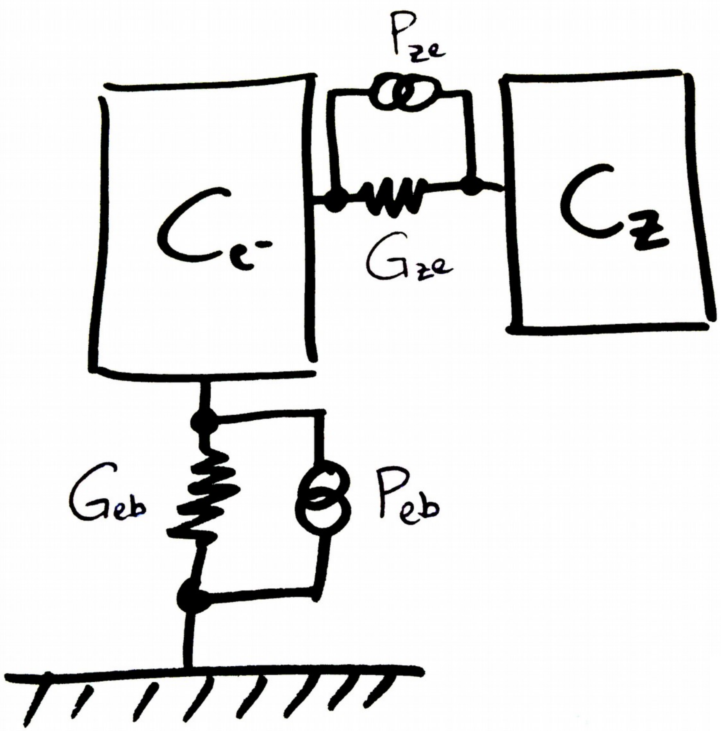

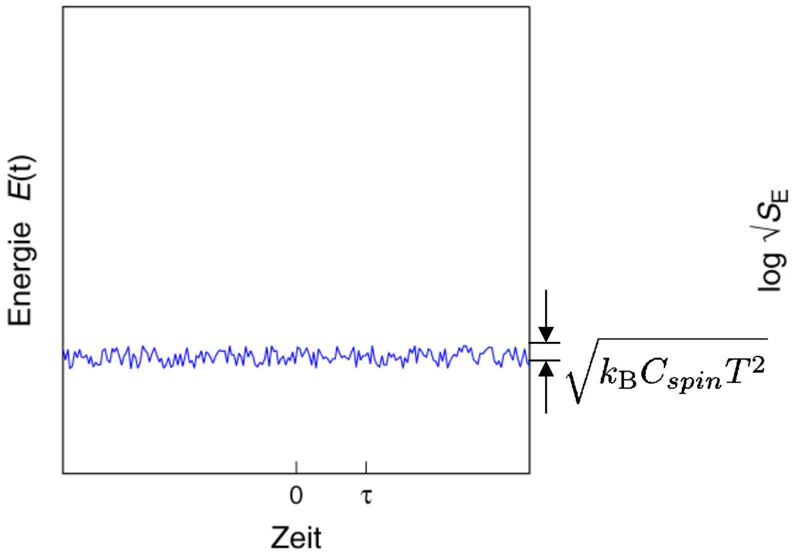

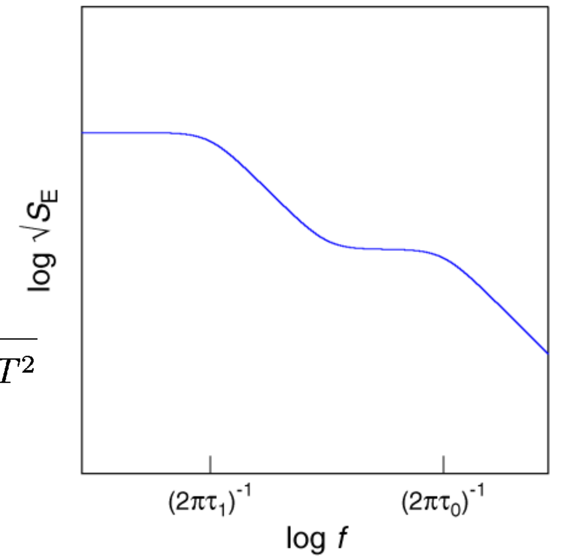

$$C_z \dot{T}_z = -(T_z - T_e) G_{ze} + P_{ze}(t)$$

$$C_e \dot{T}_e = -(T_e - T_z) G_{ze} - (T_e - T) G_{eb} - P_{ze}(t) - P_{eb}(t) + \dot{Q}(t)$$

Energy resolution – subsystems

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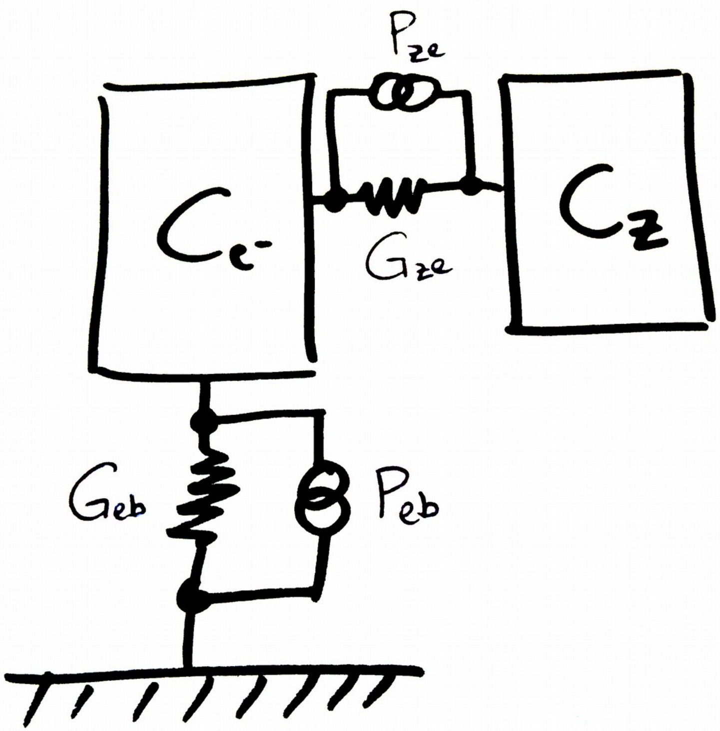

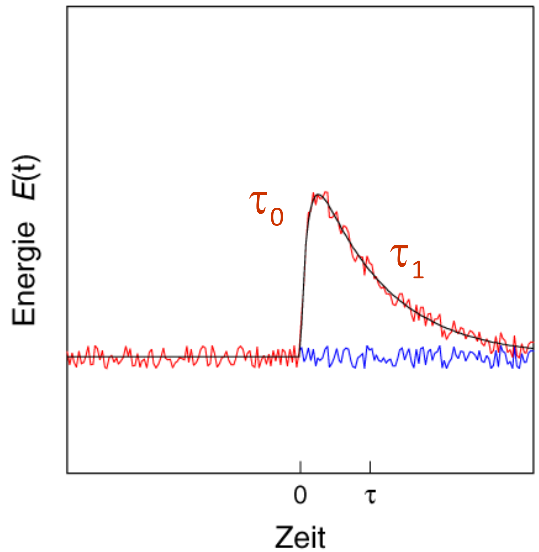

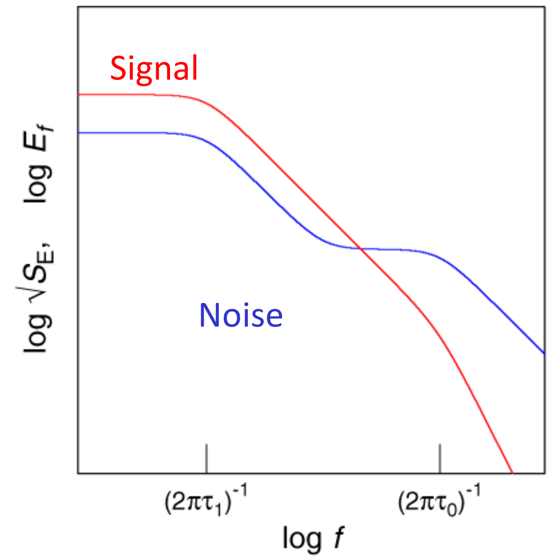

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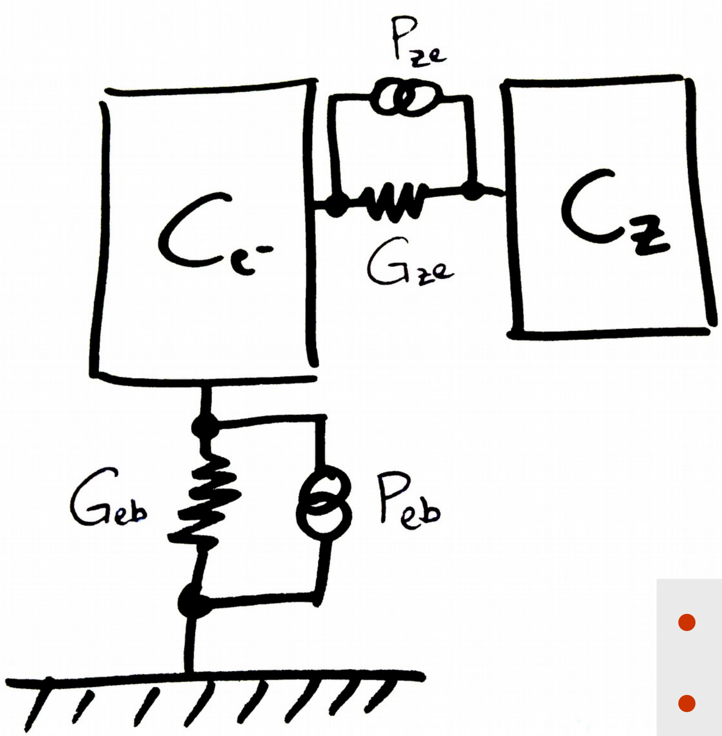
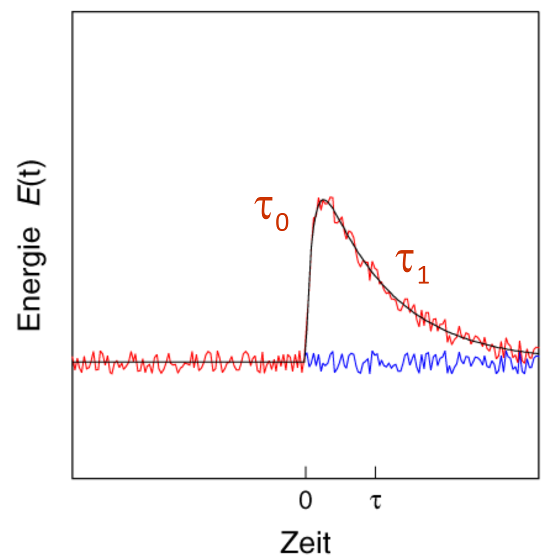
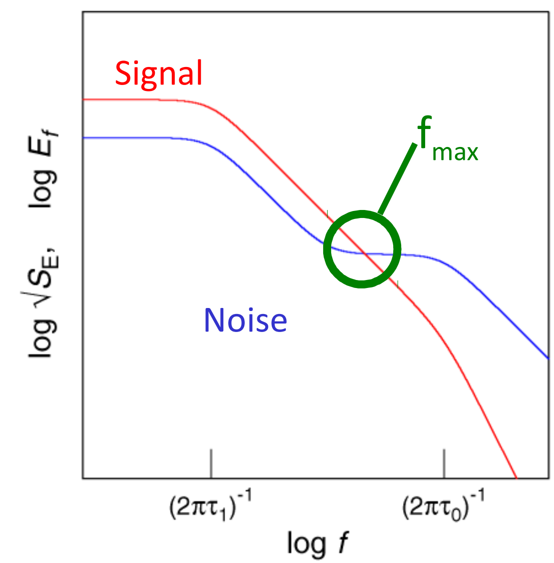






- Signal-to-noise is not constant!
- Optimum bandwidth f_{max} is finite

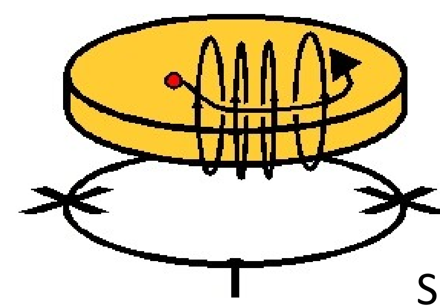
$$\Delta E_{\mathrm{FWHM}} \simeq 2{,}36\sqrt{4k_{\mathrm{B}}C_{\mathrm{Abs}}T^2}\sqrt{2}\left(\frac{\tau_0}{\tau_1}\right)^{1/4}$$

