Development of MMC Arrays for the ECHo experiment

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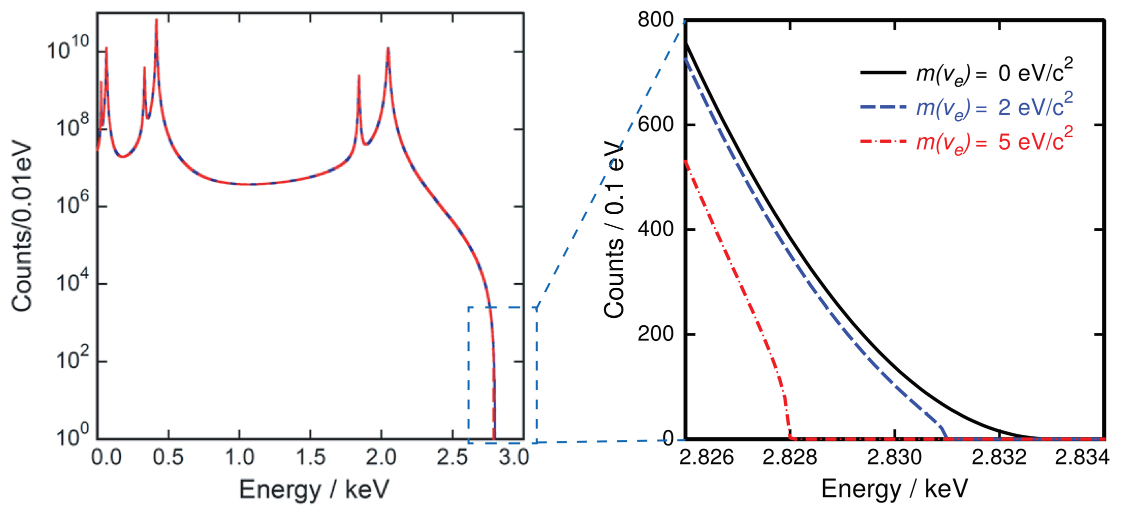
The ECHo experiment

The Electron Capture in Holmium (ECHo) experiment aims to determine the electron neutrino mass by the analysis of the electron capture (EC) spectrum of ^{163}Ho.



Detector technology: metallic magnetic calorimeters

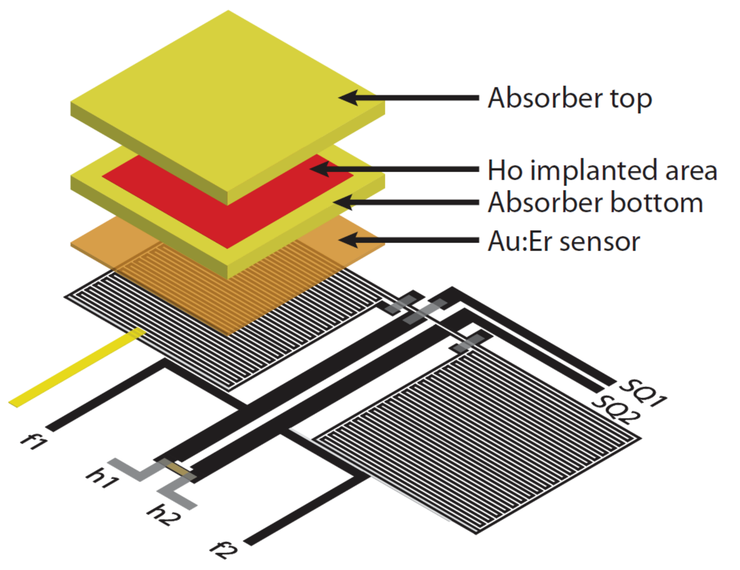
Detector requirements for ECHo:

