Development of Metallic Magnetic Calorimeter Arrays with Embedded ^{163}Ho for the ECHo Experiment

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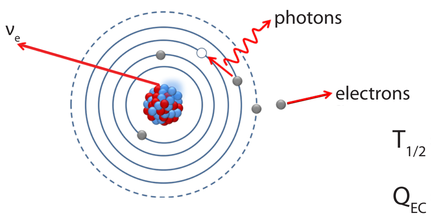
The ECHo Experiment

Electron capture of ^{163}Ho



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

$$^{163}_{66}\mathrm{Dy}^{*} \rightarrow ^{163}_{66}\mathrm{Dy} + E_C$$

$T_{1/2} \approx 4570$ y

$Q_{EC} = (2.833 \pm 0.030^{stat} \pm 0.015^{syst})$ keV

S. Eliseev et al., Phys. Rev. Lett., 115, 062501 (2015)

$Q_{EC} = (2.843 \pm 0.009^{stat} - 0.060^{syst})$ keV

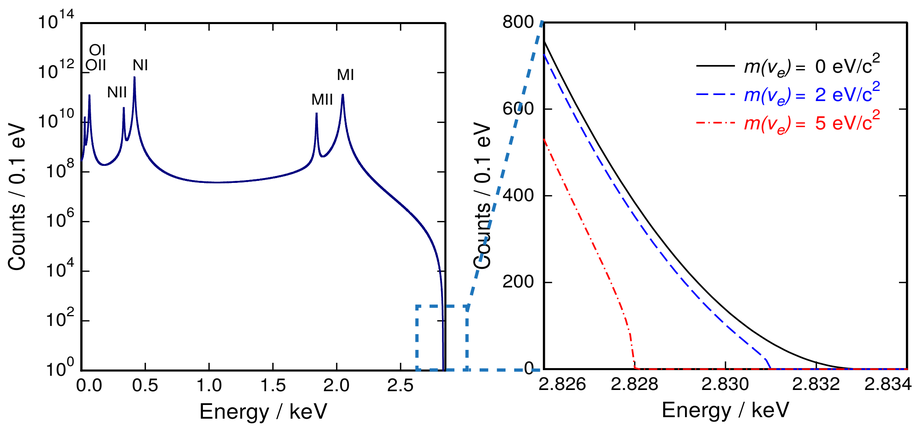
P. C.-O. Ranitzsch et al., Phys. Rev. Lett., 119, 12250 (2017)

Atomic de-excitation:

- X-ray emission
- Auger electrons
- Coster-Kronig transitions

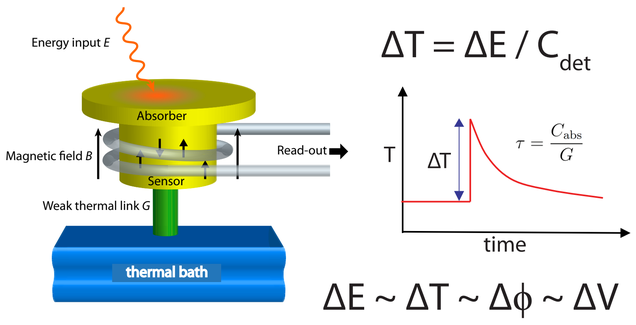
→ Calorimetric measurement

^{163}Ho calorimetrically measured spectrum



MMC Working Principle

Metallic magnetic calorimeter (MMC)



