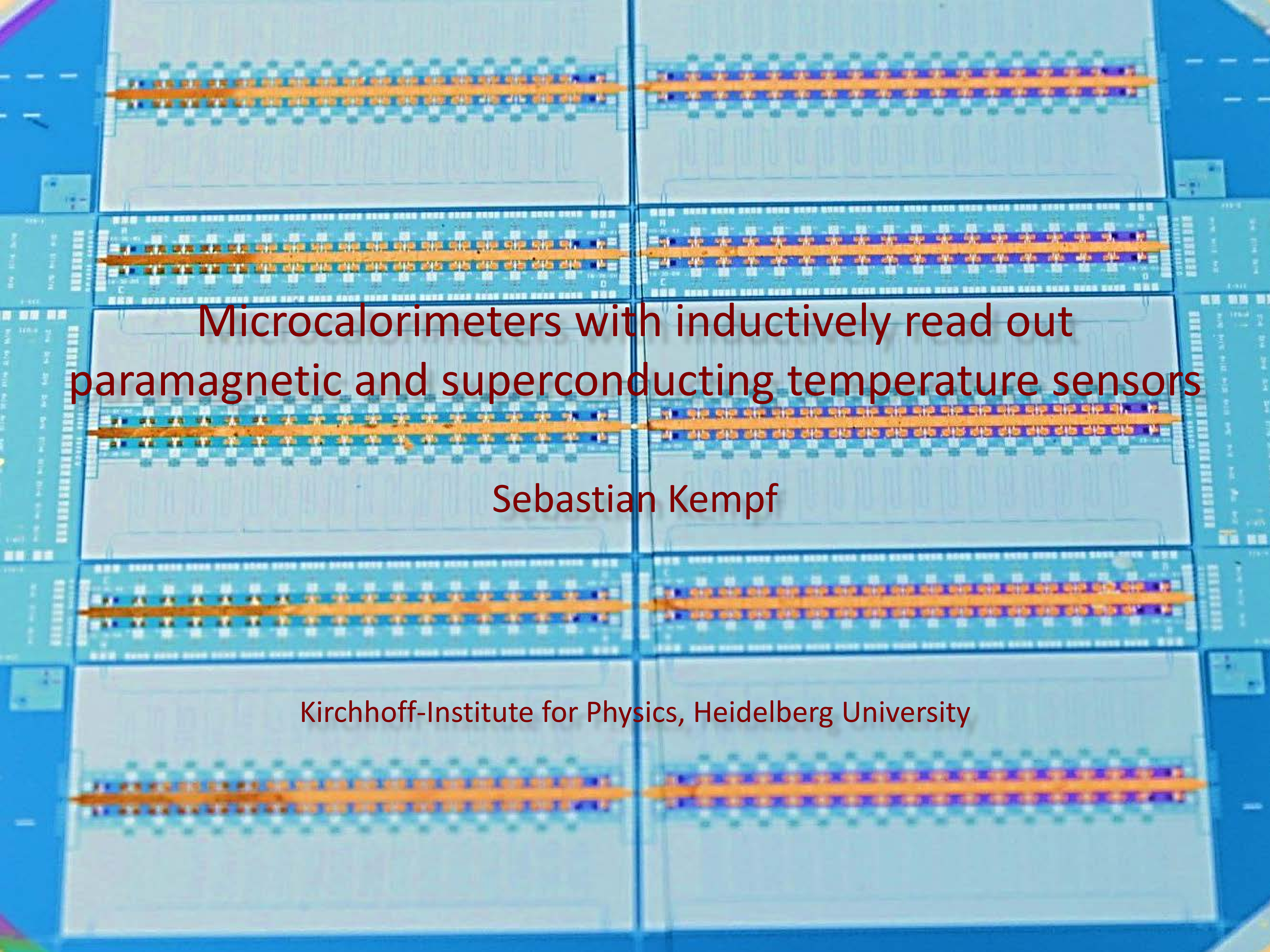
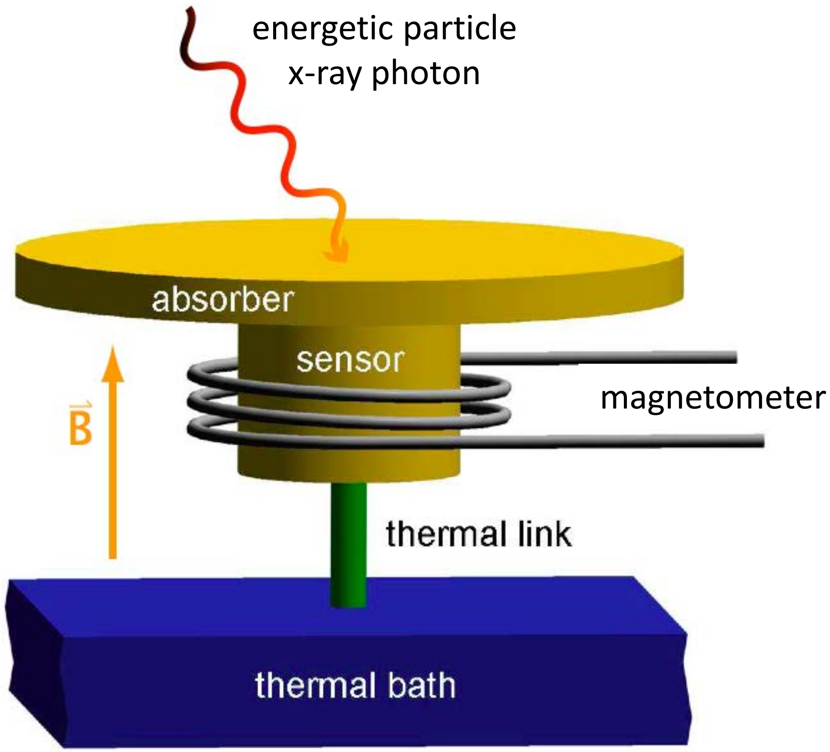


Microcalorimeters with inductively read out paramagnetic and superconducting temperature sensors