Magnetic Johnson Noise

fluctuations of energy between sub-systems

$$\Delta E_{\mathrm{FWHM}} \simeq 2{,}36\sqrt{4k_{\mathrm{B}}C_{\mathrm{Abs}}T^2}\sqrt{2}\left(\frac{\tau_0}{\tau_1}\right)^{1/4}$$

flux noise of SQUID-magnetometer



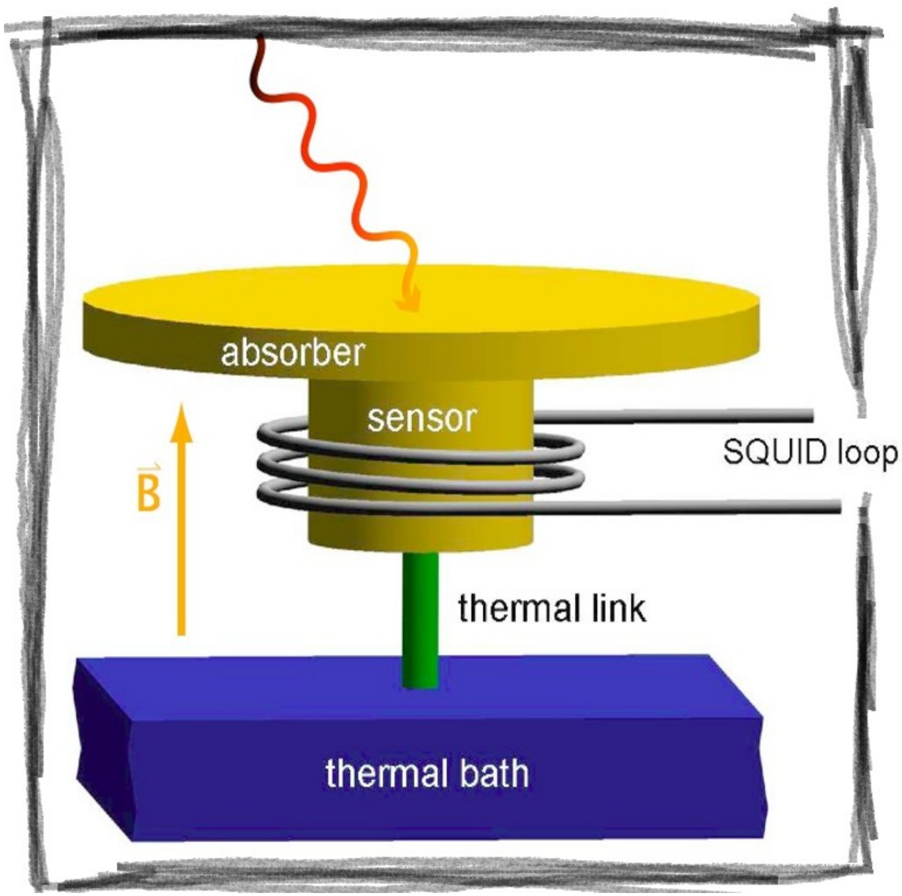
magnetic Johnson noise

- thermal currents in the metallic components
- marginal in all present detectors

excess noise

- $S_\Phi \sim N_{Er}$
- $S_\Phi \sim 1/f$
- temperature independent (20mK – 4K)

Metallic Magnetic Calorimeters



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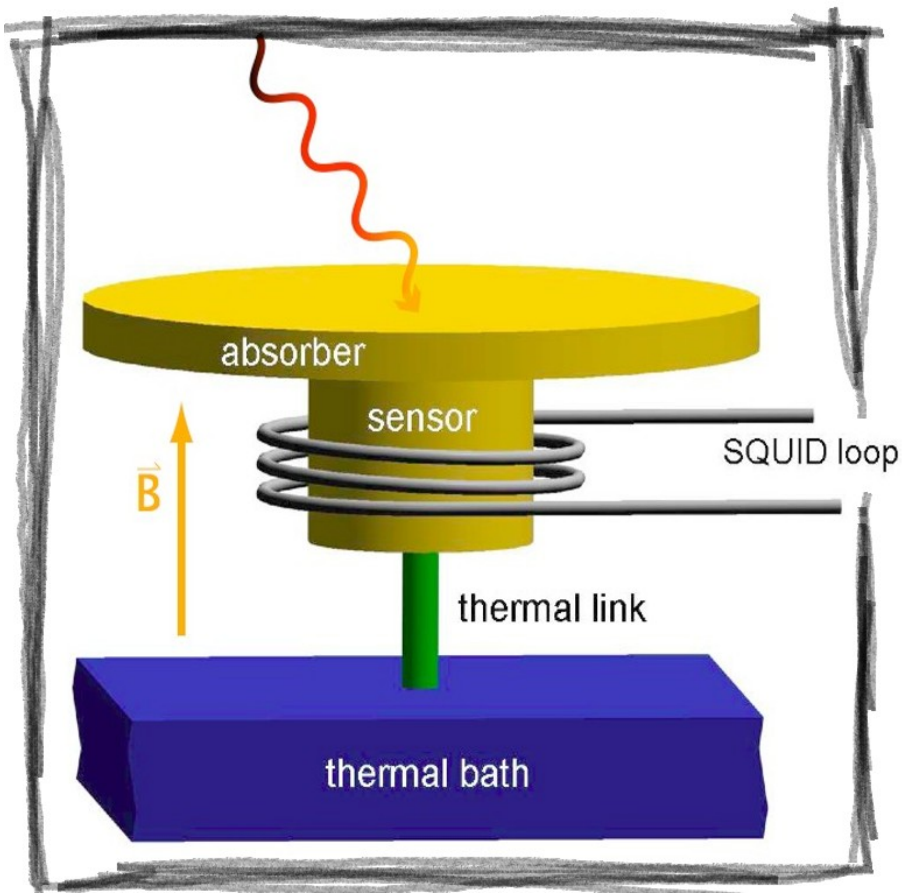

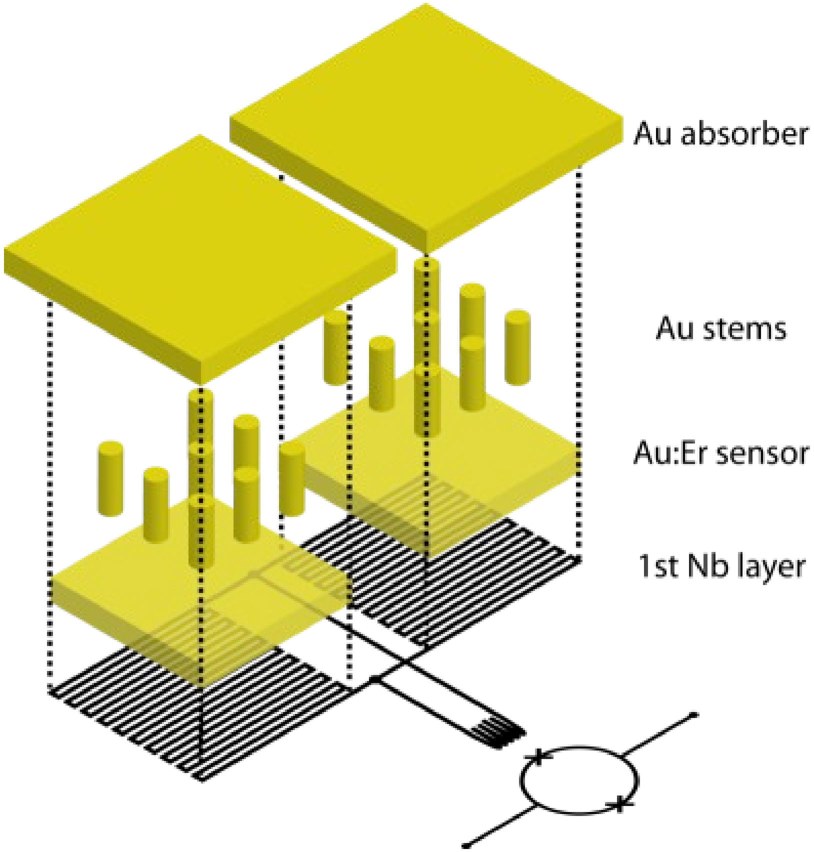

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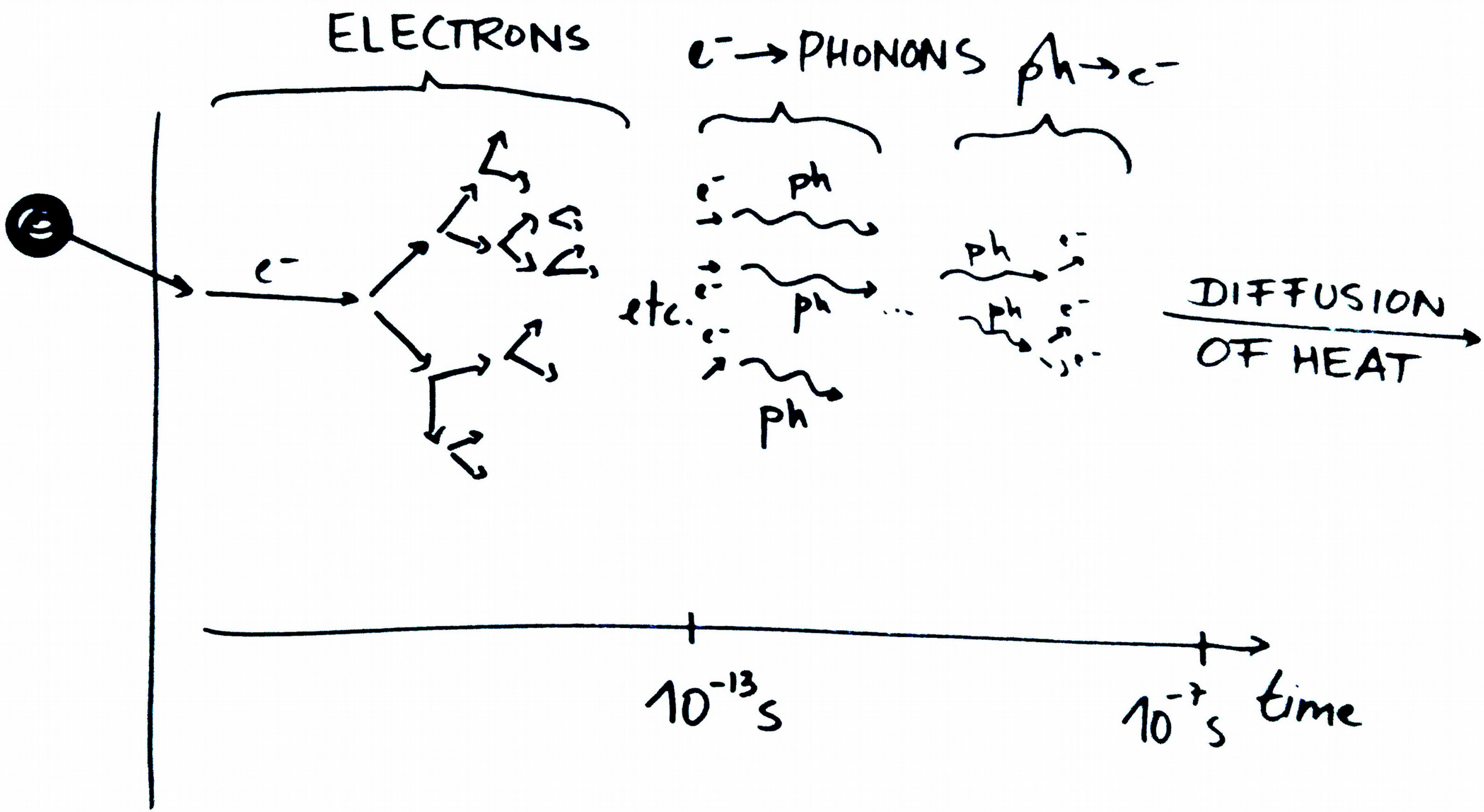