1) High energy resolution
→ to reduce the smearing in the spectrum

2) Fast response
→ to minimise unresolved pile-up

3) Good linearity
→ to achieve reliable energy calibration

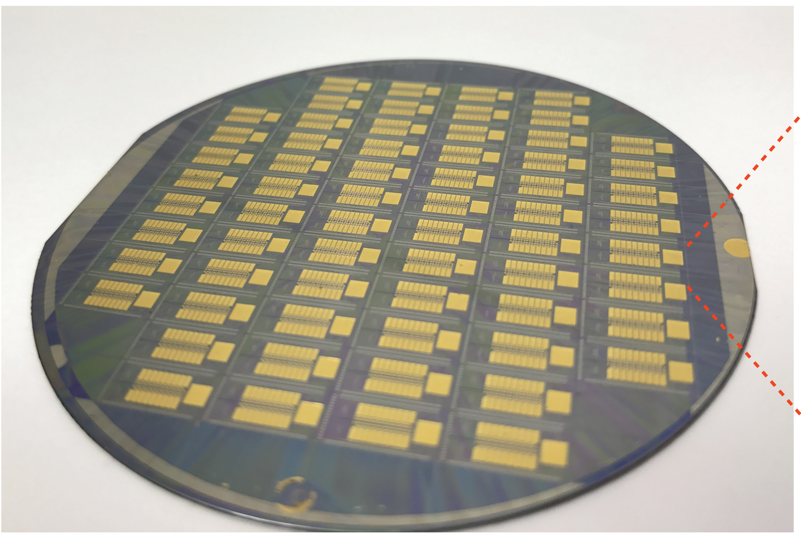
4) Radio pure materials
→ to reduce background

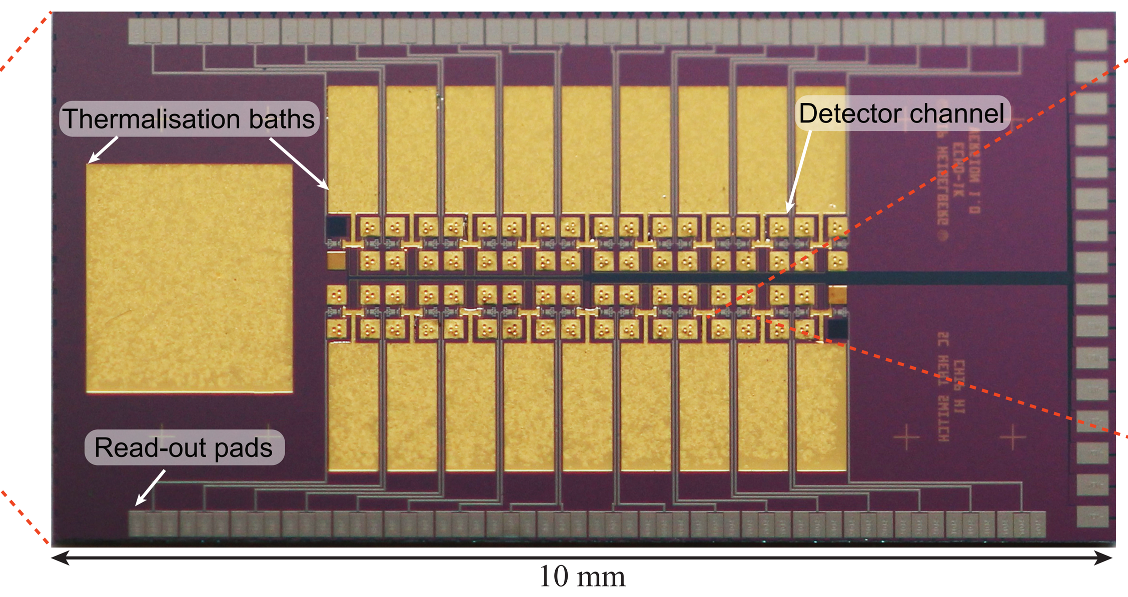


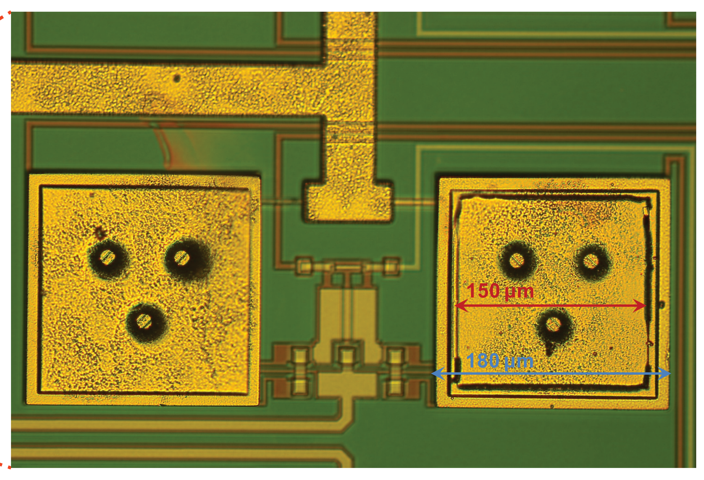
energy deposition δE → temperature change $\delta T = \frac{\delta E}{C_{\mathrm{tot}}}$ → change of magnetization $\delta M = \frac{\partial M}{\partial T}\frac{\delta T}{C_{\mathrm{tot}}}$ → change of magnetic flux in SQUID $\delta\Phi \propto \delta M \propto \delta E$