Sebastian Kempf

Kirchhoff-Institute for Physics, Heidelberg University

detection principle



massive particle absorber

paramagnetic or superconducting temperature sensor

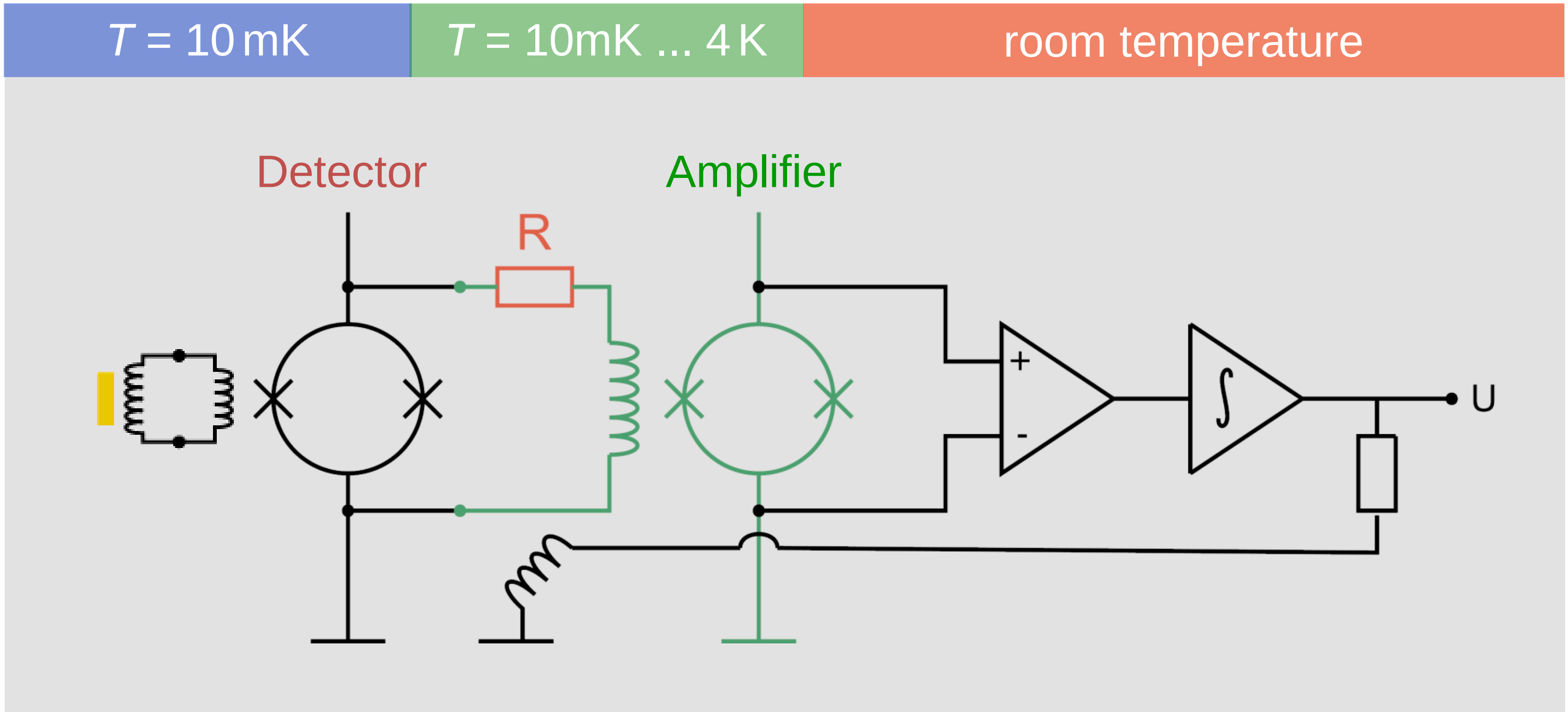
operation at low temperatures

- small heat capacity
- low thermal noise
- large temperature change

no power dissipation in the sensor

no galvanic contact to the readout circuit

SQUID based sensor readout

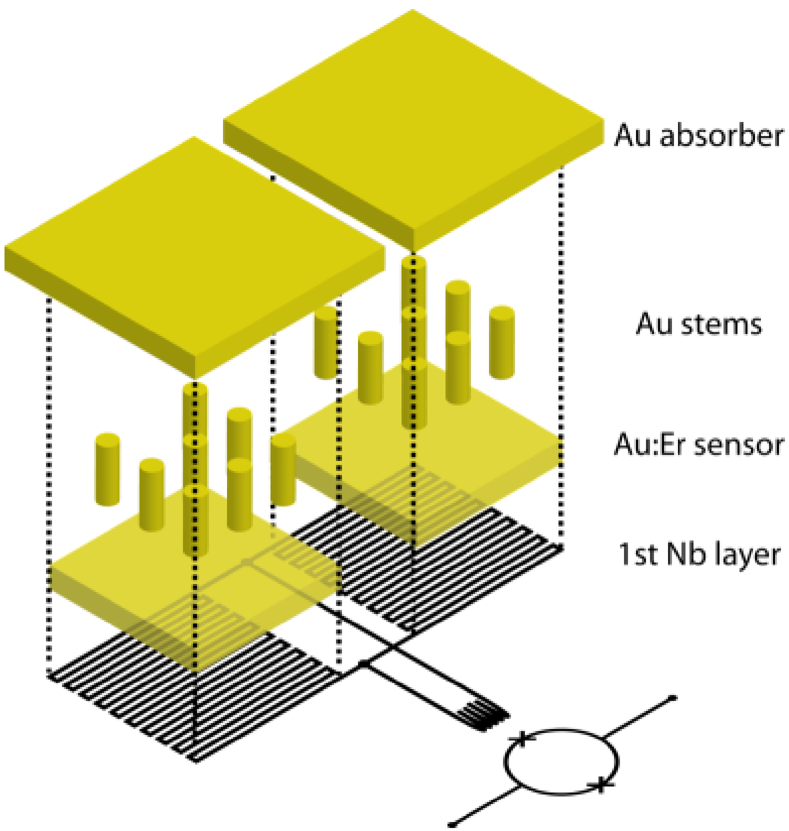


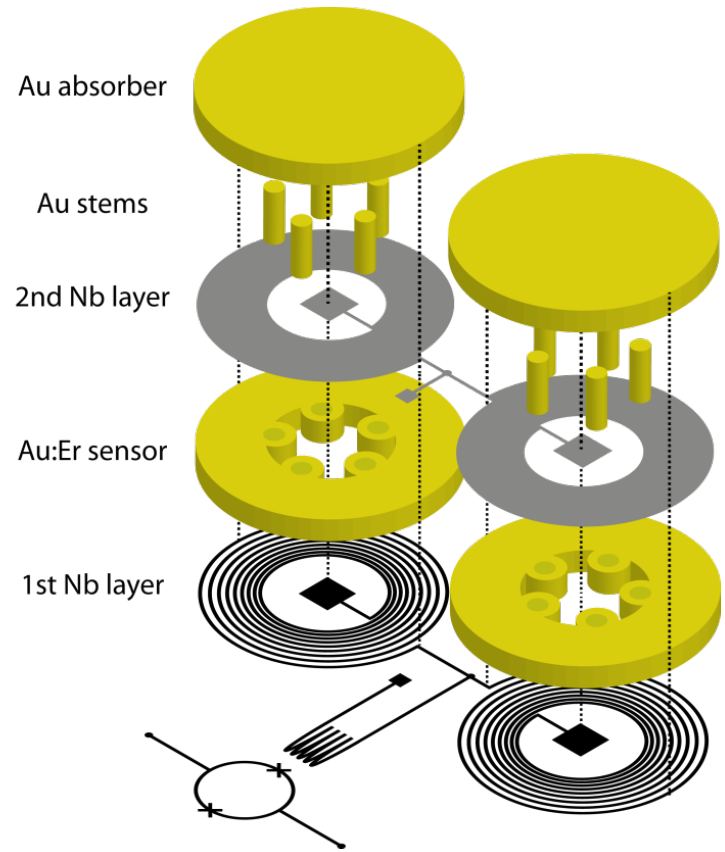
two-stage SQUID setup

- low noise
- large bandwidth
- low power dissipation

detector geometries

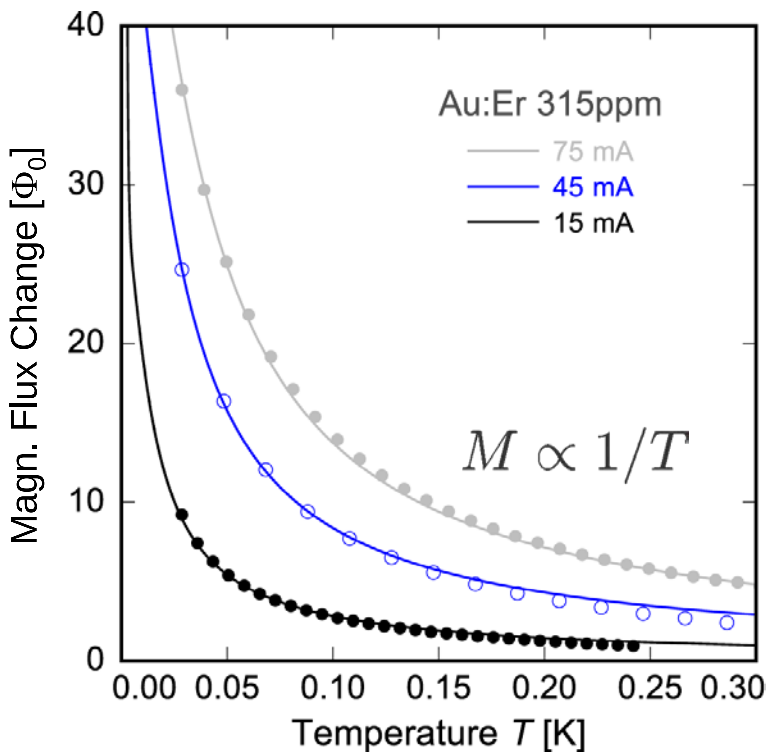
present working horses





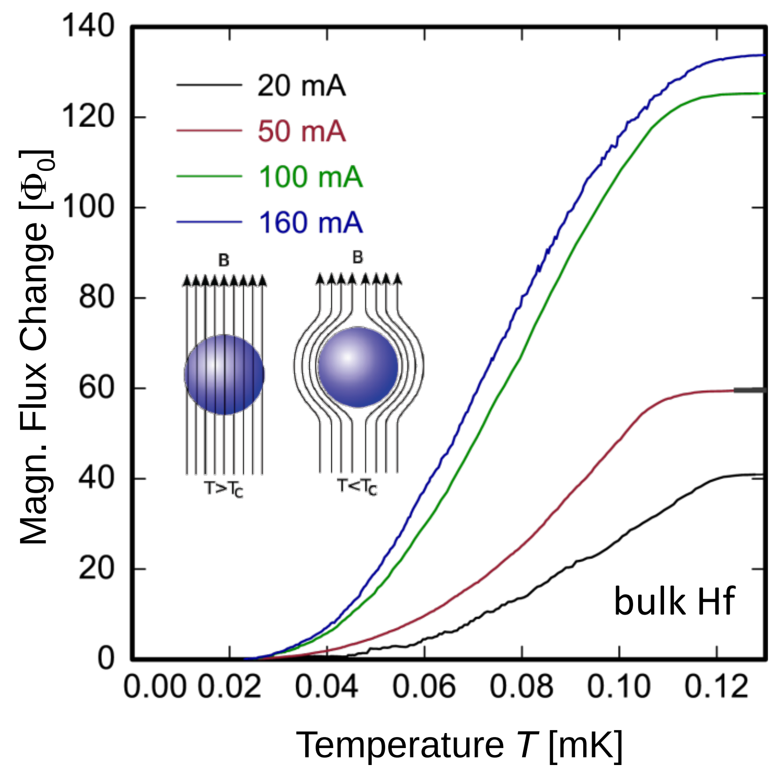
temperature sensors

