Development and optimisation of metallic magnetic calorimeter arrays towards ECHo-100k

F. Mantegazzini[1] and T. Wickenhäuser[1]
for the ECHo Collaboration

[1]Kirchhoff Institute for Physics, Heidelberg University

The ECHo Experiment

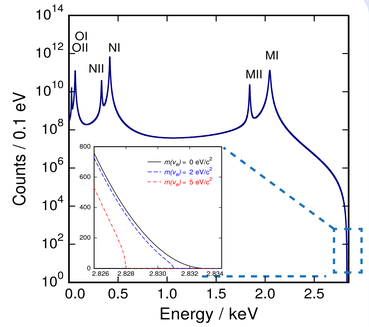
Electron capture in ^{163}Ho :

- Half-life:
  $T_{1/2} \approx 4570$ y → $2 \cdot 10^{11}$ atoms / Bq
- $Q_{EC} < 3$ keV → required resolving power > 1000

$Q_{EC} = (2.833 \pm 0.030^{stat} \pm 0.015^{syst})$ keV
S. Eliseev et al., Phys. Rev. Lett., 115, 062501 (2015)
$Q_{EC} = (2.843 \pm 0.009^{stat} - 0.060^{syst})$ keV
P. C.-O. Ranitzsch et al., Phys. Rev. Lett., 119, 12250 (2017)

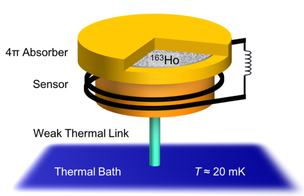
$^{163}_{67}\mathrm{Ho} \rightarrow {}^{163}_{66}\mathrm{Dy}^{*} + \nu_e$

${}^{163}_{66}\mathrm{Dy}^{*} \rightarrow {}^{163}_{66}\mathrm{Dy} + E_C$ → • X-rays • Auger electrons • Coster-Kronig transitions → **Calorimetric measurement** → Source embedded inside detectors

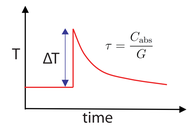


Detector Technology

Metallic **M**agnetic **C**alorimeters (**MMC**s) with implanted ^{163}Ho source



$\Delta T = \Delta E / C_{det}$



$\Delta E \sim \Delta T \sim \Delta\phi \sim \Delta V$

- $C_{det} = 1$pJ/K @ 20 mK → $\Delta T \approx 1$ mK
- $\Delta E = 6$ keV

From ECHo-1k to ECHo-100k

	ECHo-1k	ECHo-100k
^{163}Ho activity	1 Bq / pixel	10 Bq / pixel
number of detectors	100 pixels	10^4 pixels
read-out	parallel	multiplexing
→ total statistics	10^8	$3 \cdot 10^{13}$
→ limit on m(ν_e)	20 eV	2 eV

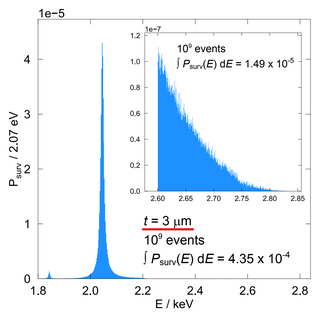
Design Requirements for ECHo-100k

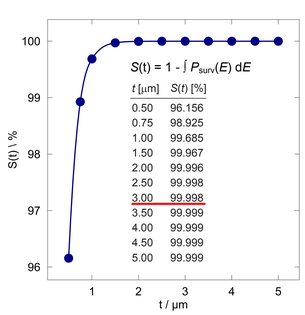
- Increased **signal to noise ratio**
  → reduced detector heat capacity
- High **^{163}Ho implantation efficiency**
  → optimisation of absorbers positioning
- **Read-out flexibility**
  → suitabile for parallel and multiplexed read-out