Detector layout and implantation

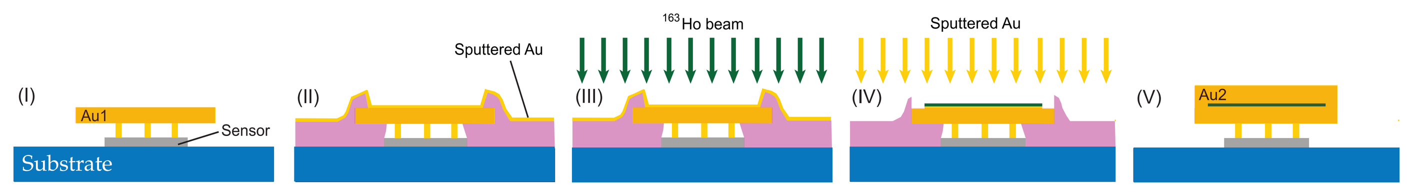
ECHo-1k detector chip: 64-pixels MMC array for implantation with ^{163}Ho







- ^{163}Ho implantation area: 150 µm x 150 µm
- Absorbers: gold layers (180 µm x 180 µm x 5 µm) x 2
- Chemically purified ^{163}Ho implanted with a mass selective ion beam

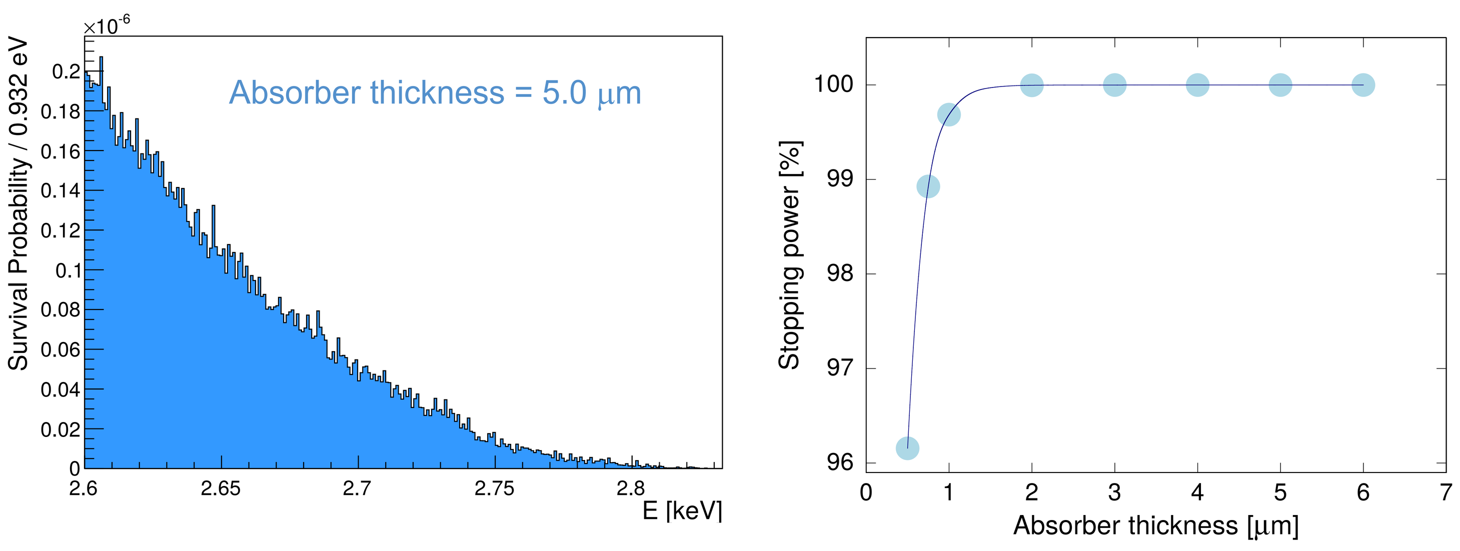


- Lithographic microfabrication on a 380 mm thick 3′′ silicon wafer
- 36 detector channels (2 non-gradiometric for temperature monitoring)