Metallic Magnetic Calorimeter



Au:Er, Ag:Er, PbTe:Er, Dy:W, W:Fe …

Magnetic Penetration Thermometer

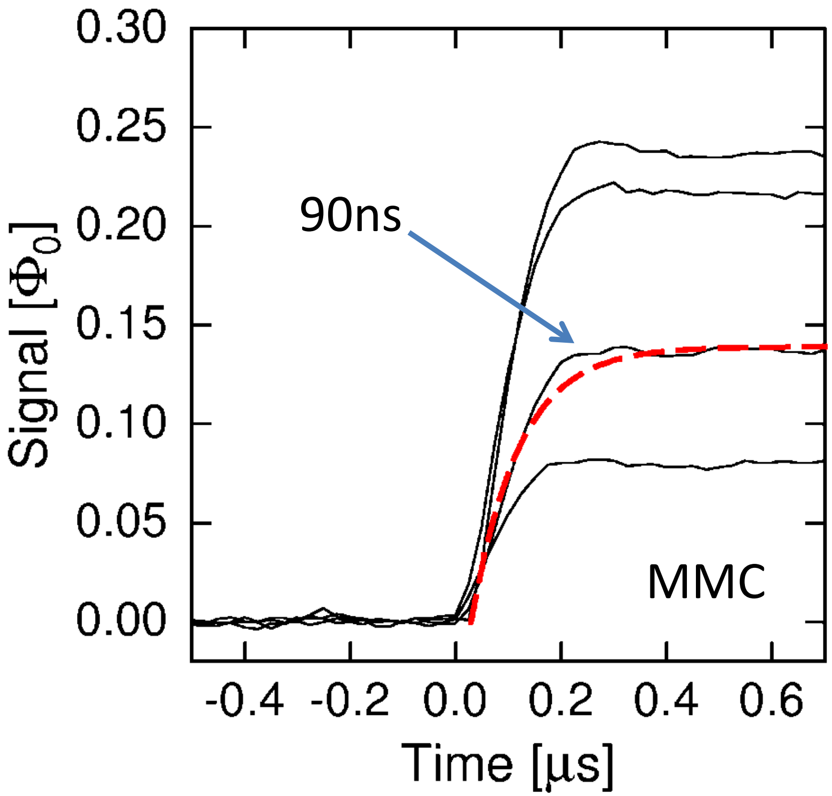


Ir, MoAu, Hf, AuTi, MoCu, …

signal shape

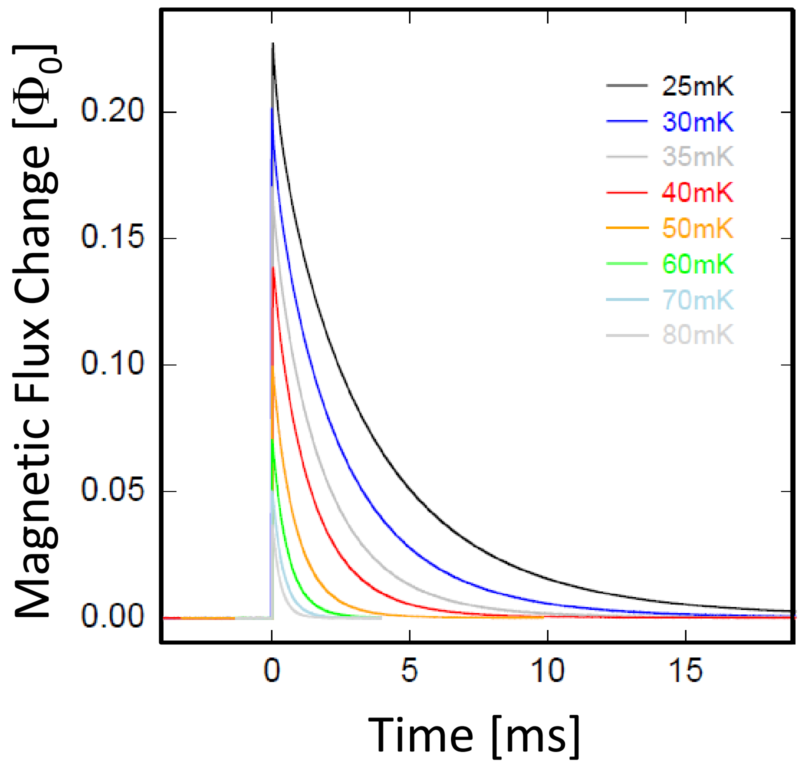
fast rise time

< 100ns @ 30mK for MMCs
<   1µs @ 30mK for MPTs



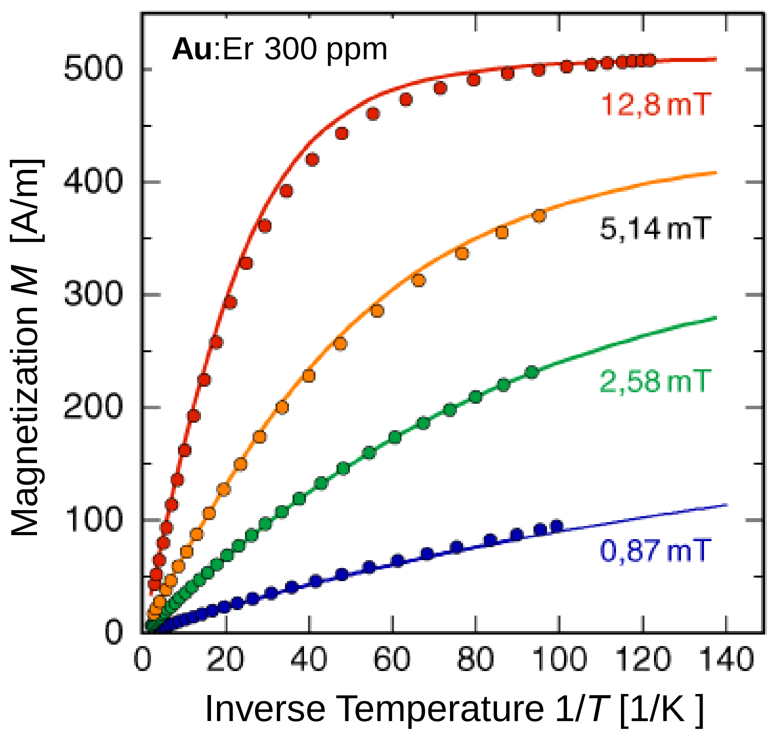
decay time

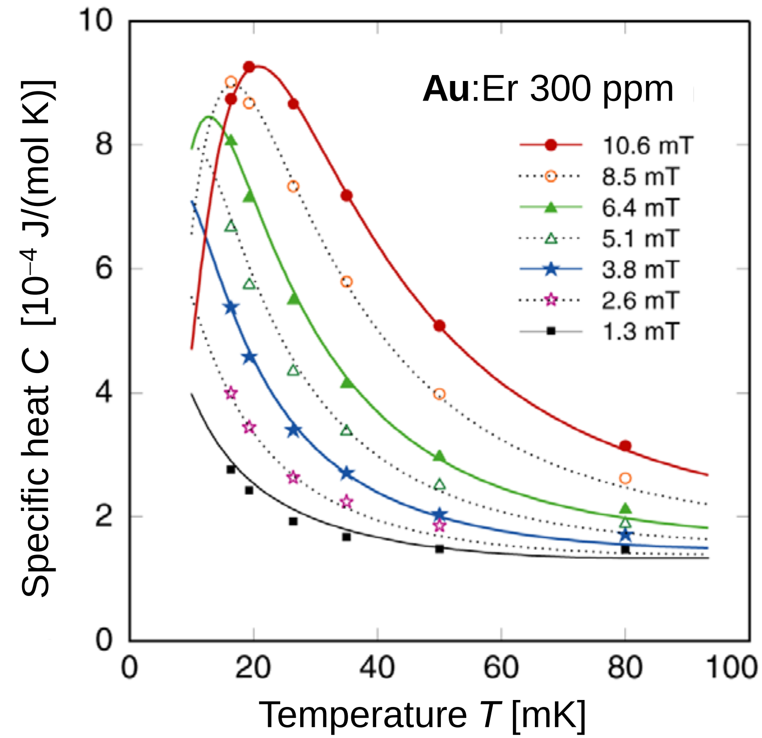
roughly single exponential
adjustable by metallic link



signal size of MMCs

$$\delta\Phi \propto \frac{\partial M}{\partial T}\frac{E}{C_{\mathrm{tot}}}$$

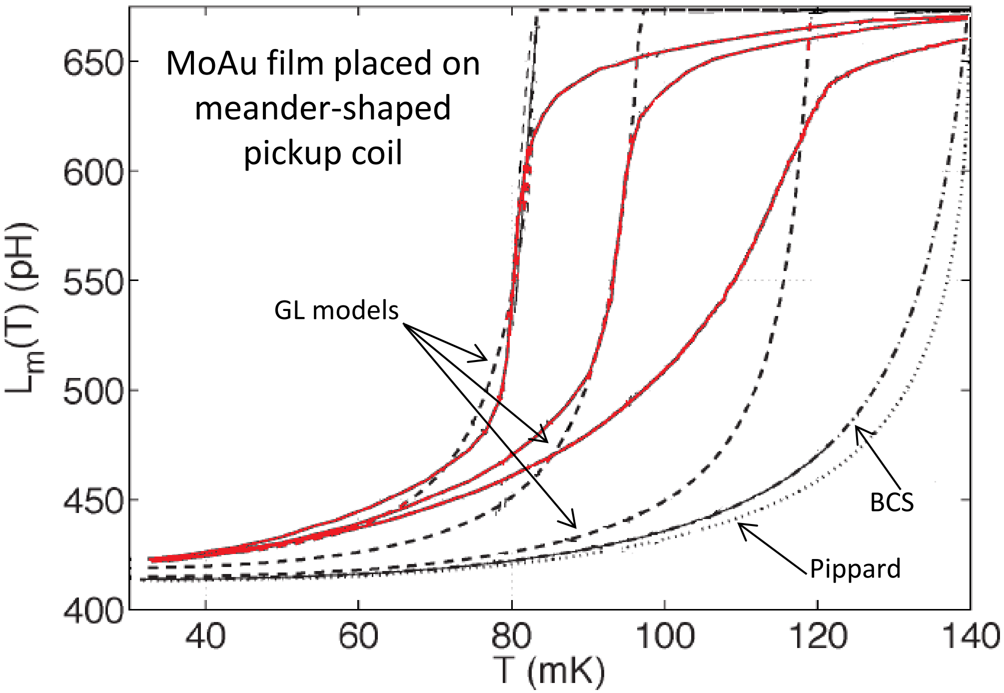




signal size of MMCs can be predicted with confidence

signal size of MPTs

T.R. Stevenson *et al.*
IEEE Trans. Appl. Supercond. **23** 2300605, 2013.