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

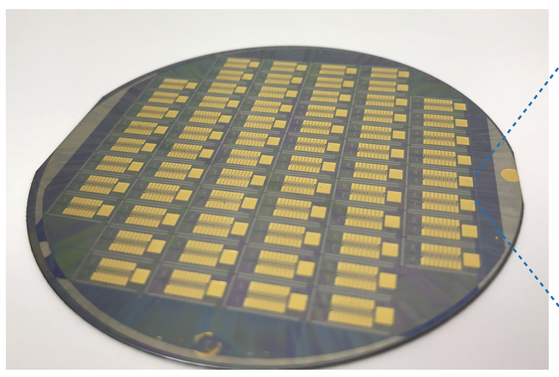
Typical MMC

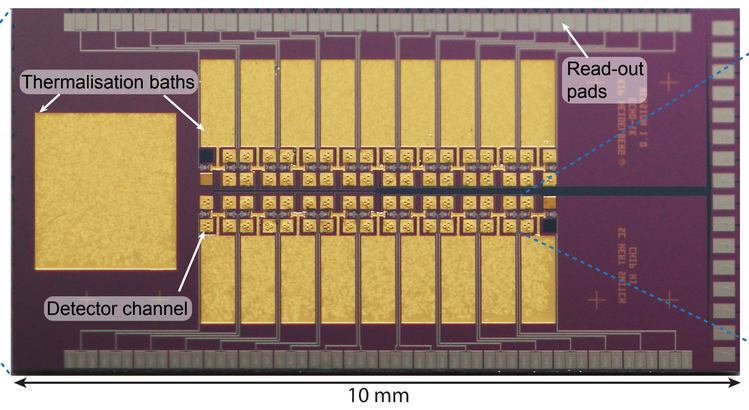
- C_{det} = 1pJ/K @ 20 mK
- ΔE = 6 keV

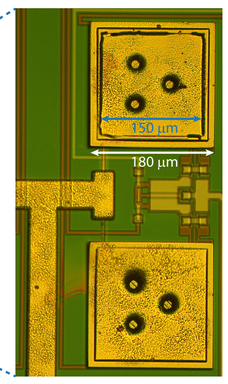
→ $\Delta T \approx 1$ mK

Detector Layout and Implantation

ECHo-1k detector chip: 64-pixels MMC array for implantation with ^{163}Ho

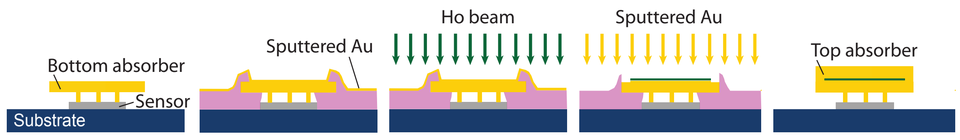






- Absorbers (first layer): gold layers 180 µm x 180 µm x 5 µm
- ^{163}Ho implantation area: 150 µm x 150 µm
- Chemically purified Holmium implanted with a mass selective ion beam
- Absorbers (second layer): gold layers 165 µm x 165 µm x 5 µm

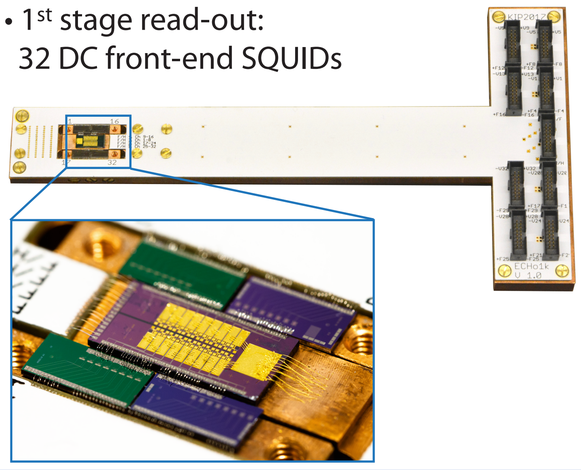
- Lithographic microfabrication on a 380 mm thick 3" silicon wafer
- 36 detector channels (4 non-gradiometric for temperature monitoring)



Cryogenic Set-up and Detector Characterisation

Detector platform

- Copper holder → good thermalisation
- Dedicated circuit board
- Gold bondings to ensure detector thermalisation
- 1st stage read-out: 32 DC front-end SQUIDs

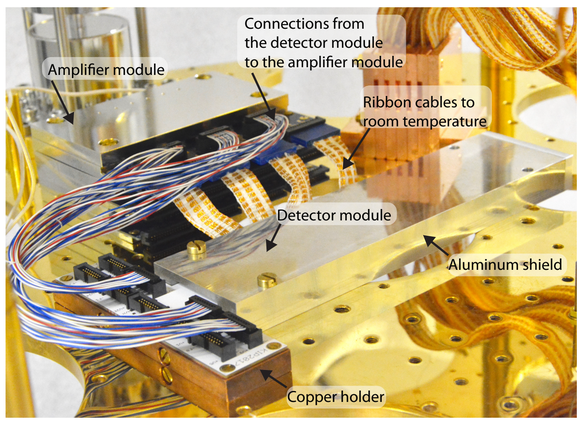


2-stage amplifier SQUID module

- 12 amplifier SQUIDs
- Tin plated copper housing
  - → Good thermal contact
  - → Electromagnetic shielding