Single Pixel Optimisation

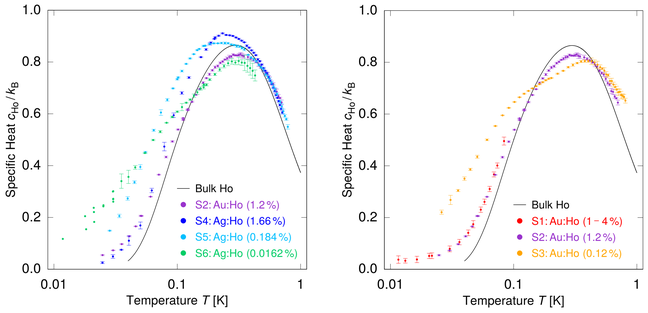
Absorber (optimisation for activity of 10 Bq)

- Montecarlo simulations to determine absorber thickness *t*:
  → minimise heat capacity C_{abs}, ensuring high stopping power *S*





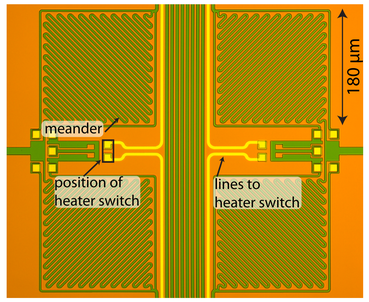
- ^{163}Ho host material: silver
  → ^{163}Ho ions in silver show smaller heat capacity contribution at higher concentration with respect to ^{163}Ho in gold



M. Herbst et al., arXiv:1912.09354v2, submitted to JLTP

Sensor and meanders

- C_{sensor} matches C_{abs}
  → optimised size:
  (168.75 µm) x 0.48 µm
- Sensor material: Ag:Er
  → optimal concentration: 410 ppm
- Meanders: 39 Nb stripes
  → width = 3 µm, pitch = 6 µm, thickness = 250 nm



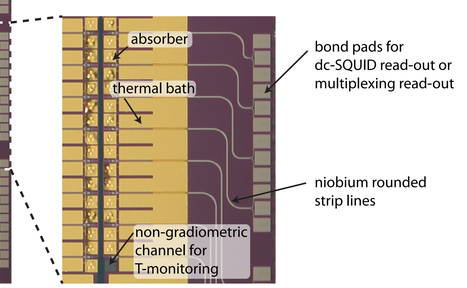
Microscope image of microfabricated round-shaped meanders

Thermal link

- Gold thermal link connecting sensor and thermal bath
- Size: 42.5 µm x 5 µm x 300 nm
  → expected decay time at *T*= 10 mK: $\tau_d \approx 2$ ms

ECHo-100k Detector Chip Layout

- **Compact absorber geometry** for efficient implantation
- **Flexible read-out**: new bondpads scheme
- **Persistent current injection** in meanders quarter by quarter or in all the meanders
- **Rounded niobium lines** to prevent high density of field lines at the corners



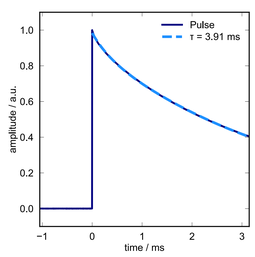
Conclusion and Outlook

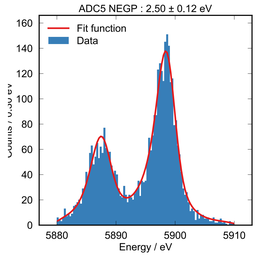
- The new detector design for the ECHo-100k phase has been
  - developed and successfully fabricated
  - tested at 4K and at millikelvin → heater switch for persistent current injection functional and energy resolution as desired
- Next steps:
  - ^{163}Ho implantation
  - characterisation of performances of implanted detectors

ECHo-100k Detector Performances

- Room temperature resistance characterization
  → no shorts, no open circuits
- First tests at $T = 4.2$ K :
  - expected values for resistances measured
  - characterization of persistent current switch
    → average values: $R_H = 50\ \Omega$, $I_H = 1.3$ mA
- First test at $T = 10$ mK :
  - persistent current in meander: $I = 35$ mA
  - characterization with external ^{55}Fe source
  - full functionality has been proven
  - energy resolution: ΔE_{FWHM} @ 6 keV = **2.5 eV**

  → fulfill requirements for ECHo





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The ECHo Experiment