- magnetic flux change
- specific heat
- magnetic work

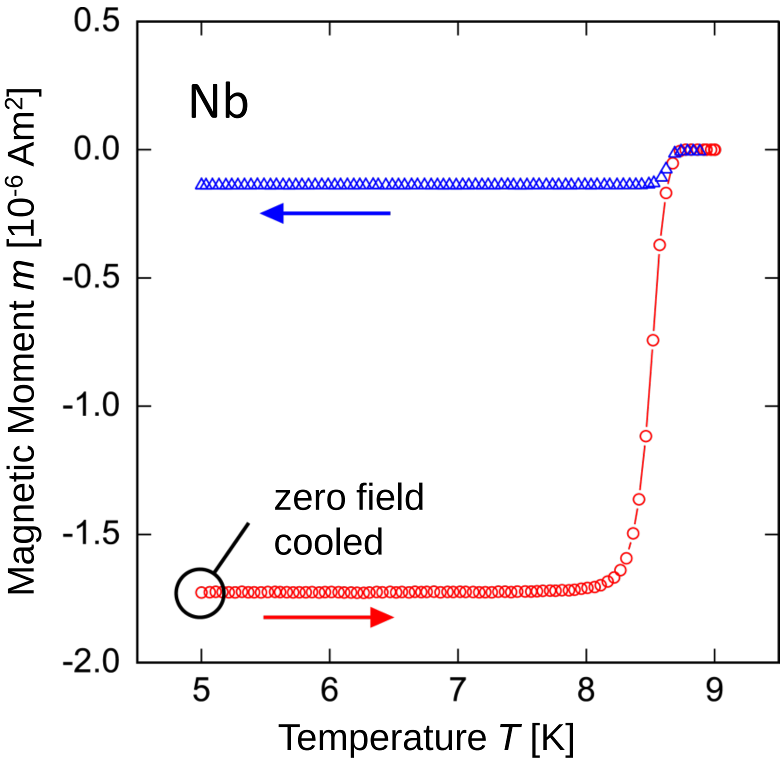
calculation of signal size of MPTs challenging but feasible

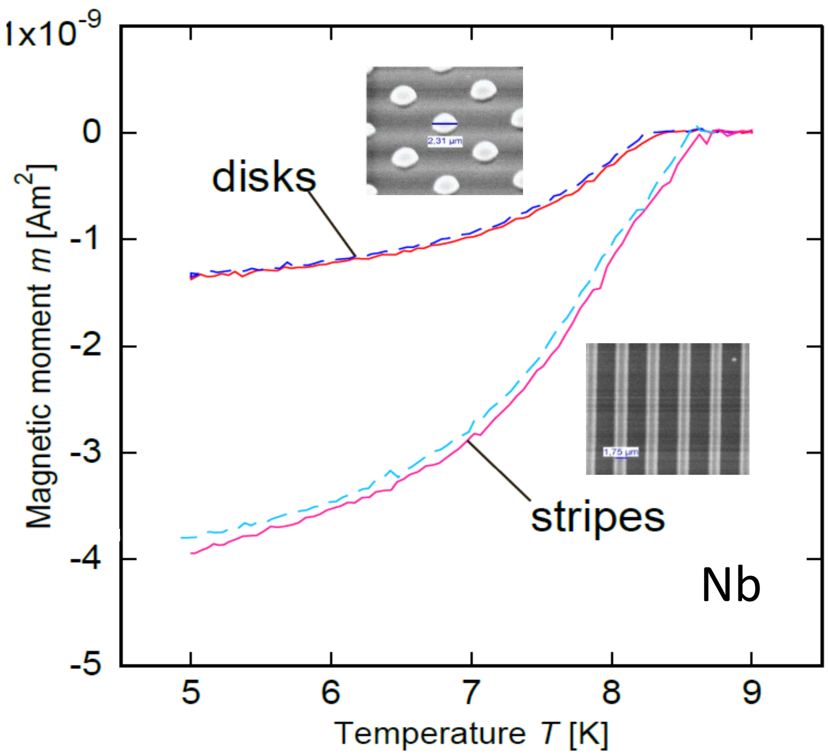
hysteresis effects in MPTs

large area sensors show hysteretic behaviour

non-hysteretic behaviour for patterned sensors

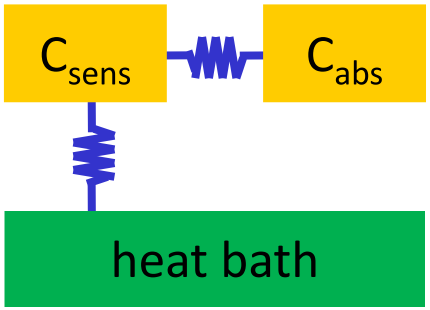
$$B \cdot w^2 < \frac{\Phi_0}{2}$$





noise contributions

thermodynamical fluctuations of energy

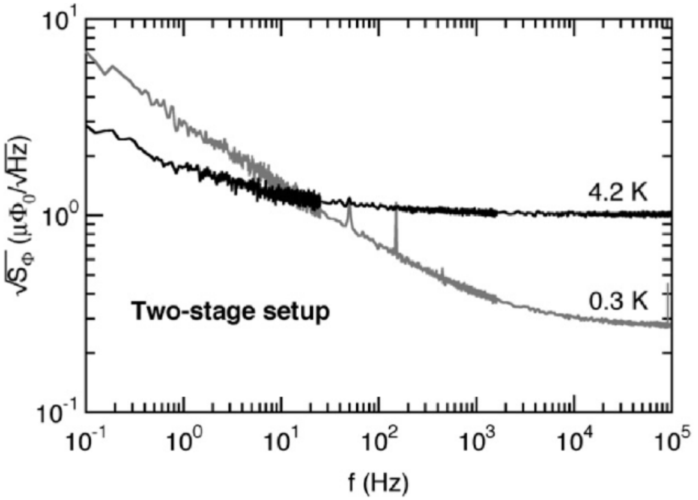


$$\Delta E_{\mathrm{FWHM}} = 2.36\sqrt{4k_{\mathrm{B}}TC_{\mathrm{abs}}T^2}\sqrt{2}\left(\frac{\tau_0}{\tau_1}\right)^{1/4}$$

optimum for $C_{\mathrm{abs}} \approx C_{\mathrm{sens}}$

sensor ‚intrinsic' noise

- excess noise observed for Au:Er temperature sensors
- ….



amplifier (SQUID) noise

$$\epsilon_{\mathrm{s}} = \frac{S_\Phi}{2L_{\mathrm{s}}} \quad \text{or} \quad \epsilon_{\mathrm{c}} = \frac{1}{2}L_{\mathrm{i}}S_I$$

required $\epsilon < 50 \cdots 500\,\hbar$

magnetic Johnson noise

- thermal currents in metallic detector components
- can be kept marginal small

detector optimization

signal

- pickup coil geometry
- coupling scheme
- detector responsitivity

noise

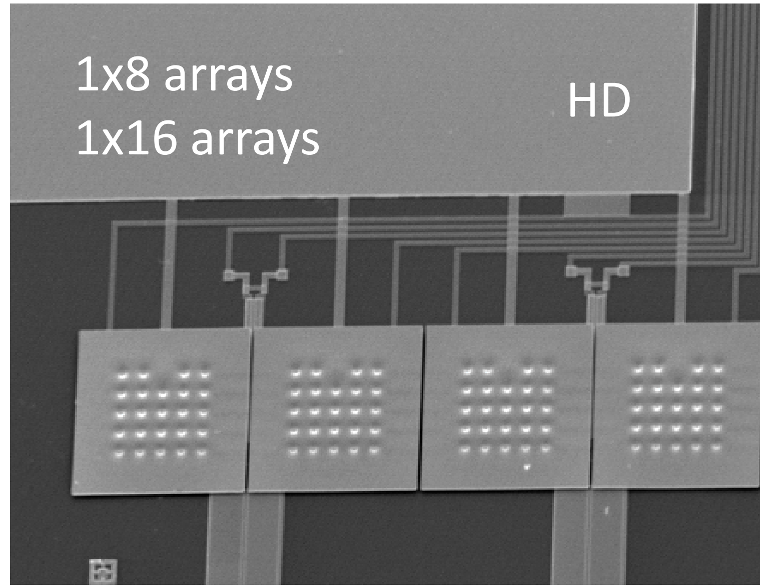
- energy fluctuations
- amplifier noise
- magnetic Johnson noise
- intrinsic sensor noise

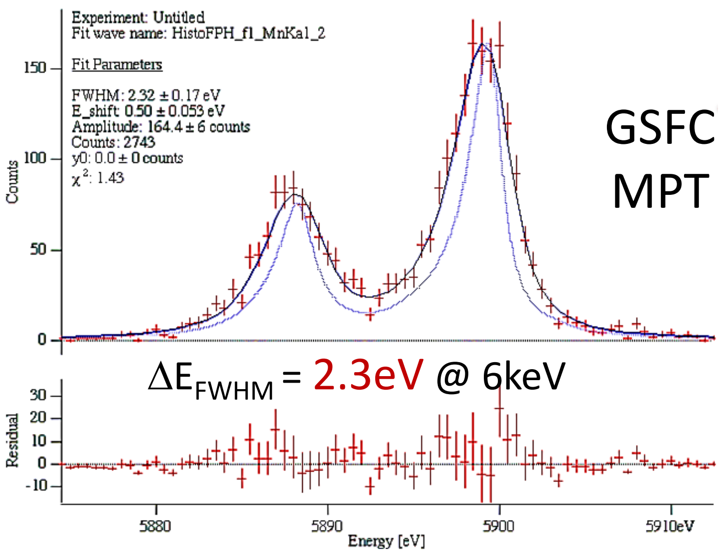
→ NEP → ΔE_{FWHM}

C_{abs} [pJ/K] @50mK	ΔE_{FWHM} [eV] @ 50mK	ΔE_{FWHM} [eV] @ 30mK	
0.3	1.1	0.6	High resolution x-ray spectroscopy
1	2.2	1.2	
500	50	25	α-, β- and γ- spectroscopy up to MeV energies

high resolution x-ray spectroscopy

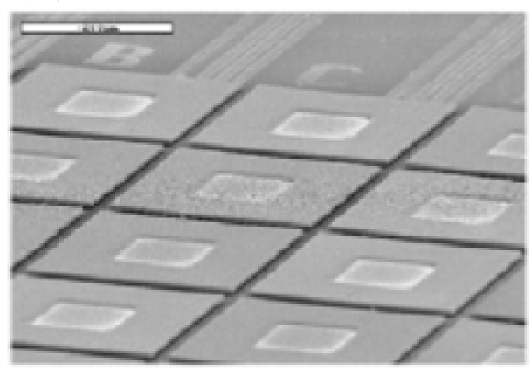
1d and 2d arrays
for x-ray spectroscopy
with photon energies
up to 200keV