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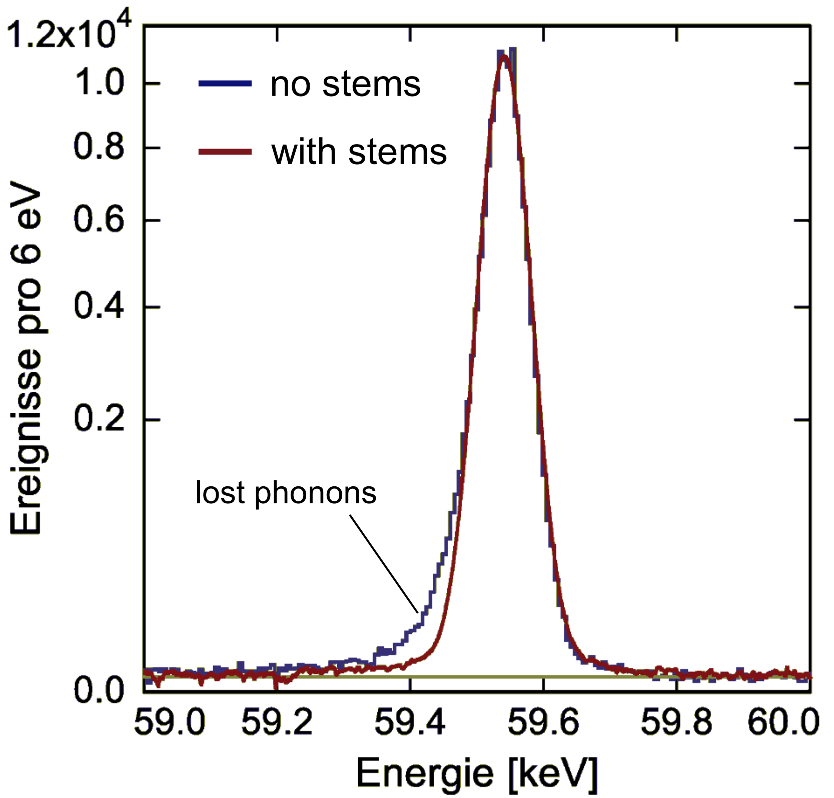
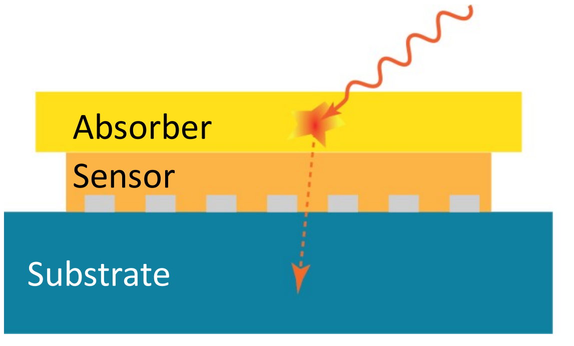
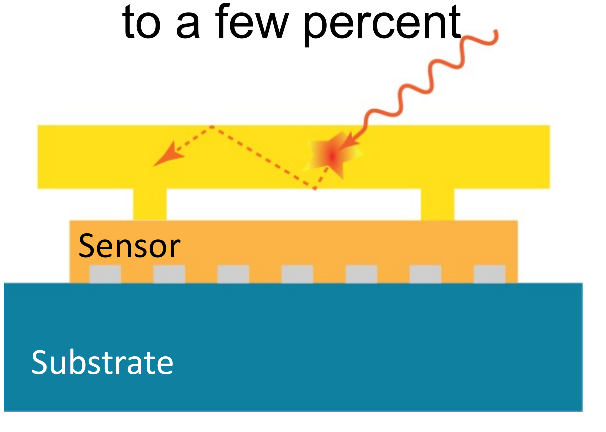


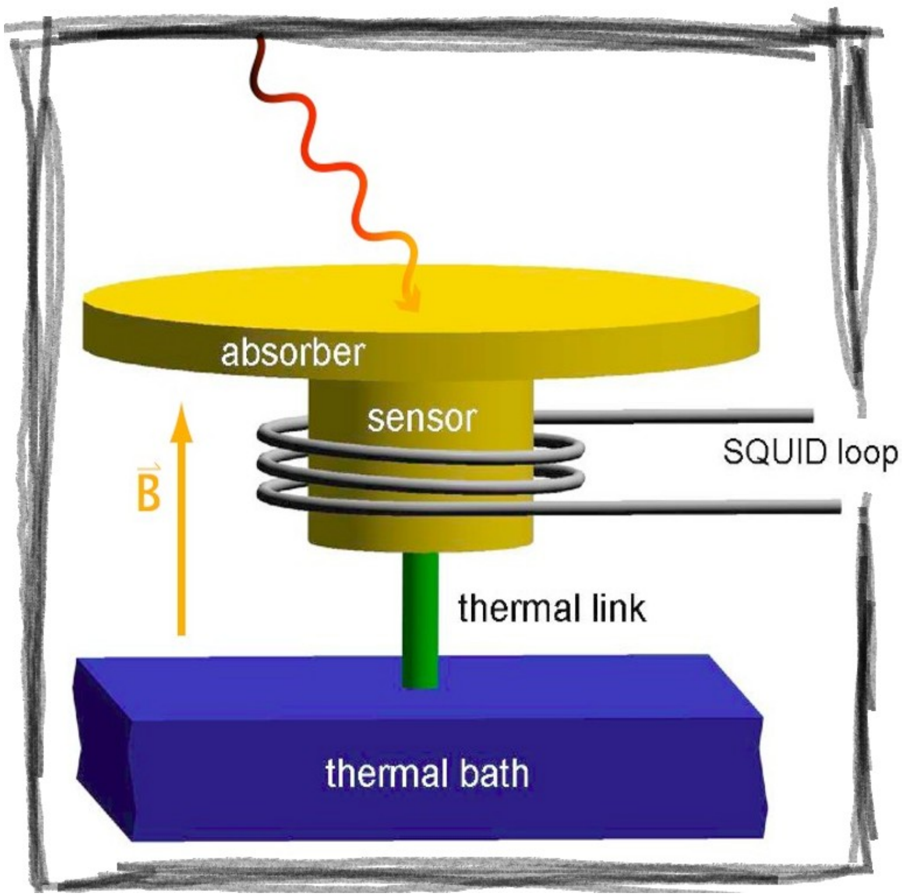
Energy of athermal phonons may be lost to substrate

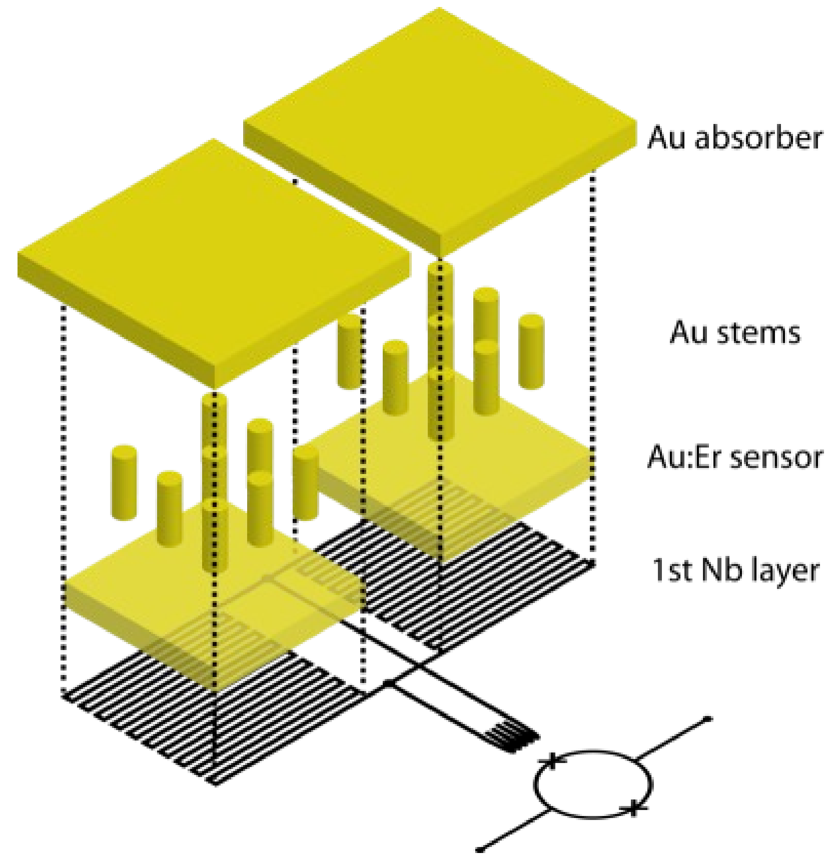


Stems reduce contact area to a few percent



Metallic Magnetic Calorimeters





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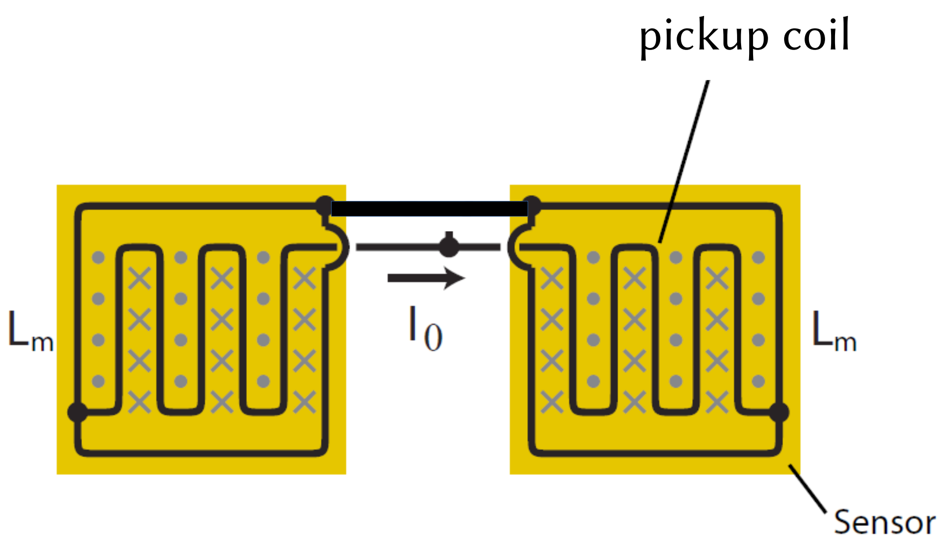

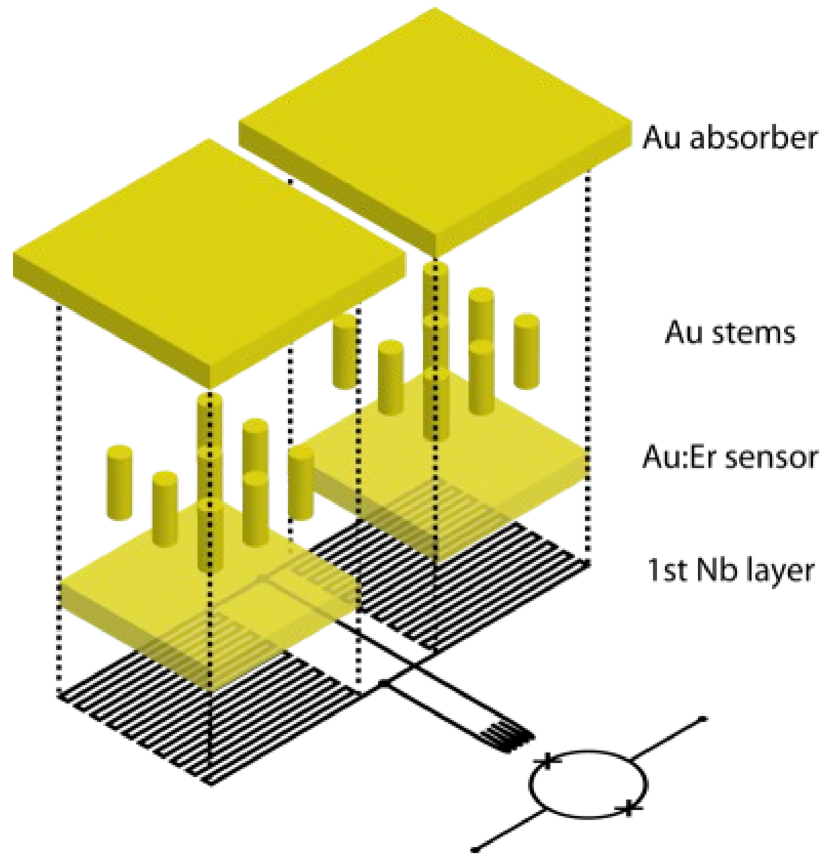

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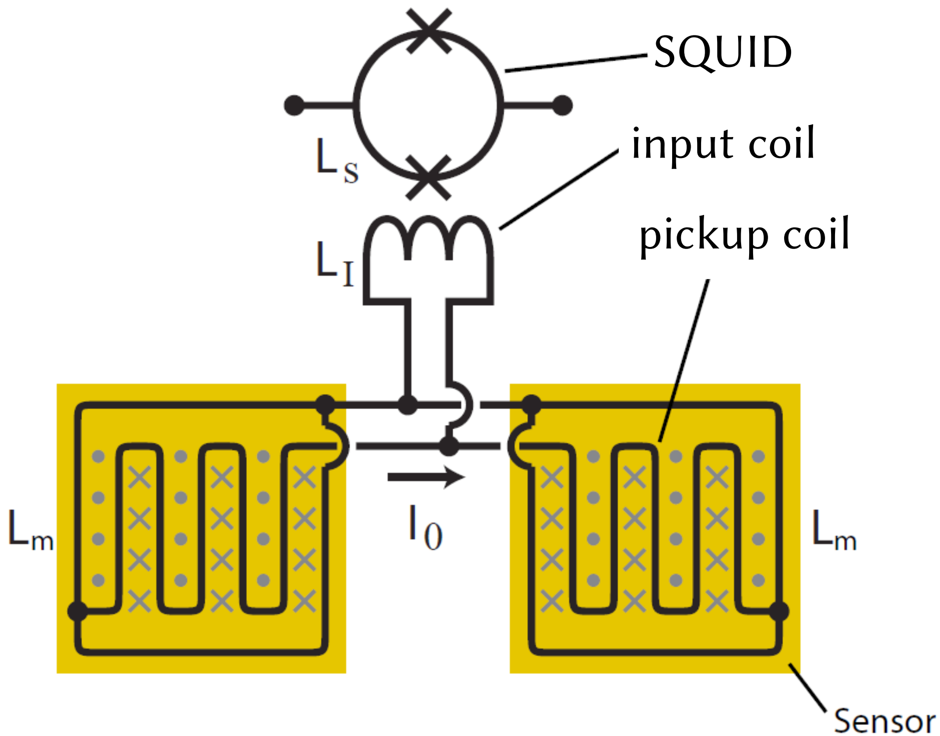