Detector optimisation and characterisation

Quantum efficiency studies

Monte Carlo simulations to estimate stopping power for ^{163}Ho electron capture photons for different absorber geometries

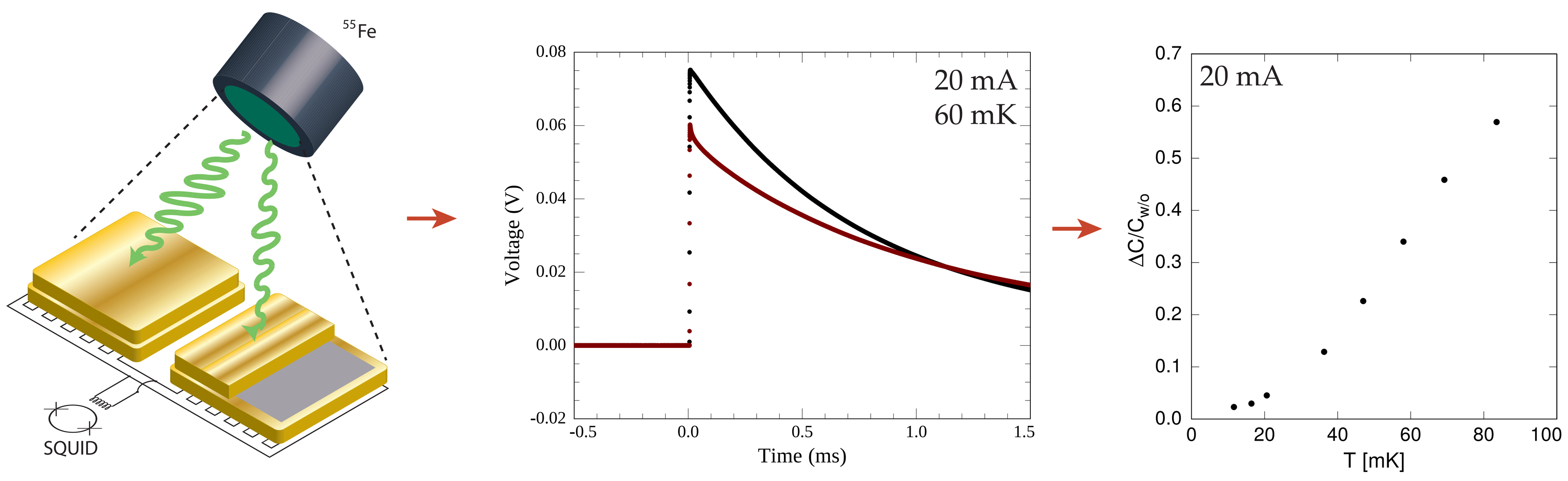


→ New absorber geometry for next generation ECHo design with reduced volume → reduced heat capacity

→ Optimisation of energy resolution: $\Delta E_{\mathrm{FWHM}} \propto (C_{\mathrm{abs}})^{1/2}$
→ Optimisation of signal amplitude: $A \propto E/C$