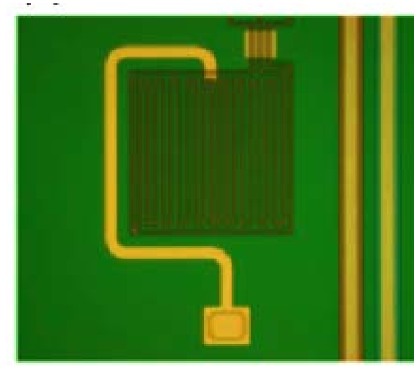




ΔE_{FWHM} = 2.3eV @ 6keV

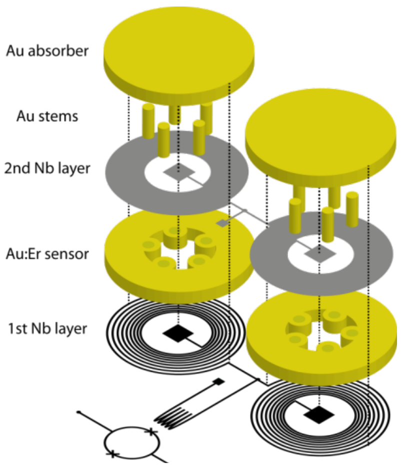
GSFC
MPT

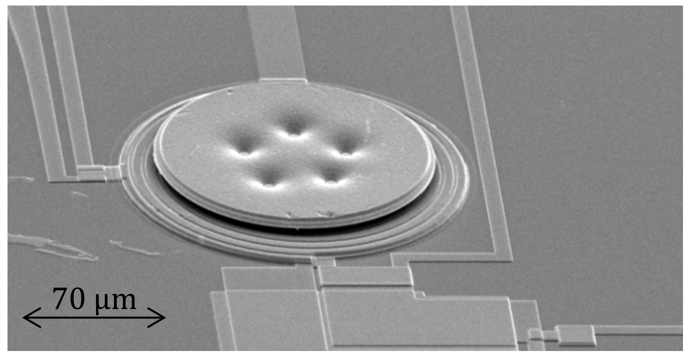




GSFC 5x5 array, larger arrays in development

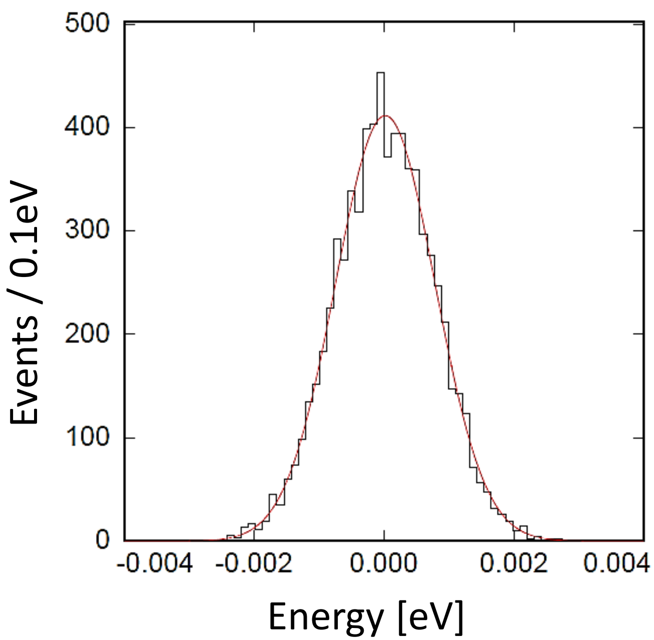
high resolution x-ray spectroscopy

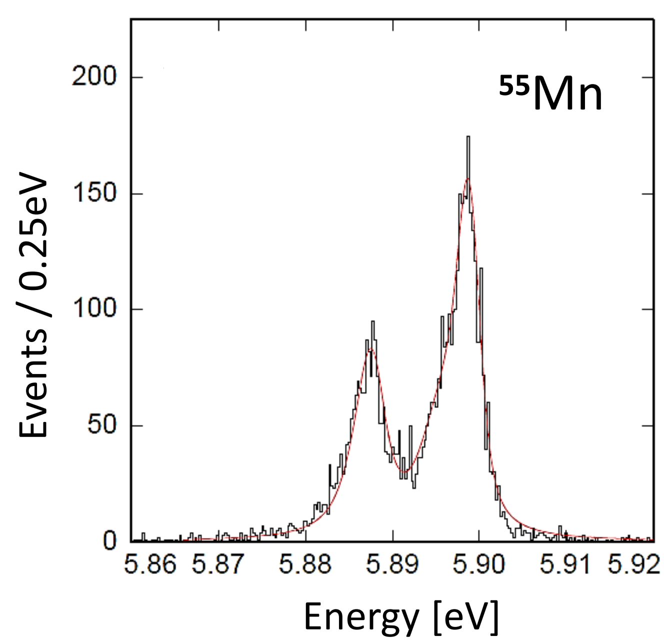




single pixel device

non-linearity: 1% @ 6 keV





ΔE_{FWHM} = 1.8eV @ 0 keV

ΔE_{FWHM} = 2.0eV @ 6 keV

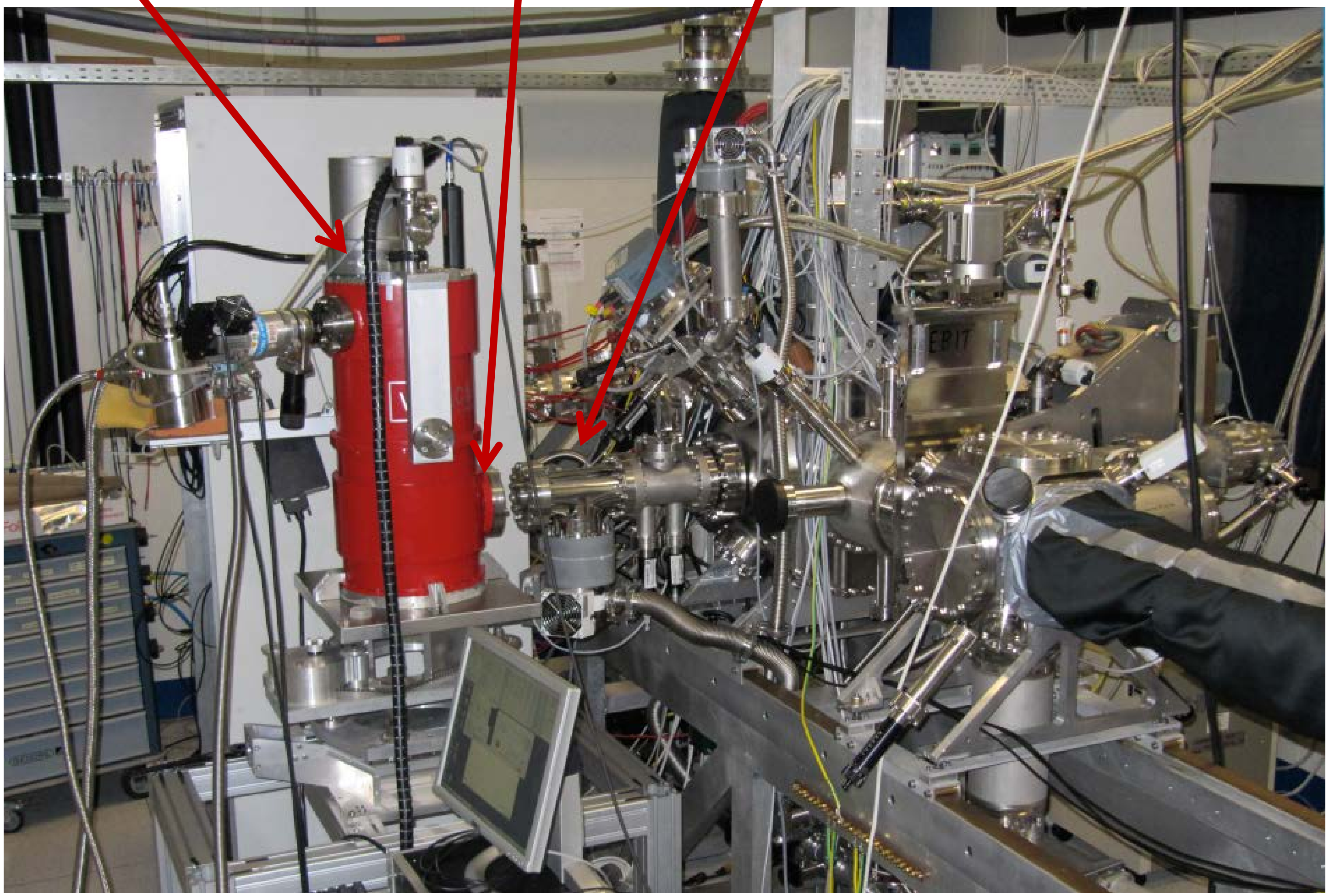