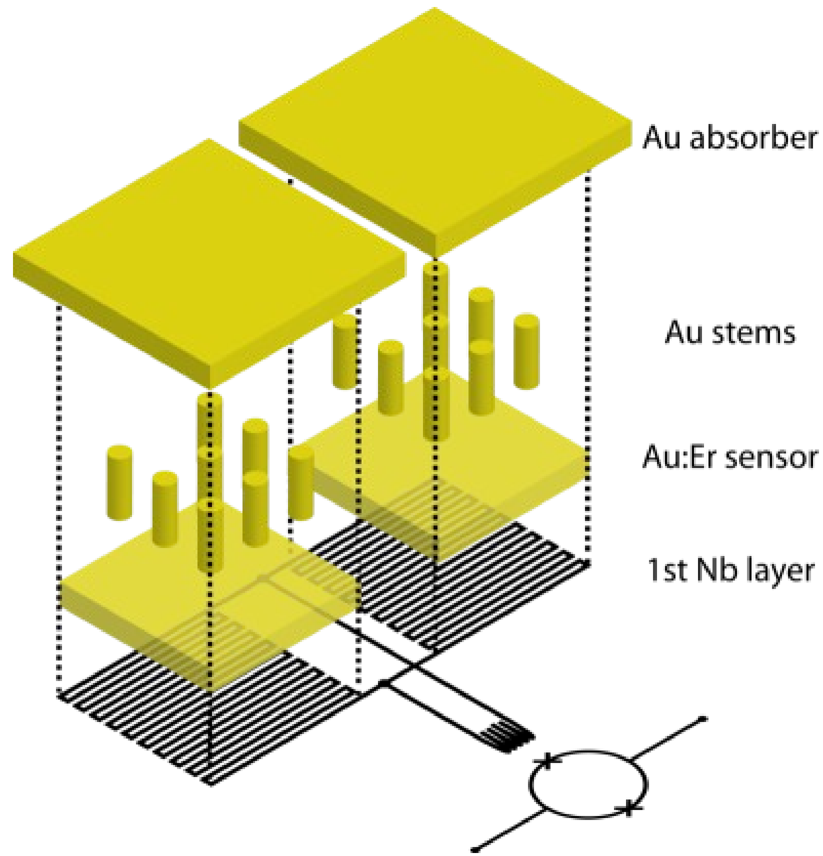

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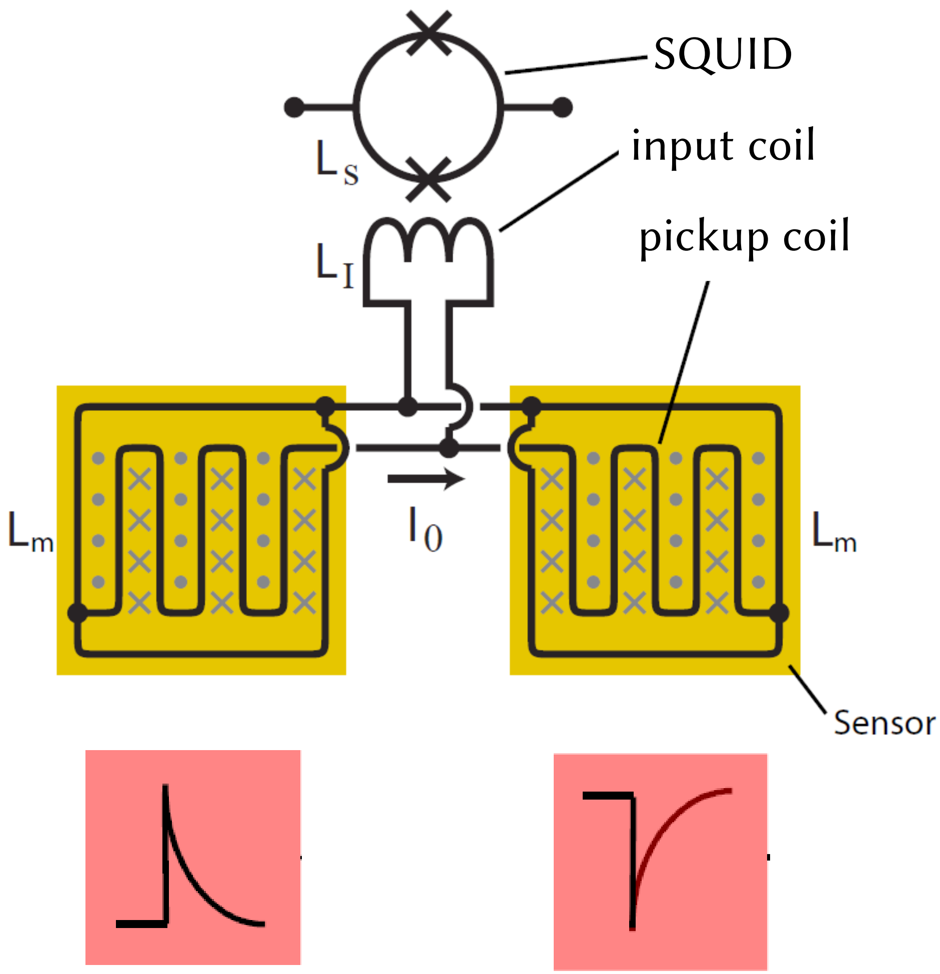