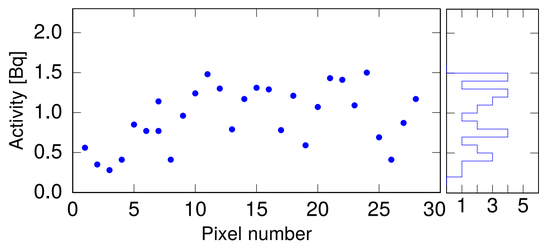
Full mounted set-up

- 32 channels for parallel read out
- Mounted at the cryostat mixing chamber plate ($T \approx 8$ mK)
- T-shaped copper holder with aluminium shielding against external magnetic fields

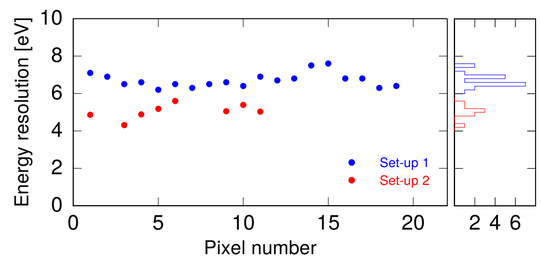


System characterisation

- Activity per pixel: average activity = 1.06 Bq / pixel

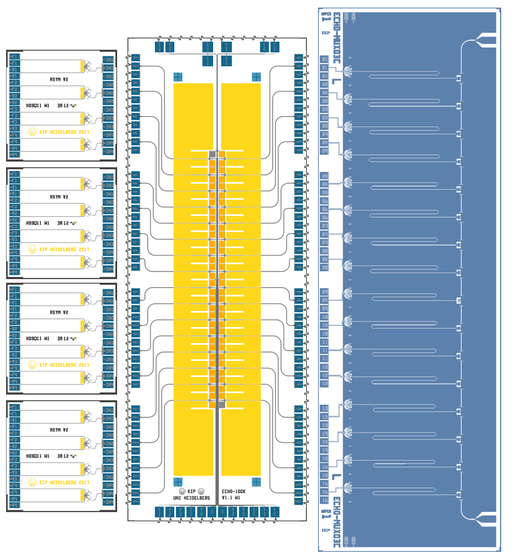


- Energy resolution: ΔE_{FWHM} @ 0.41 keV (NI line) between 6.0 eV and 7.7 eV



- Total background: $< 1.6 \cdot 10^{-6}$ events/eV/det/day

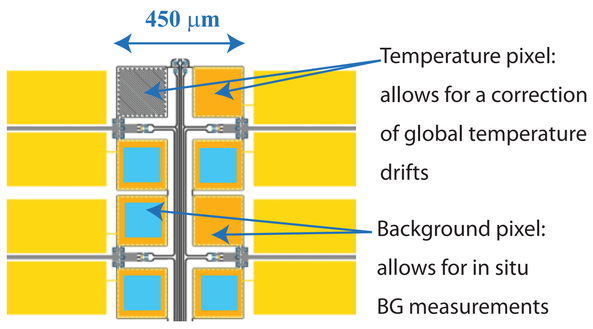
New Detector Design

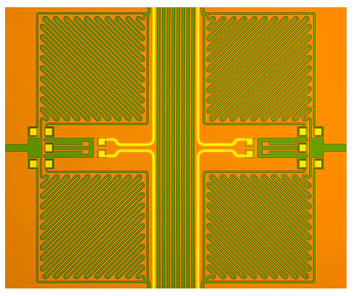


Parallel read-out: 4 ch. dc-SQUIDs chip x 8

Multiplexed read-out: 16 ch. MUX chip x 2

- Absorber thickness = 2.5 µm → minimisation of absorber heat capacity, keeping high quantum efficiency
- Compact absorber geometry for highly efficient ^{163}Ho implantation
- Flexible read-out: parallel / multiplexing





Microscope image of microfabricated round-shaped meanders

Summary and Outlook

- ECHo 1st generation MMC arrays were successfully
  - produced and tested
  - implanted with ^{163}Ho source
- New design for next generation MMC arrays for ECHo has been developed and it's currently being produced

Next steps:

- characterisation of new design at mK temperatures
- ^{163}Ho implantation on wafer scale
- characterisation of different ^{163}Ho implantation concentrations
- characterisation of different host materials for implanatation

The ECHo Experiment