‚physics‘ with MMCs / MPTs

maXs-20

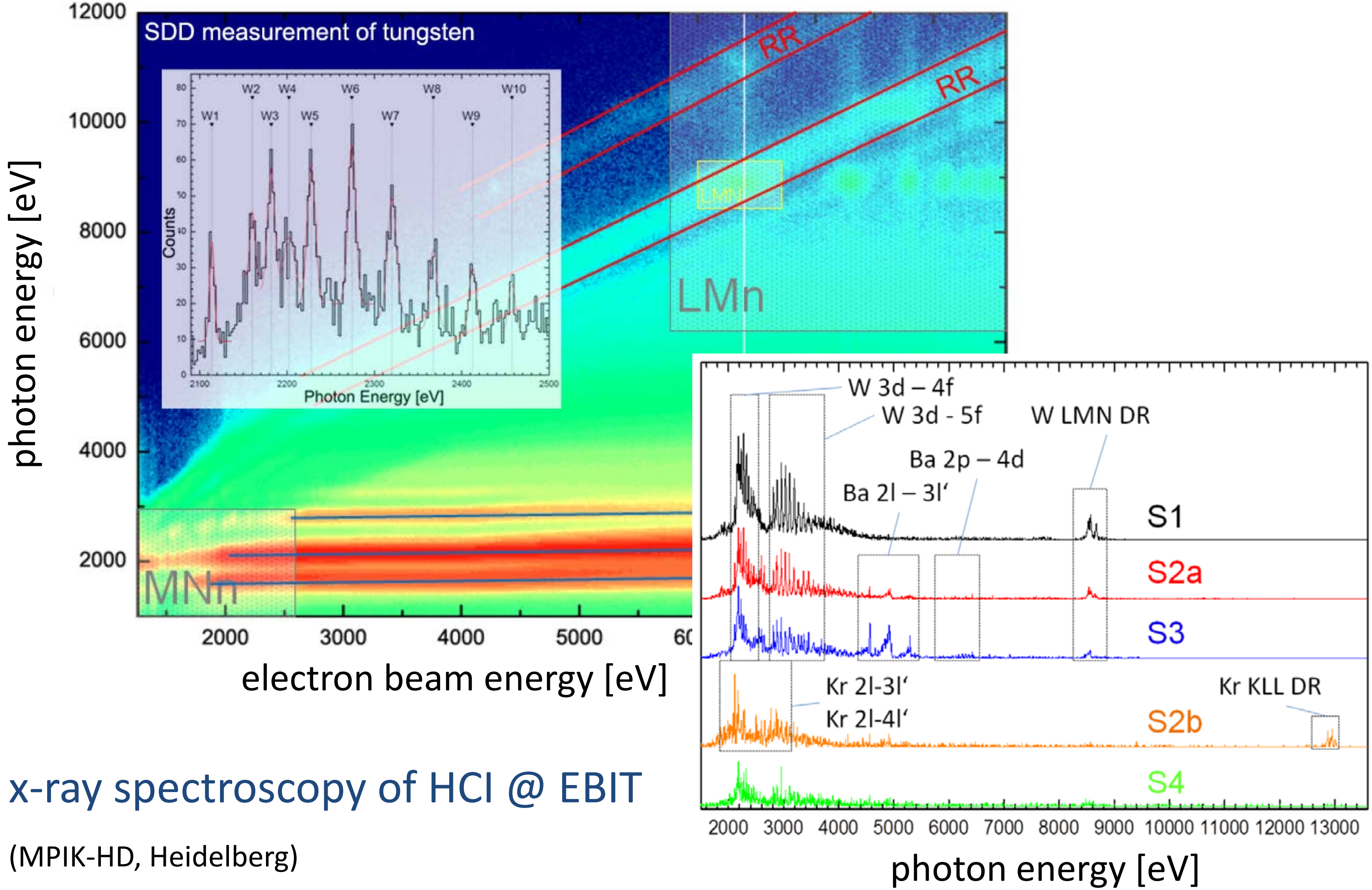
x-ray lens

pulse tube cooled ADR

electron beam ion trap (MPI-K,HD)



‚physics‘ with MMCs / MPTs

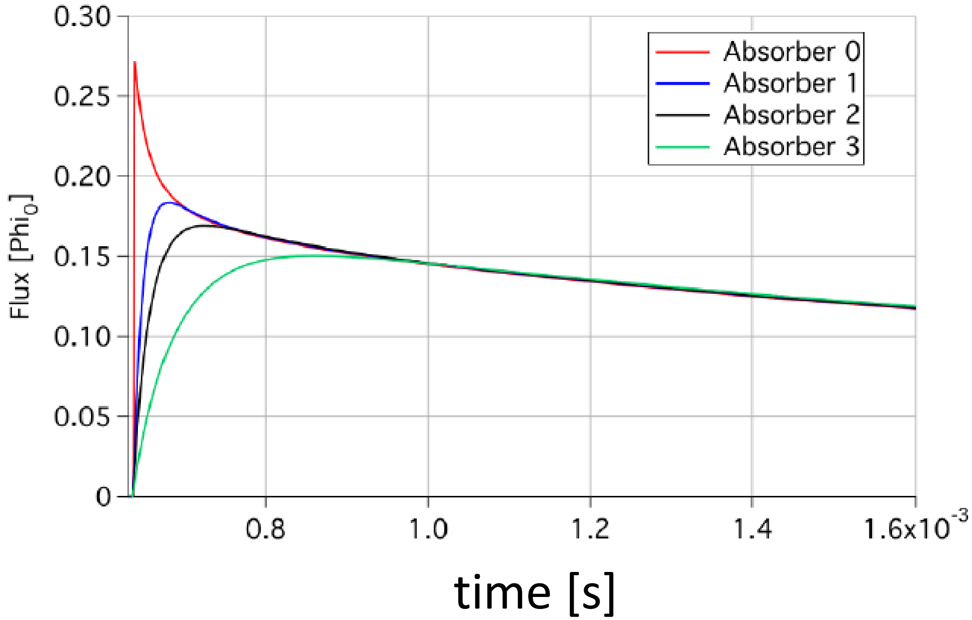


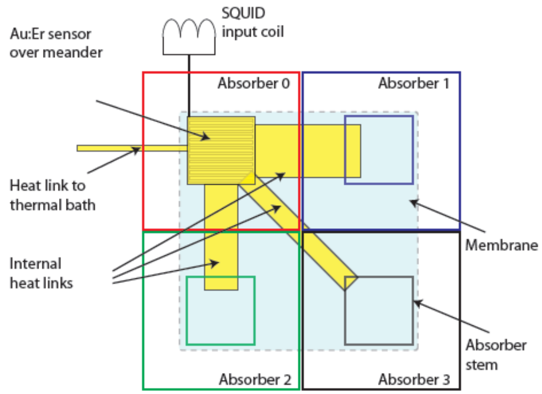
x-ray spectroscopy of HCI @ EBIT

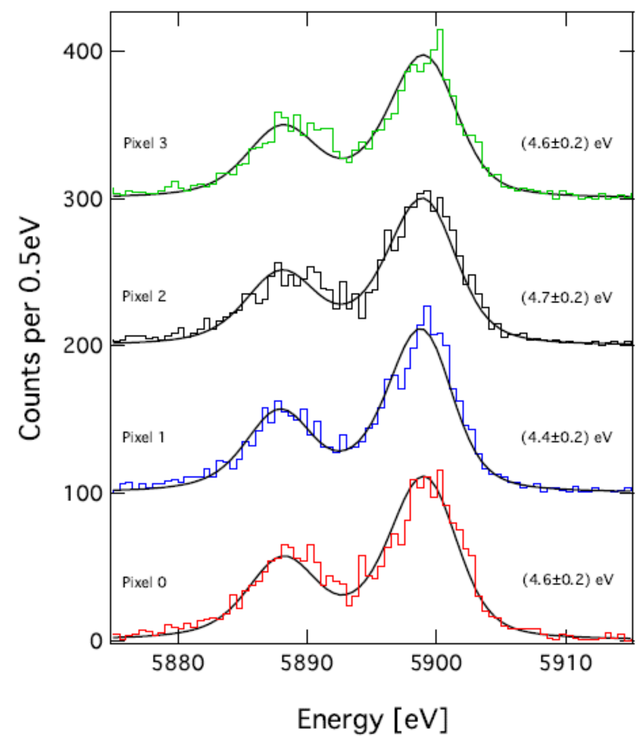
(MPIK-HD, Heidelberg)

detectors with position resolution

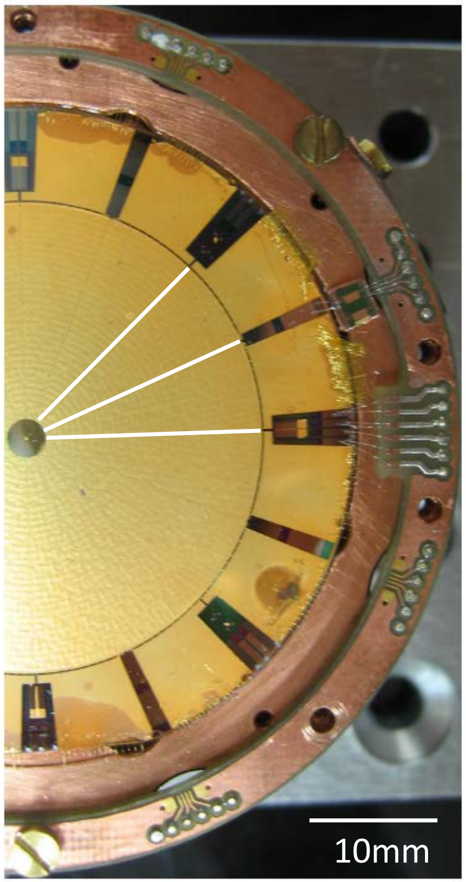
hydra (GSFC)