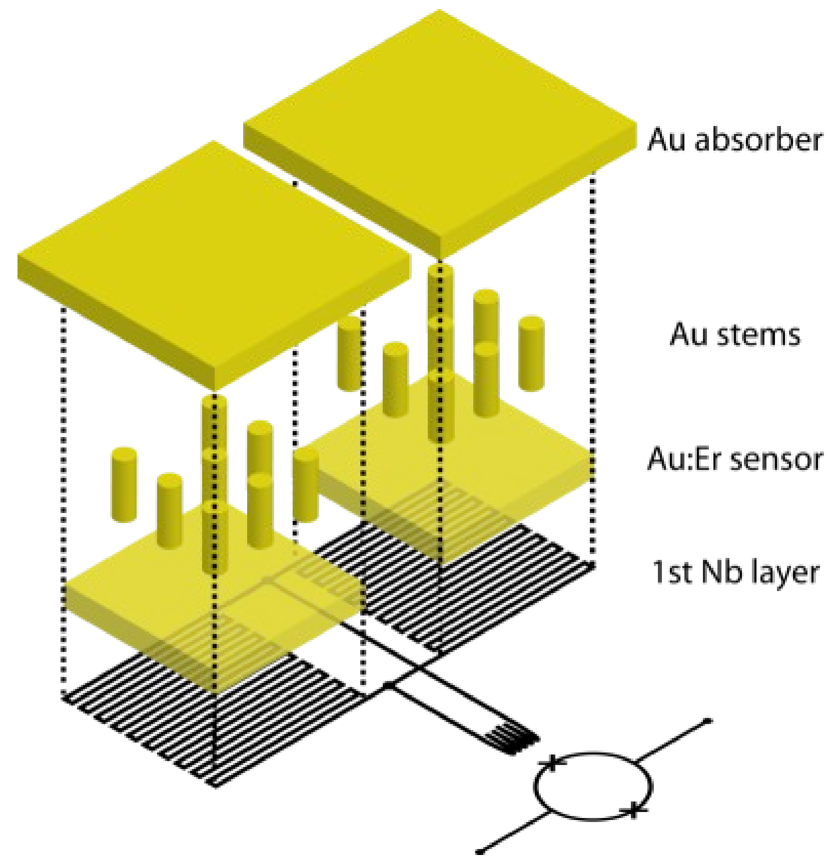

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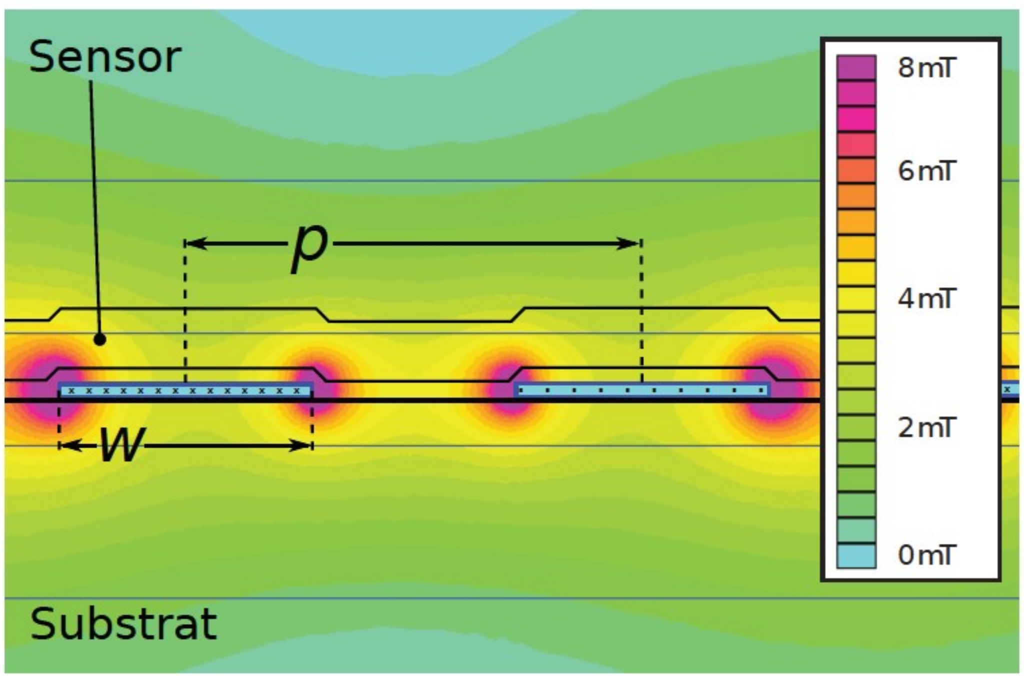
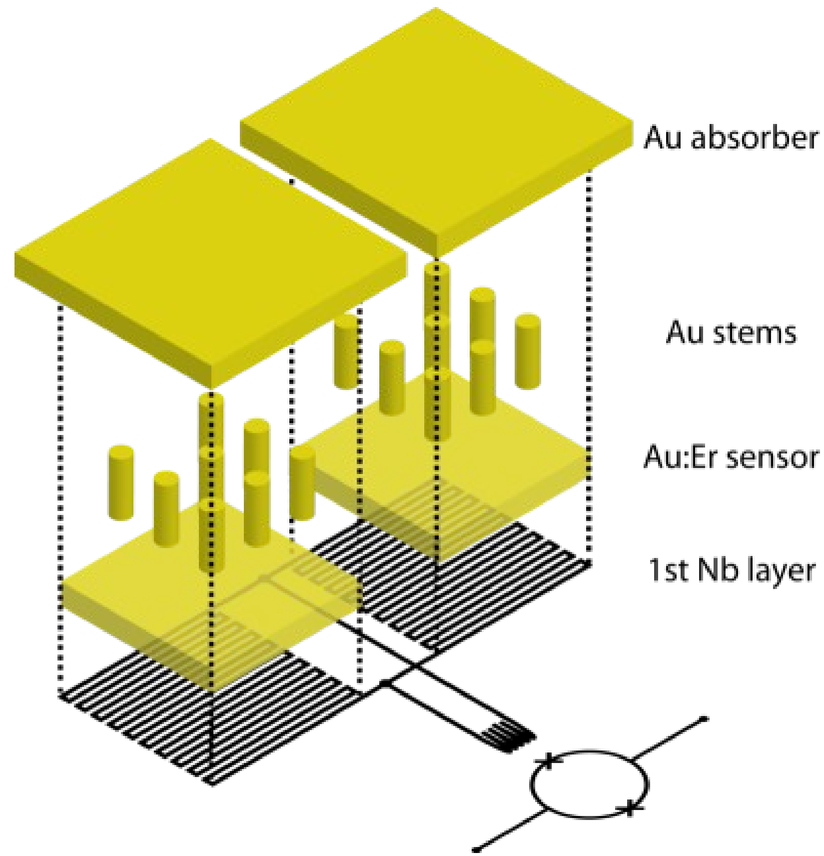
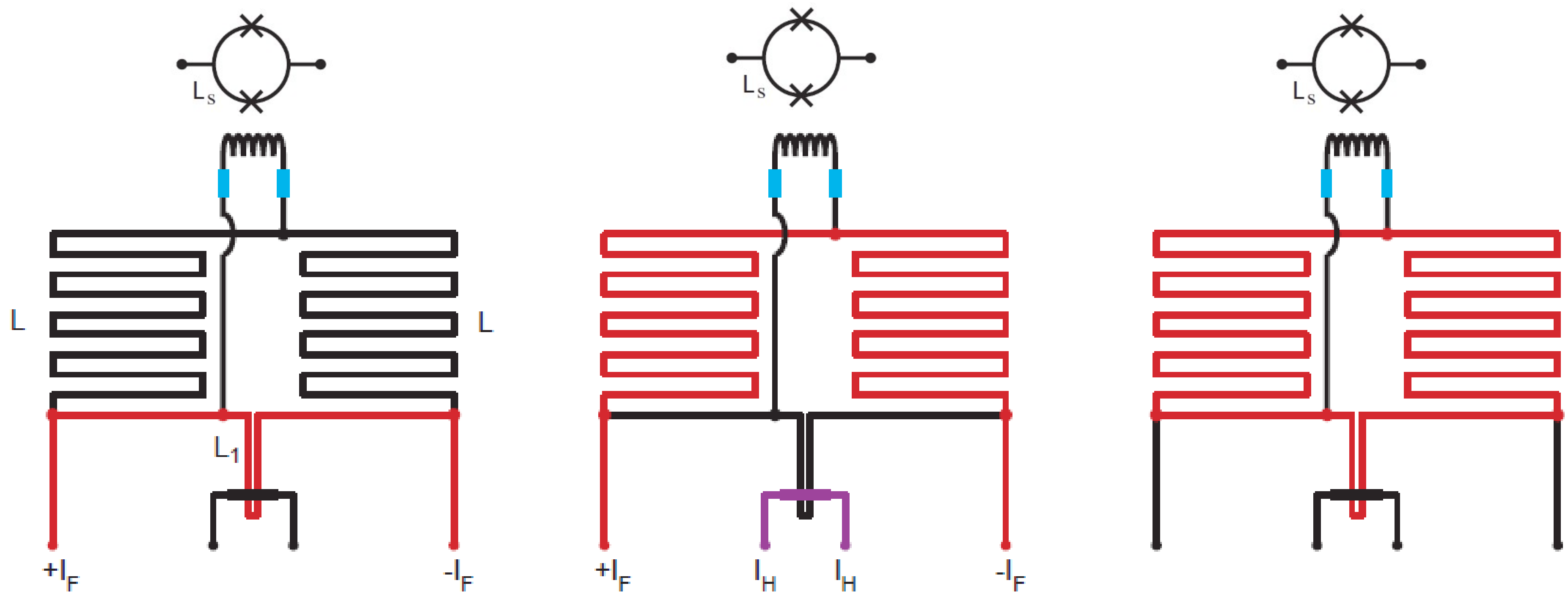




Superconducting heat switch



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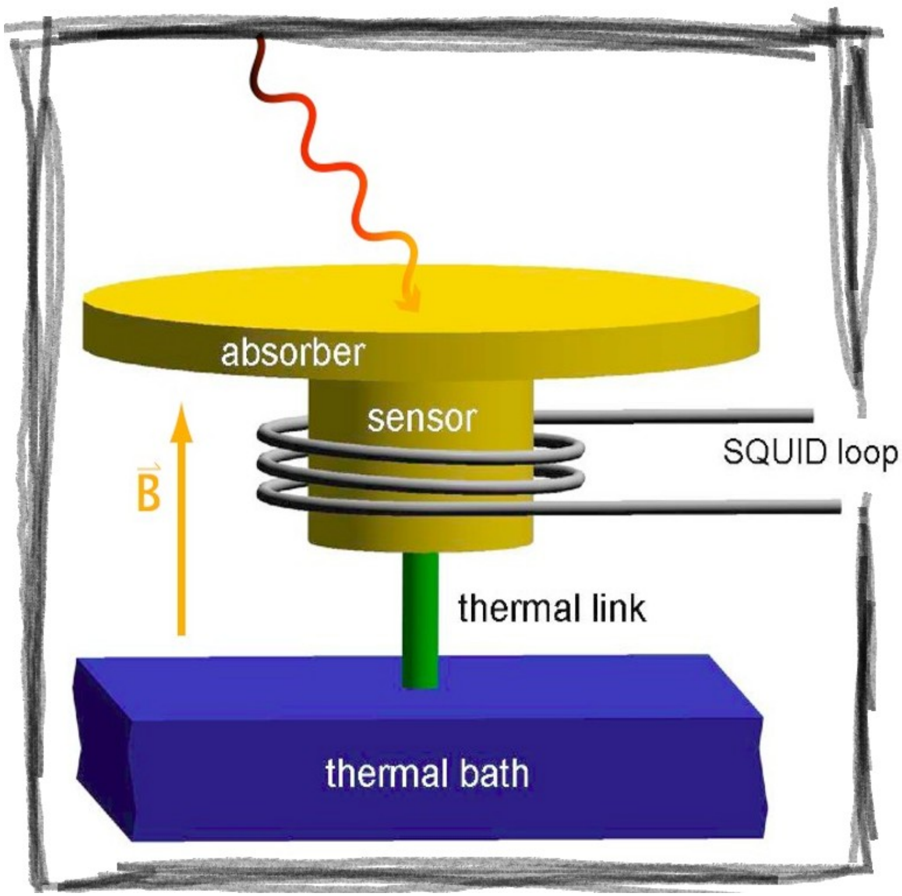
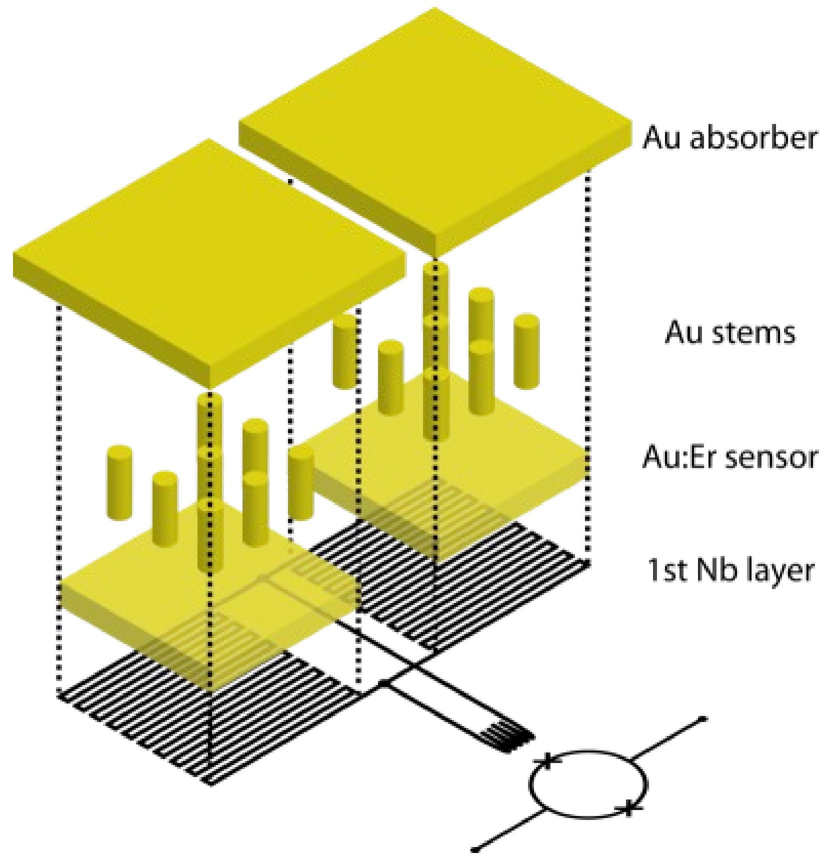
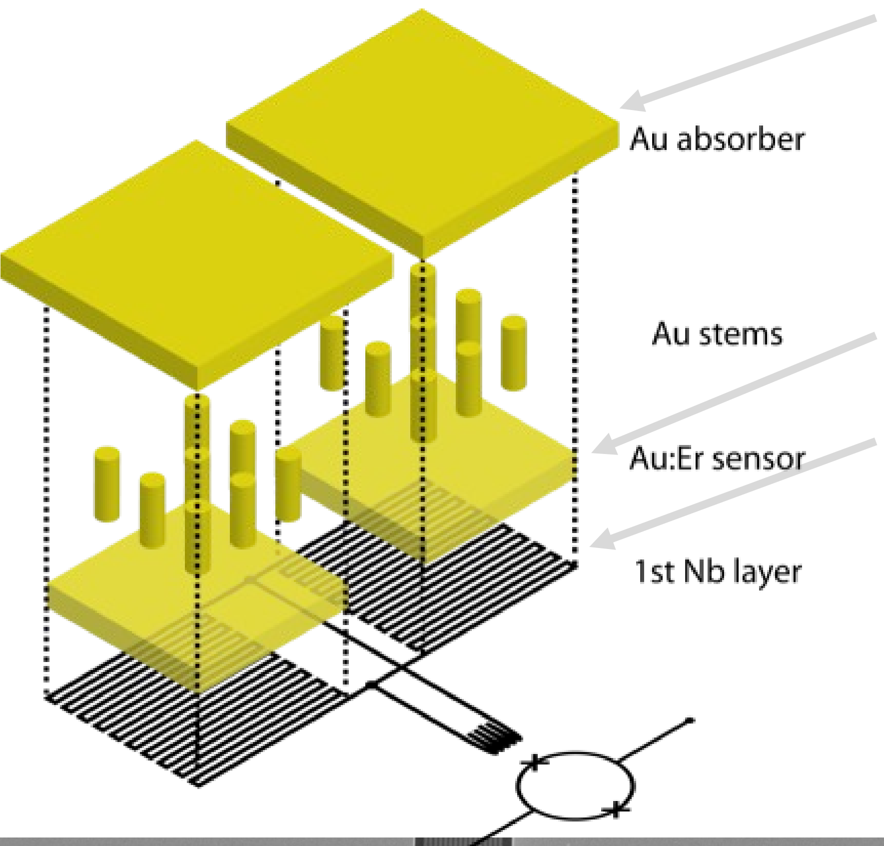
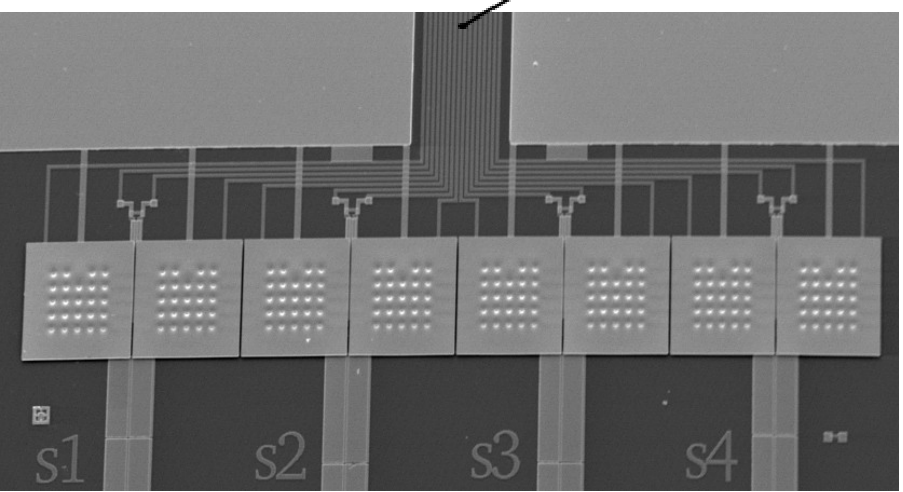