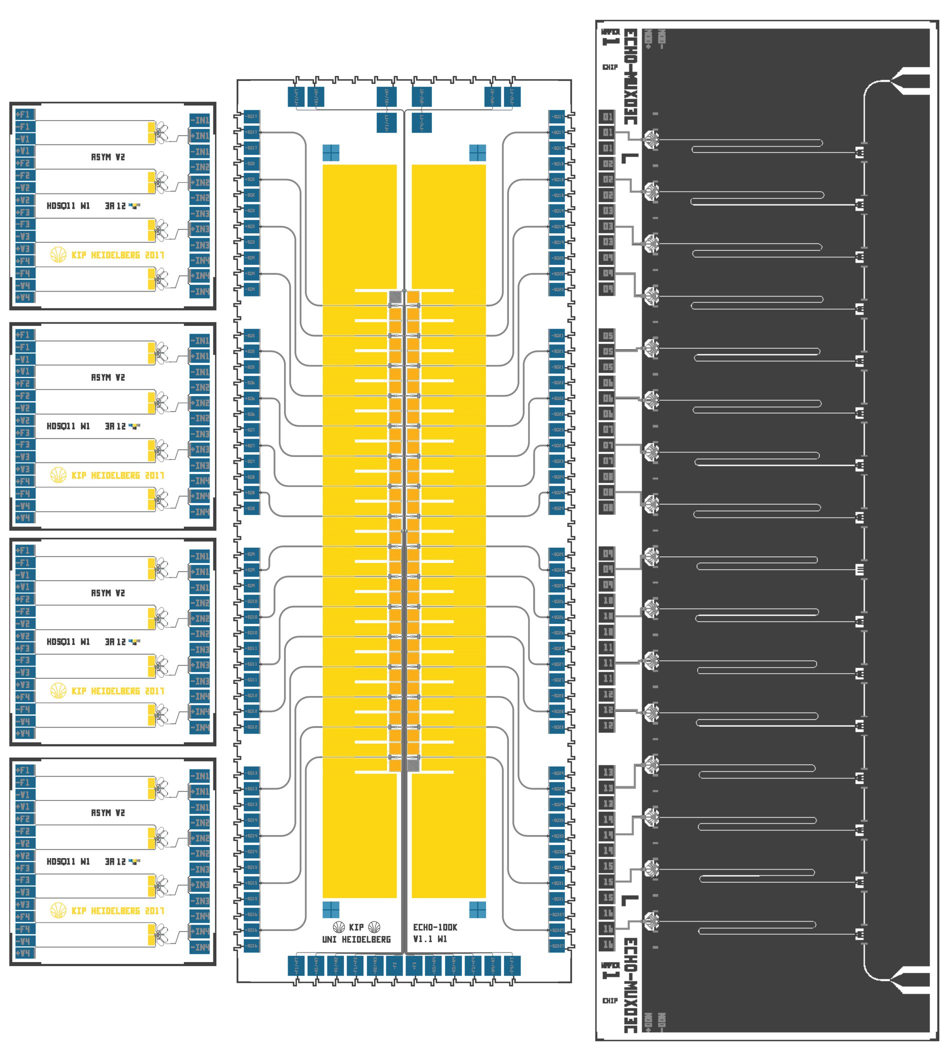
^{163}Ho heat capacity contribution

- Measurement of heat capacity due to ^{163}Ho atoms
  → signal amplitude comparison for detectors with/without implanted ^{163}Ho



- At working temperature of 20 mK the effect due to ^{163}Ho is $\sim$4% for an activity of 0.9 Bq
- The ^{163}Ho heat capacity contribution sets the lower limit to the heat capacity for a given activity in the detector

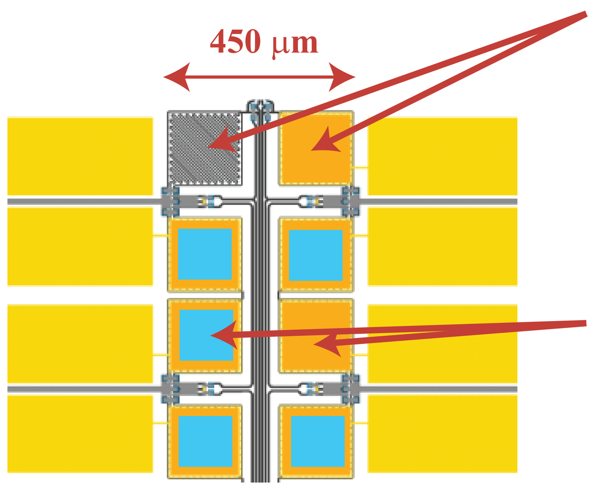
New detector design



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



Temperature pixel: allows for a correction of global temperature drifts

Background pixel (only one of two pixels of one detector is implanted with ^{163}Ho): allows for in situ BG measurements

^{163}Ho implanted

Summary and outlook

- ECHo 1st generation MMC arrays were successfully
  - produced and tested
  - implanted with ^{163}Ho source
- Optimisation studies have been performed in order to enhance energy resolution and signal amplitude
  - quantum efficiency studies
  - measurement of ^{163}Ho heat capacity contribution
- A new design for next generation MMC arrays for ECHo has been developed

Next steps:

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