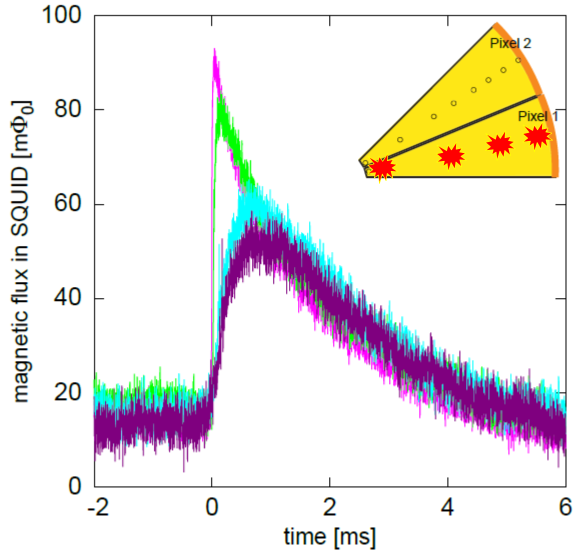




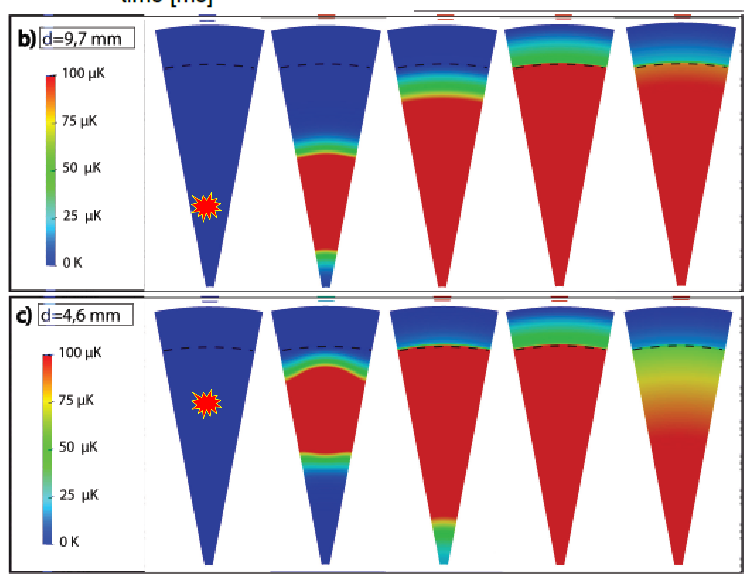


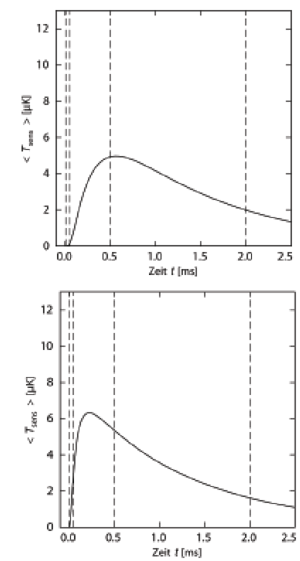
detectors with position resolution





‚Pizza‘ (Heidelberg)





further applications

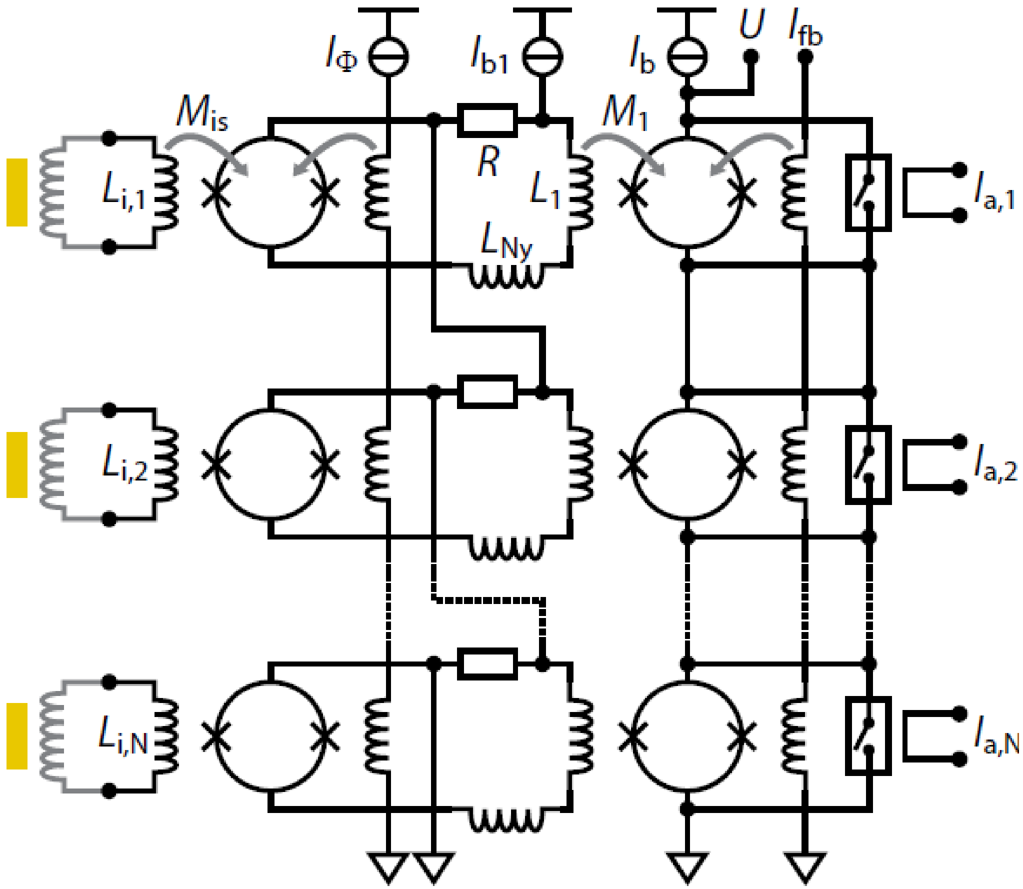
- neutrino mass measurements
  investigation of the neutrino mass is one of the big challenges in particle physics
  - $0\nu\beta\beta$–decay (AMoRE, LUMINEU)
  - EC of ^{163}Ho (ECHo)
  - β-endpoint of ^{187}Re (MARE)

- radiation metrology
  absolute activity and Q value measurements

- spectroscopy of heavy ions and molecular fragments

... and many, many more...