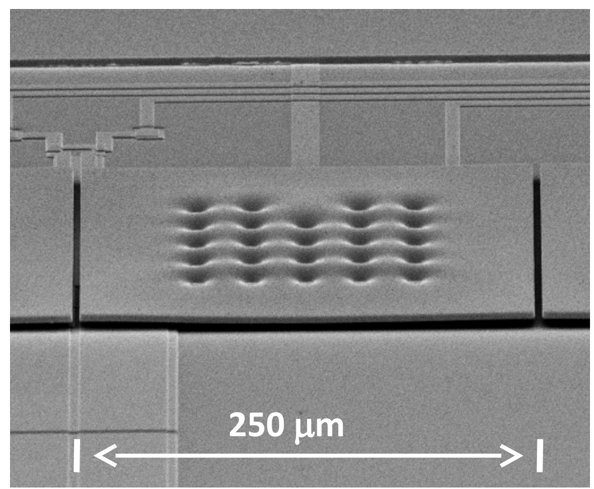


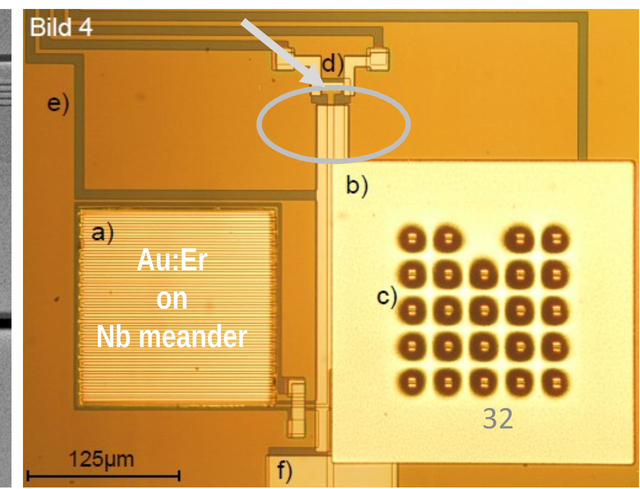
maXs20: a 1-D array for soft x-rays



- **1×8 x-ray absorbers**
  - **250µm×250µm** gold**, 5µm thick**
  - **98%** Qu.-Eff. @ 6 keV
  - electroplated into photoresist mold (RRR>15)
  - **mech/therm contact to sensor by stems**
  - to prevent loss of initially hot phonons
- **Au:^{166}Er$_{300ppm}$ temperature sensors**
  - co-sputtered from pure Au and high conc. AuEr target
- **Meander shaped pickup coils**
  - 2.5 µm wide Nb lines
  - I_c **≈ 100mA**
- **On-chip persistent current switch** (AuPd)



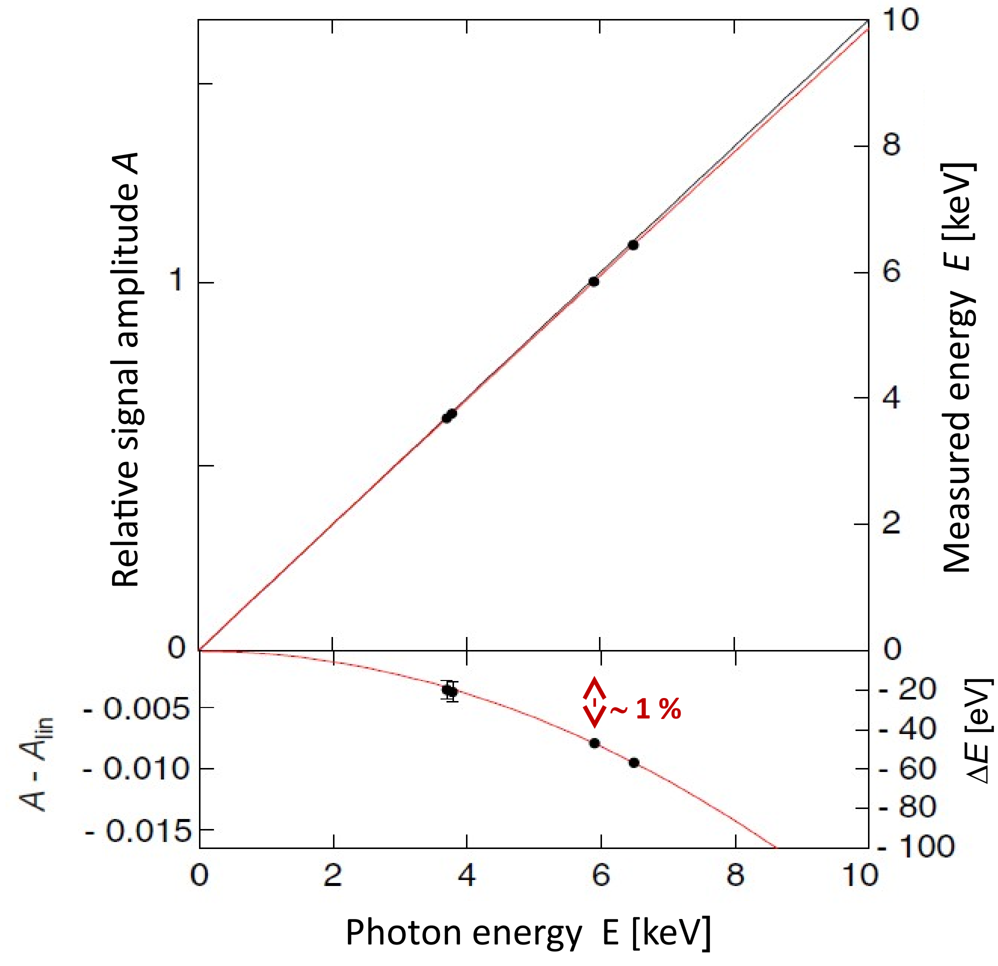




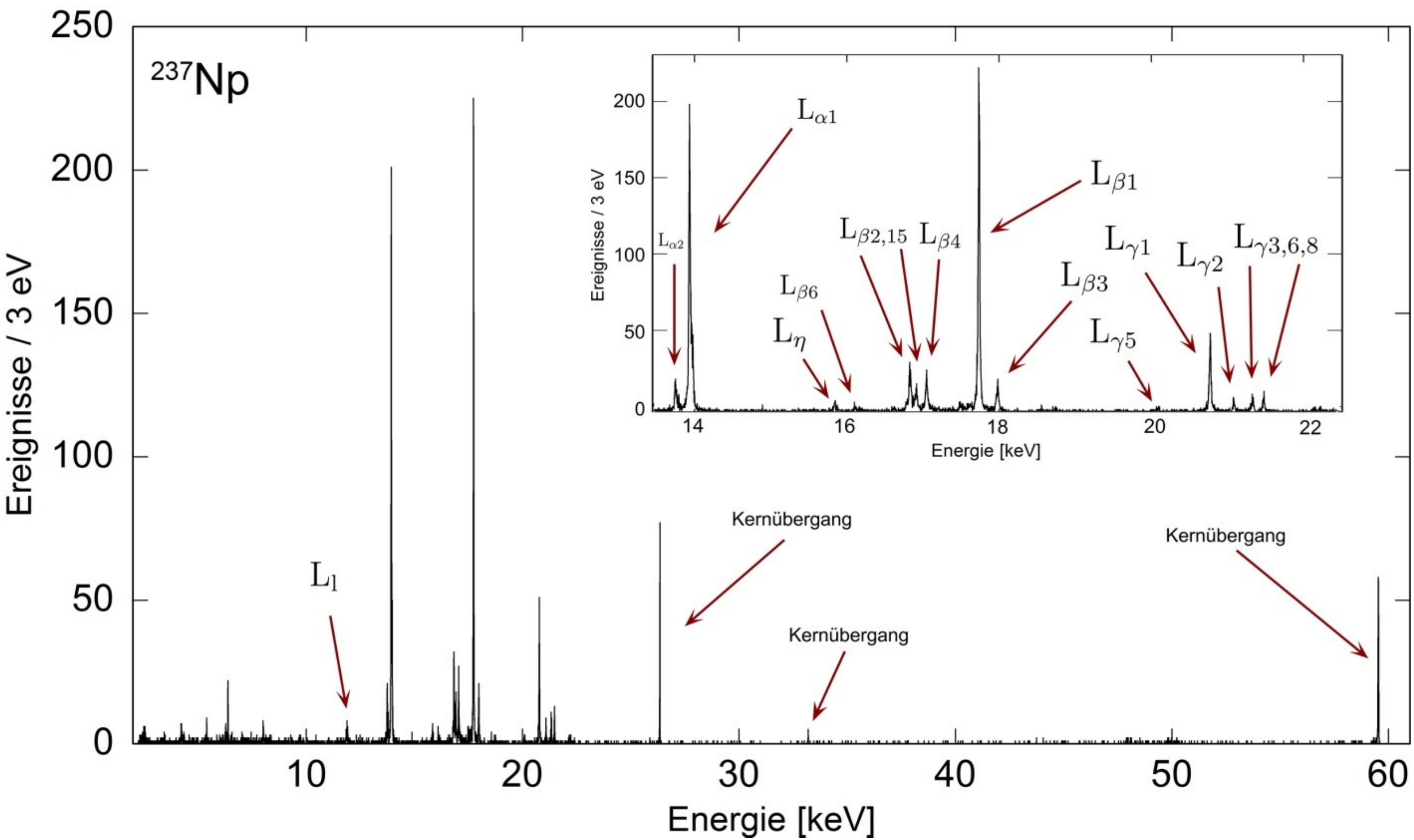
Calibration curve

- **non-linearity: 1%** at **6 keV**
- as expected from thermodynamical properties
- well described by quadratic term

The energy scale is defined with high precision



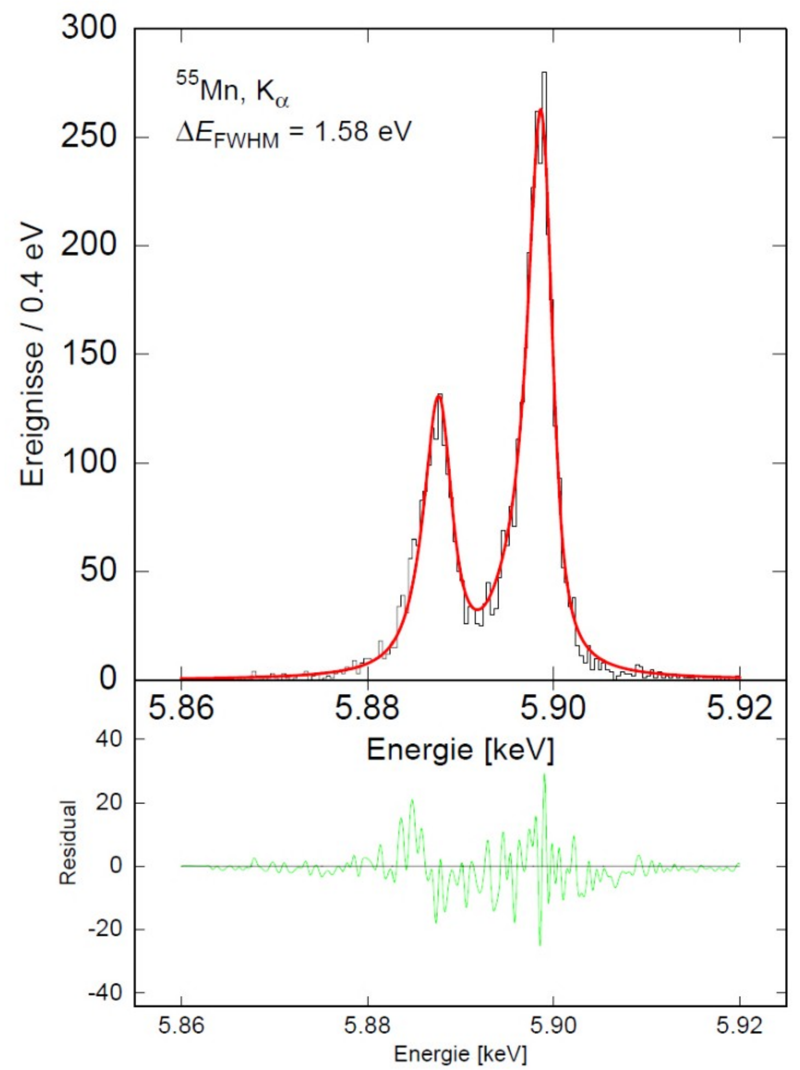
A measured spectrum



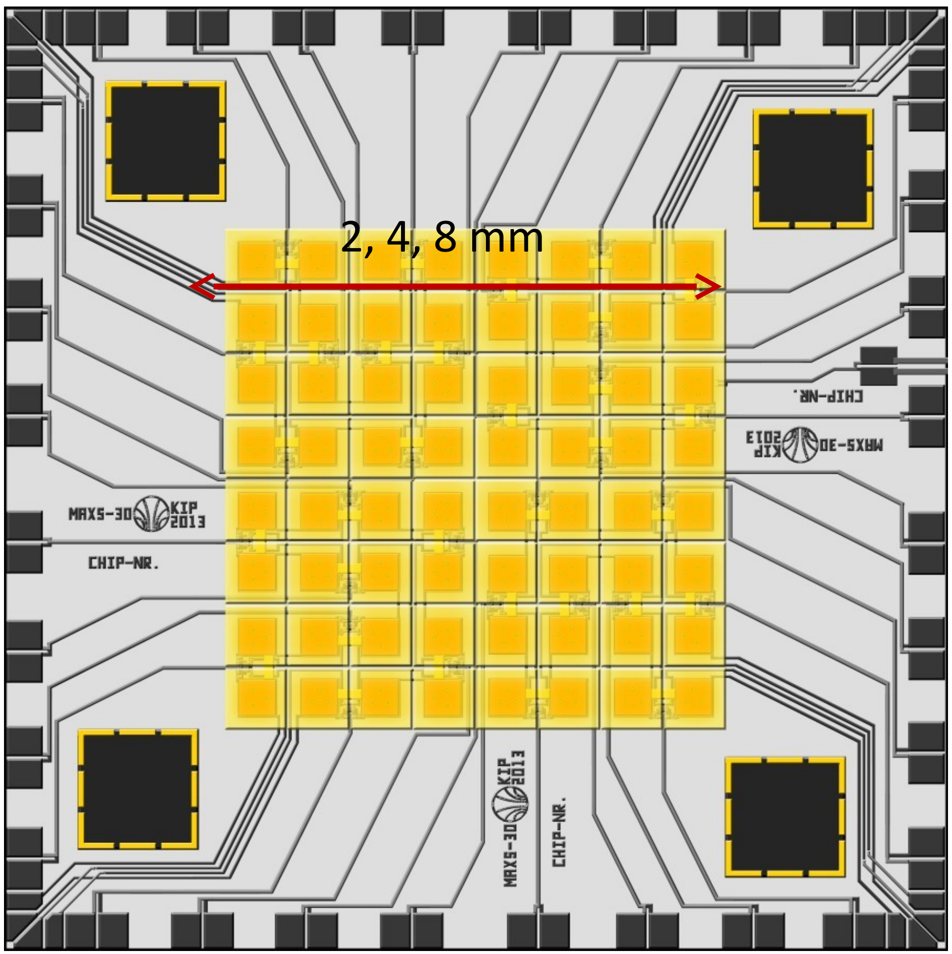
Energy resolution of a MMC

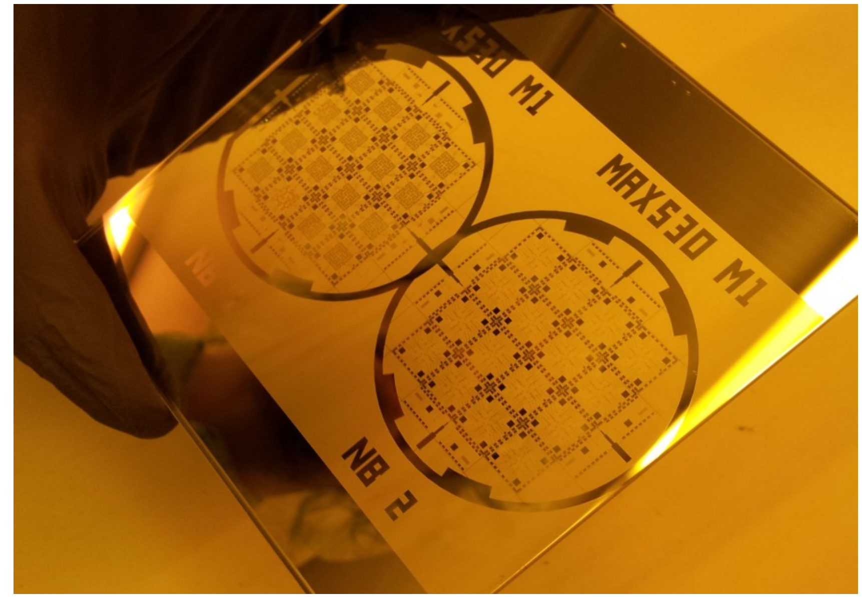
- Very good energy resolution

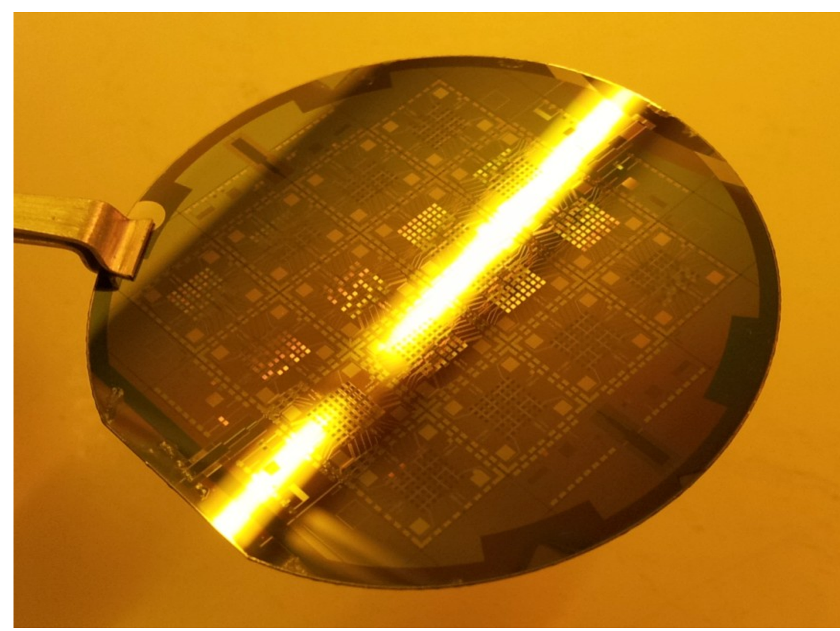
  ΔE_{FWHM}= 1.6 eV @ 6 keV



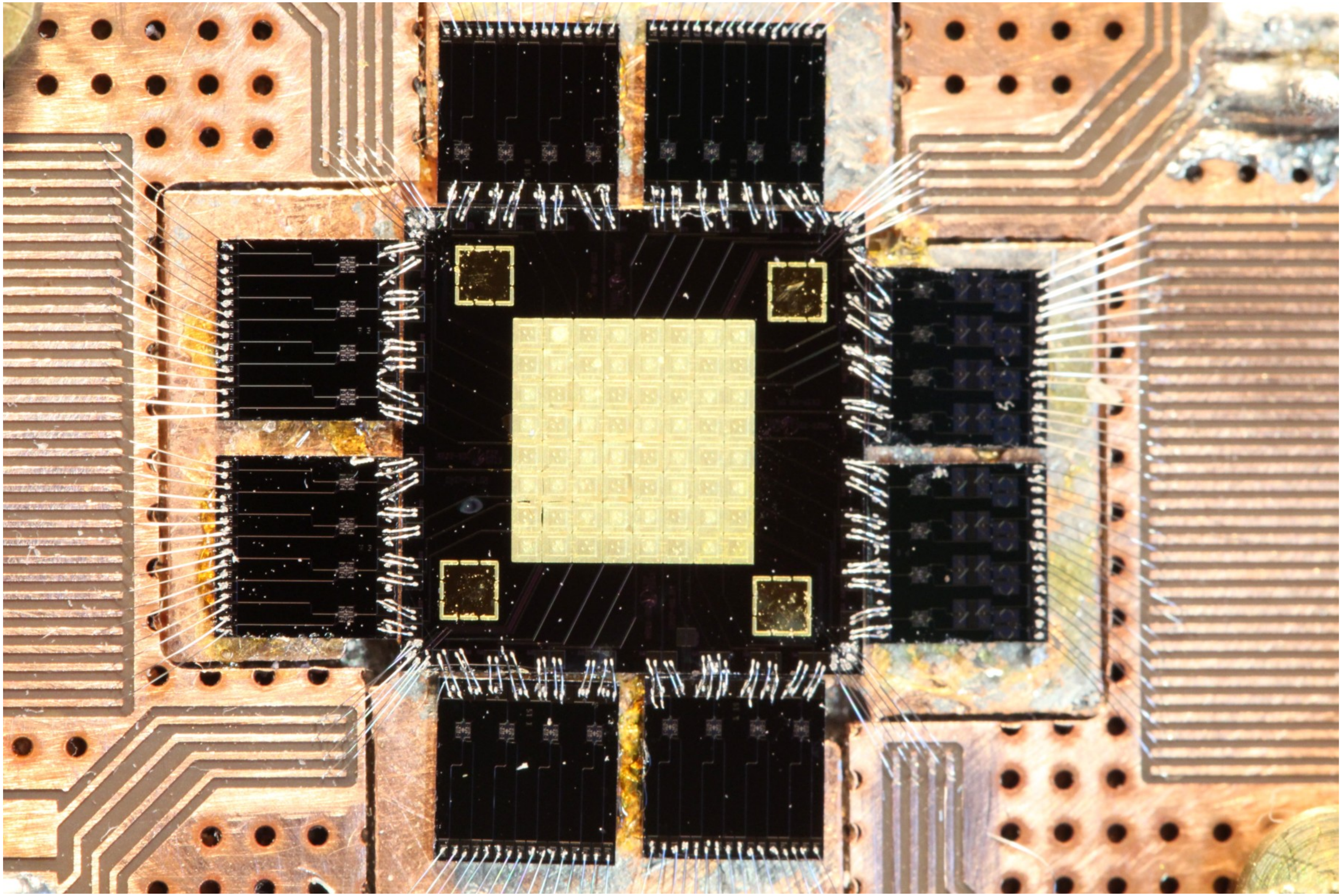
Large arrays



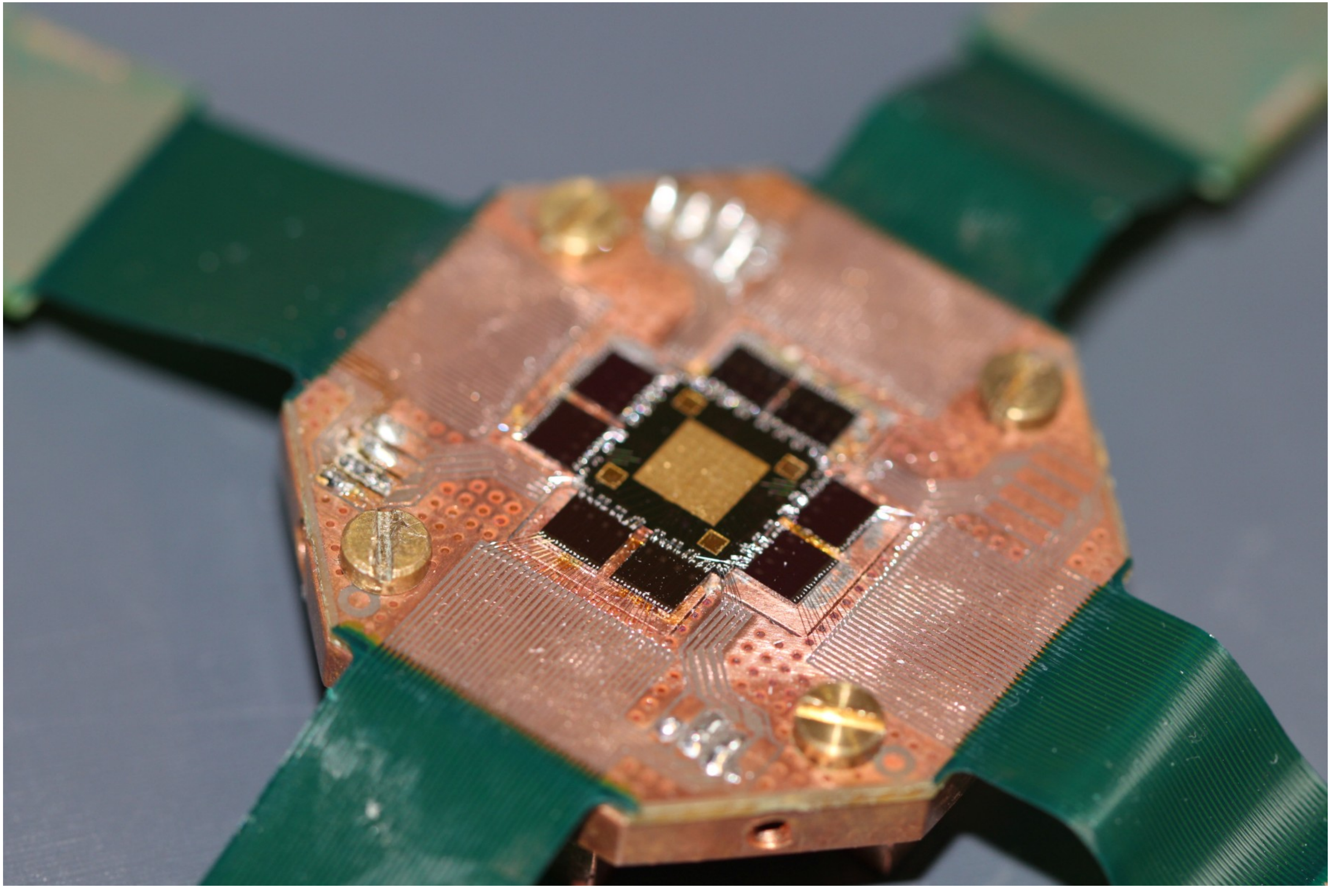




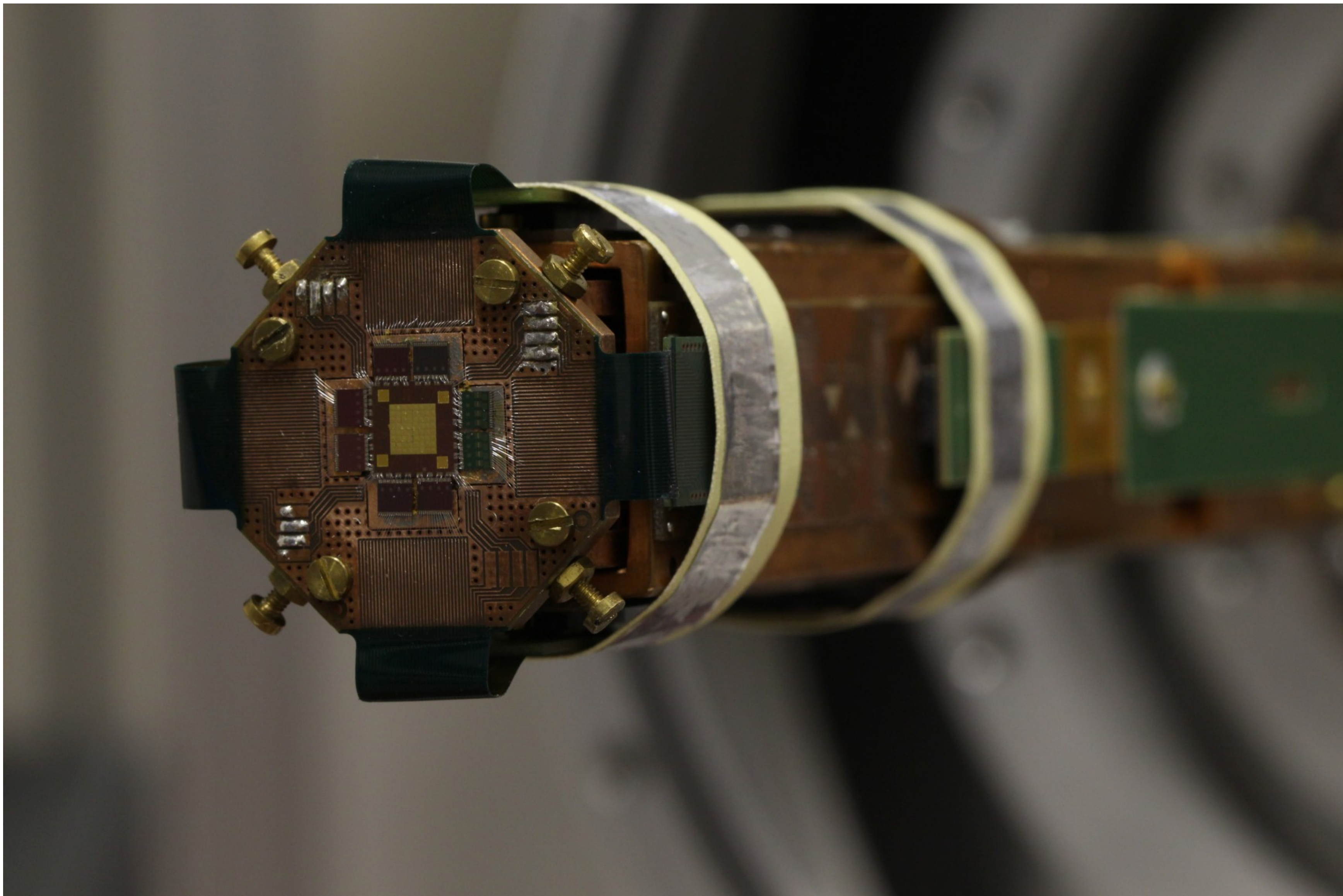
Example of assembly



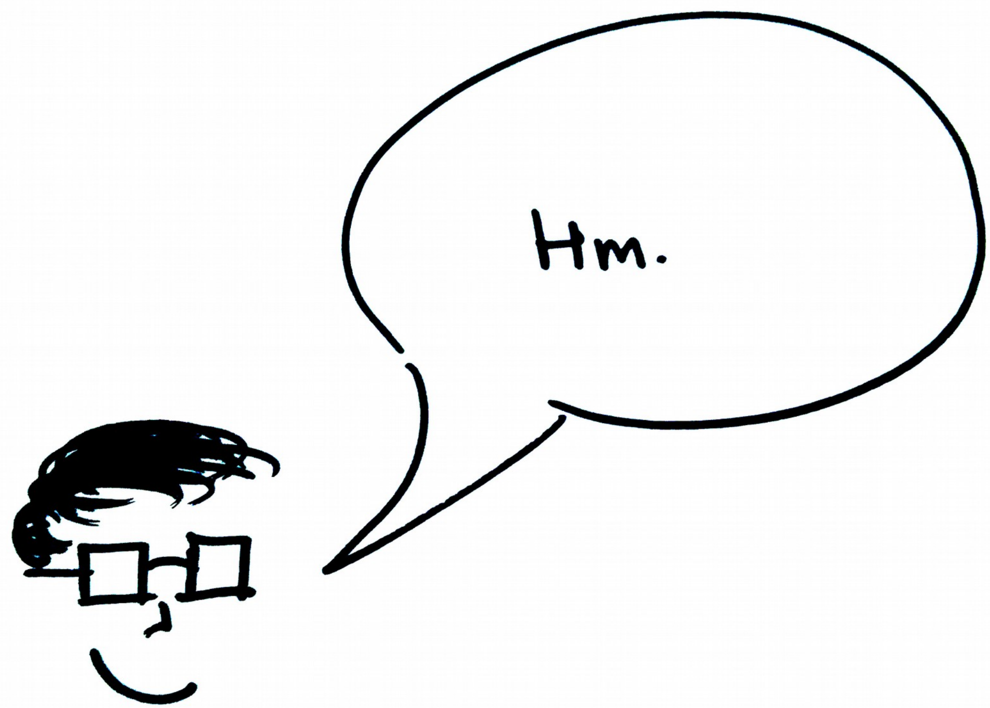