time domain multiplexing

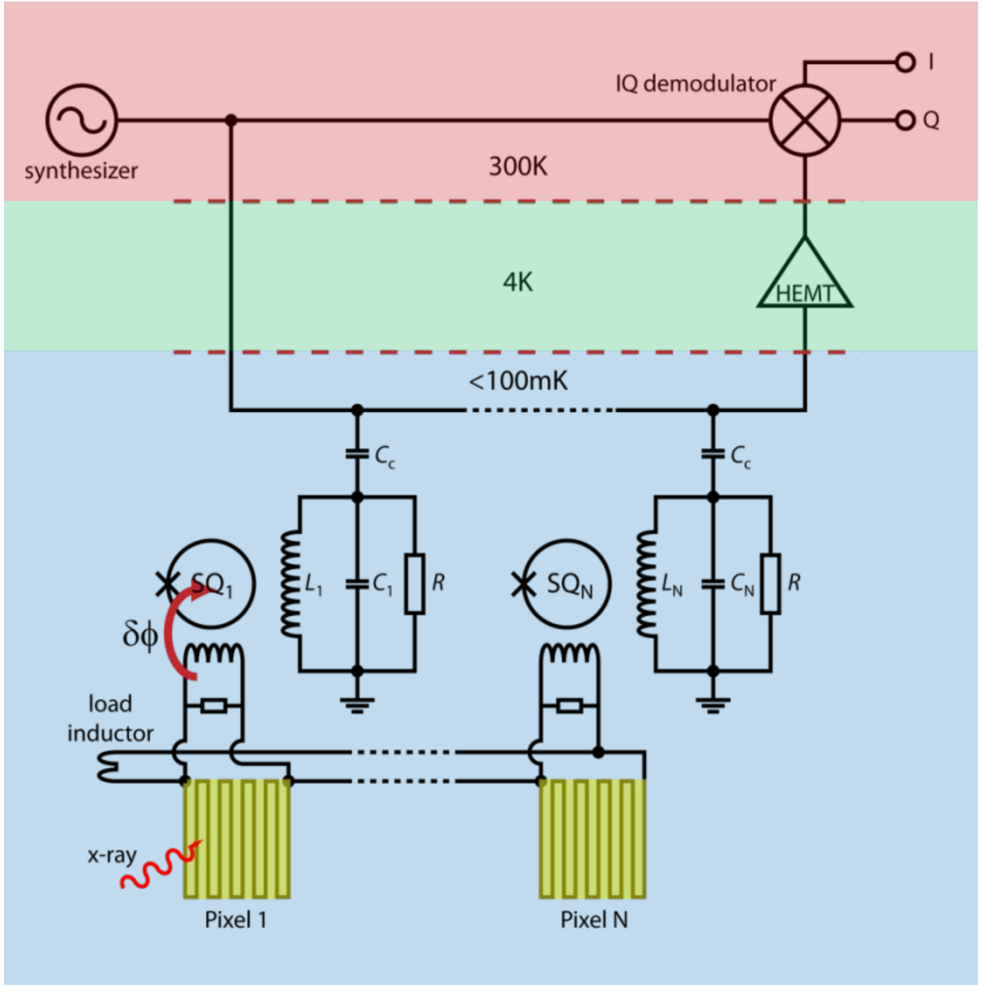


successful TDM demonstration

GSFC detector, PTB Multiplexer, NIST DFB electronics

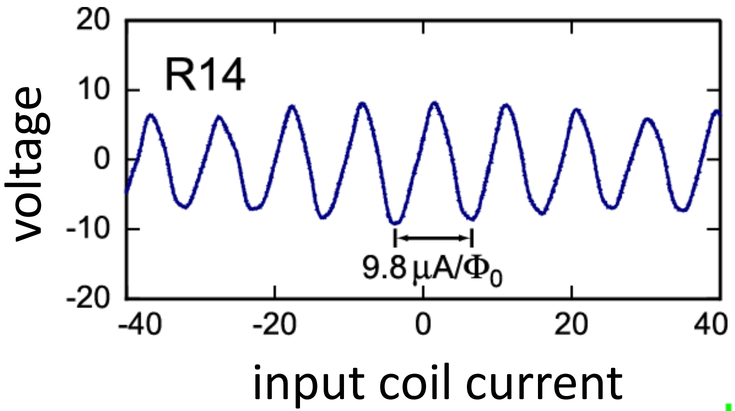
ΔE_{FWHM} = 4.1eV @ 6keV

microwave SQUID multiplexing



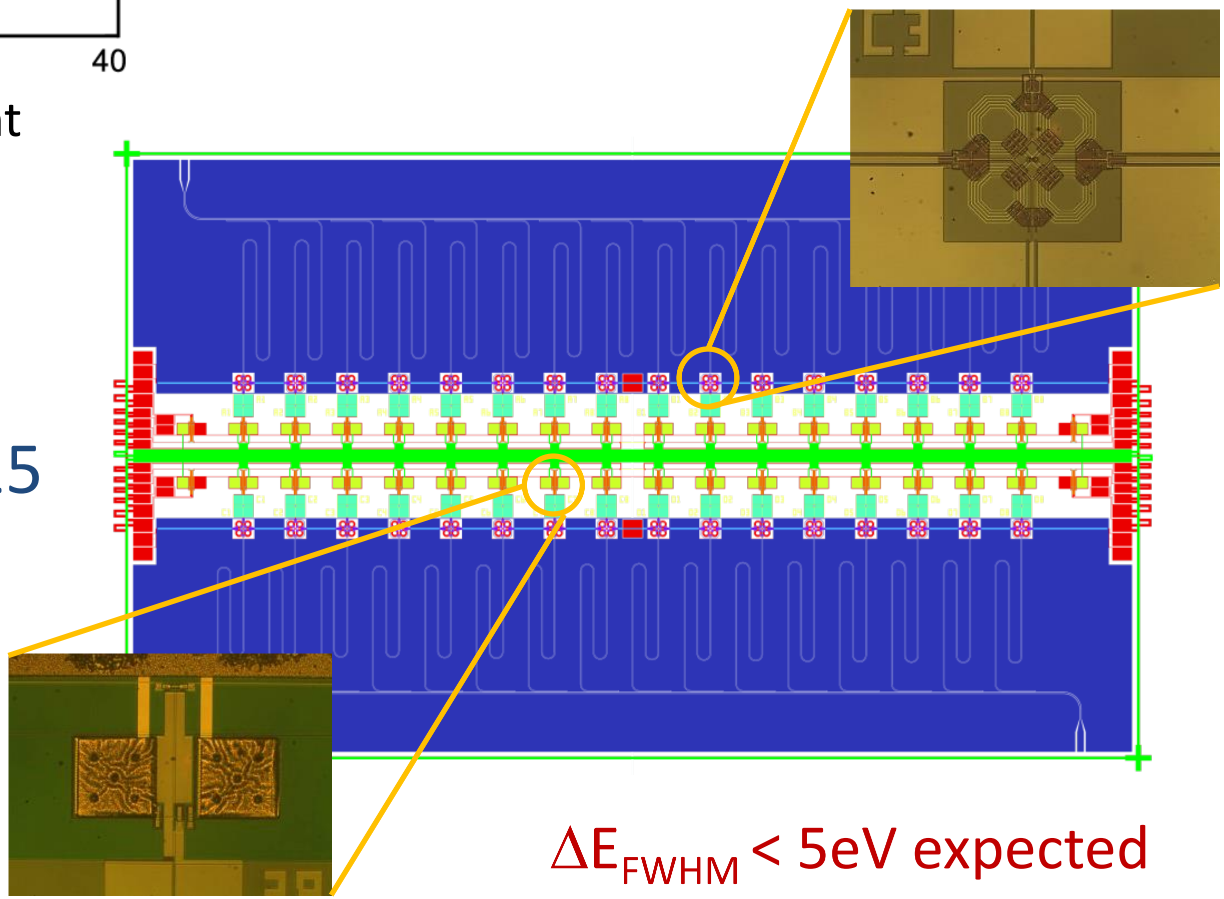
single HEMT and two coaxes for readout of ~1000 detectors

microwave SQUID multiplexing



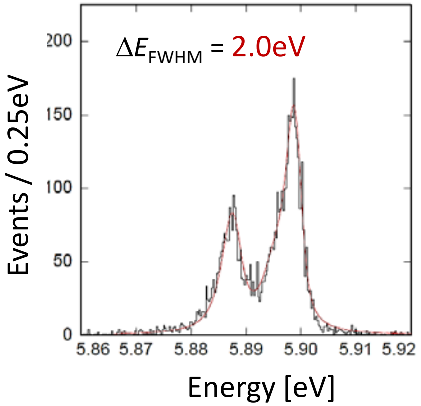
2 years ago @ LTD14 ...

... and now @ LTD 15



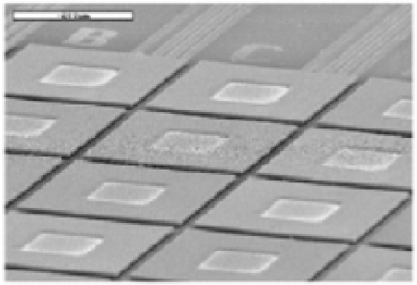
ΔE_{FWHM} < 5eV expected

conclusions



MMCs and MPTs

- flexible detectors
- fast rise times, excellent energy resolution, linearity large spectral bandwidth
- device fabrication ‚mature'

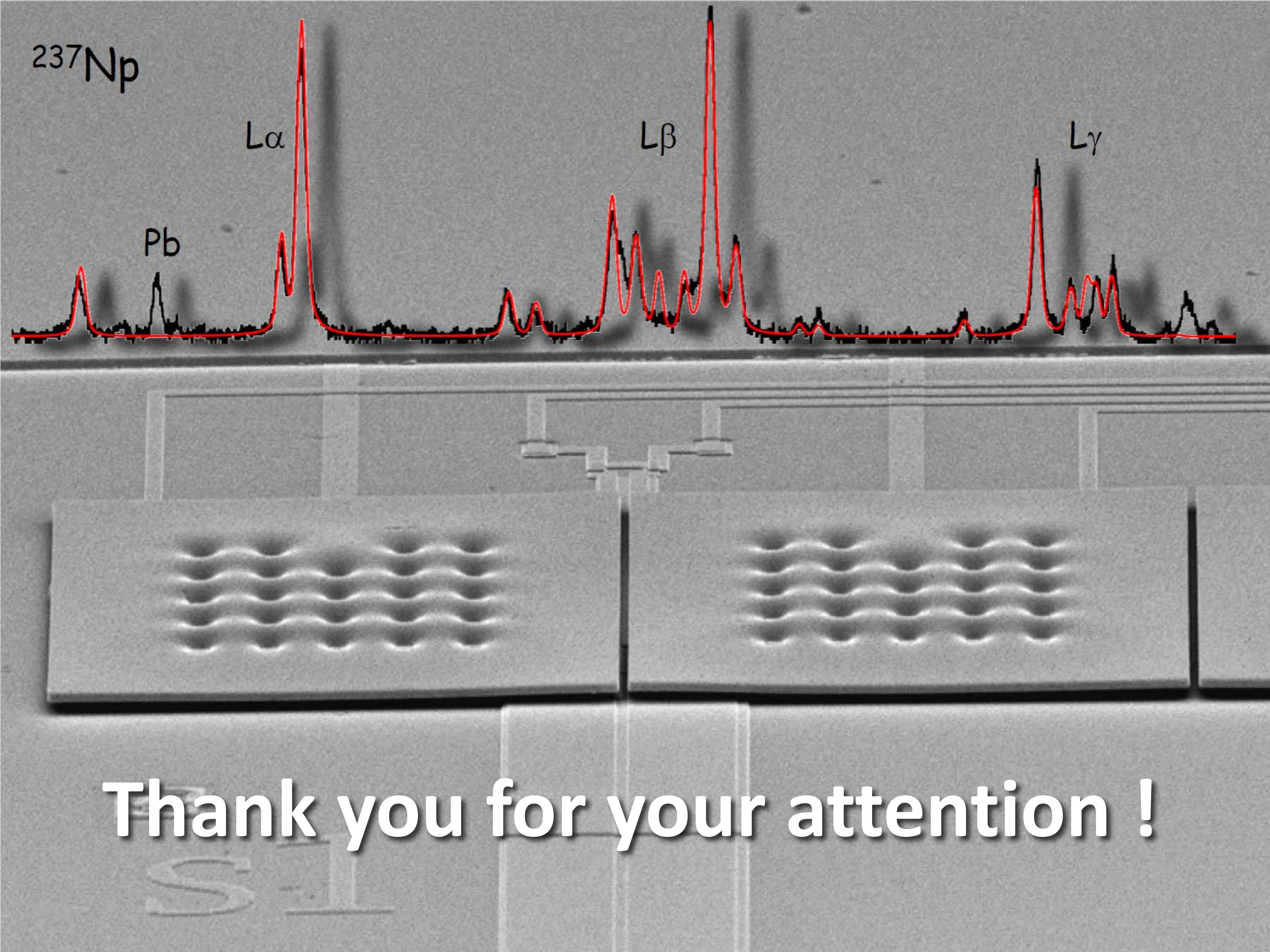


detector arrays and multiplexing

- small size arrays are ‚standard'
- array readout is rapidly progressing
- detector arrays with ~100 pixel in near future

living, fruitful and collaborating MMC / MPT community

Brown, USA	KRISS, South Korea	NIST, USA
CEA, Saclay, France	Leiceister, UK	PTB-Berlin, Germany
Heidelberg, Germany	NASA/GSFC, USA	UNM, USA


^{237}Np
Pb
Lα
Lβ
Lγ
S1
Thank you for your attention !