Microcalorimeters: examples of assembly



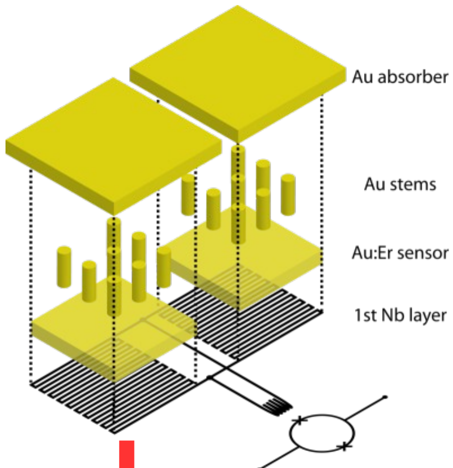
Microcalorimeters: examples of assembly

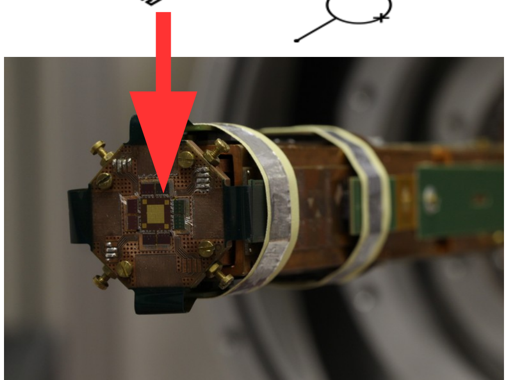


Summary



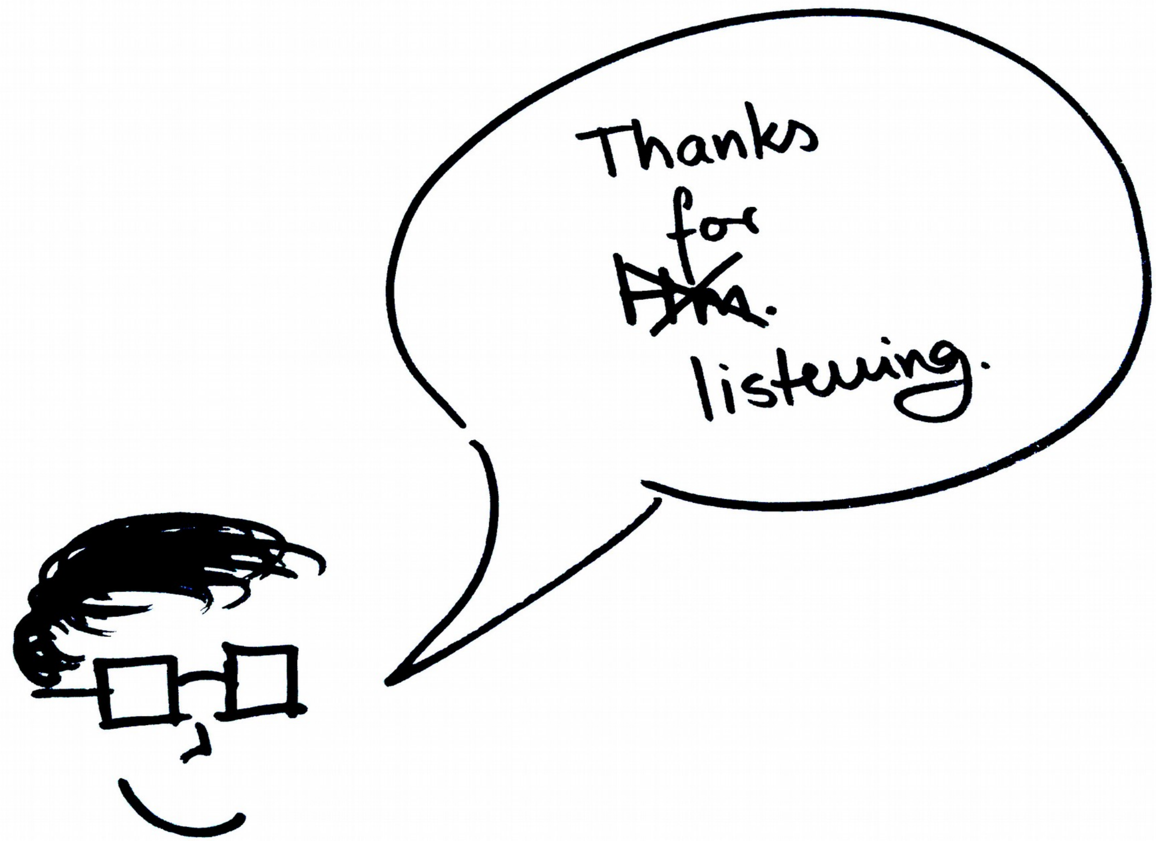
Summary





Metallic magnetic microcalorimeters:

- high-resolution, high-bandwidth detectors
- that we design and fabricate in our cleanroom
- that have to be cooled down to some mK
- that use magnetic properties for thermometry
- of metallic sensors.


Thanks
for
listening.