



Determination of fractional electron capture probabilities of Nickel-59 by means of Metallic Magnetic Calorimeters

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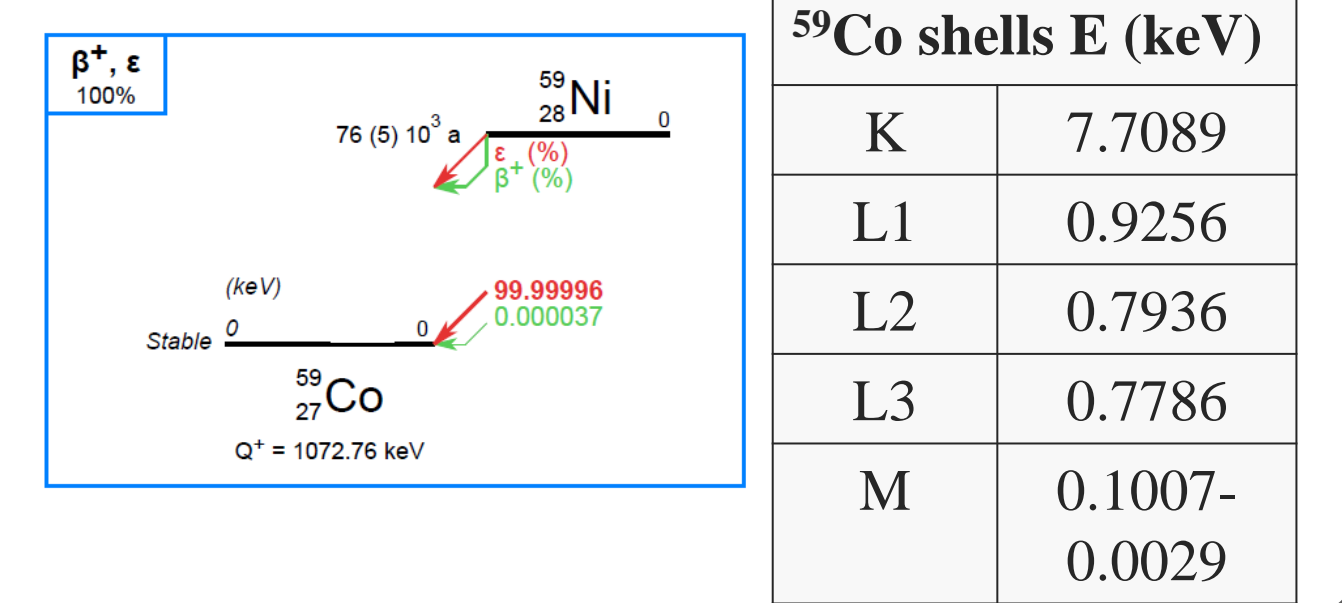
The measurement is part of the European metrology research project MetroMMC (2018-21). In the project, MMCs have been optimized and utilized for decay energy spectrometry of radionuclides decaying via electron capture (EC). Several EC-decaying radionuclides emitting radiation in the energy range between 20 eV and 100 keV were selected.

The project's main objectives are to measure fractional electron capture probabilities and absolute X-ray emission intensities. To improve theoretical models and calculations of electron capture and subsequent atomic relaxation and to validate the theoretical data with the high-precision experimental data from this project.

Motivation

Nickel-59, one of the radionuclides chosen for the MetroMMC project, decays mainly by EC to the ground state of Co-59 and has a long half-life of 76,000 years. The decay is a 2^{nd} forbidden non-unique transition. The main applications where the electron capture probability ratios are required are:

- Isotope geology: ^{59}Ni is used to date meteorites and determine the abundance of extraterrestrial dust in ice and sediment.
- Nuclear power plant radioactive waste qualification: ^{59}Ni is produced in nuclear reactors as an activation product of Ni-cladded control rods and other steel structural components. It is present in nuclear waste, and its detection is very difficult because of its long half-life and no γ -ray emission.



Detection technique: Metallic Magnetic Calorimeters (MMCs)

- MMCs with the radionuclide embedded in the absorber \rightarrow Decay energy spectrometry (DES).

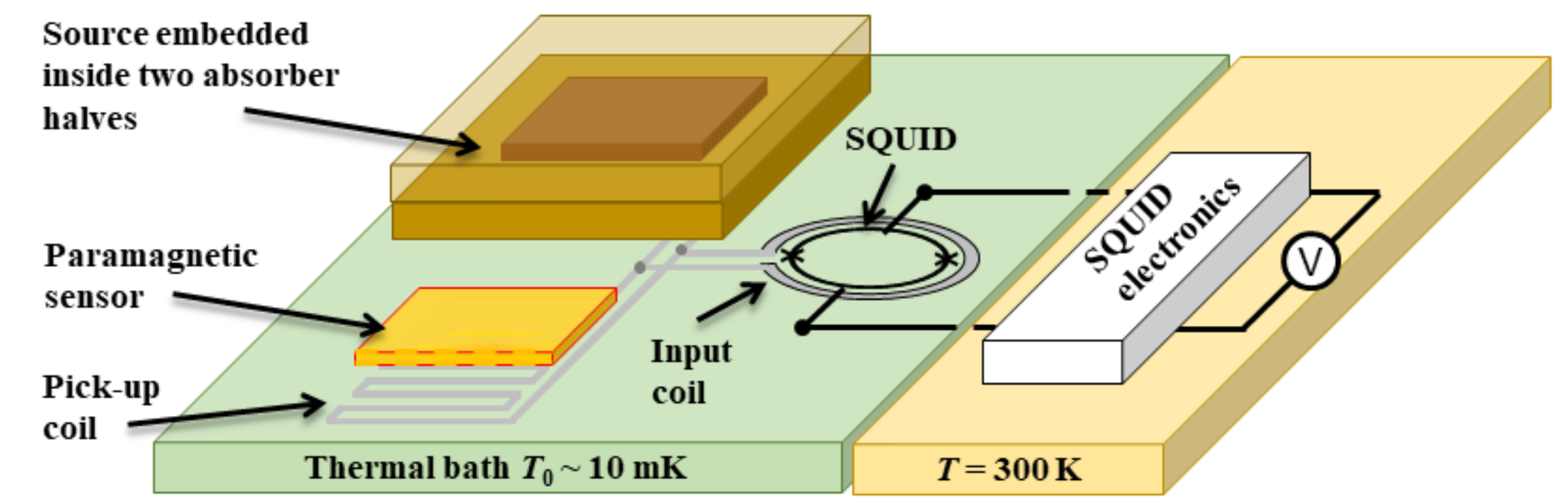
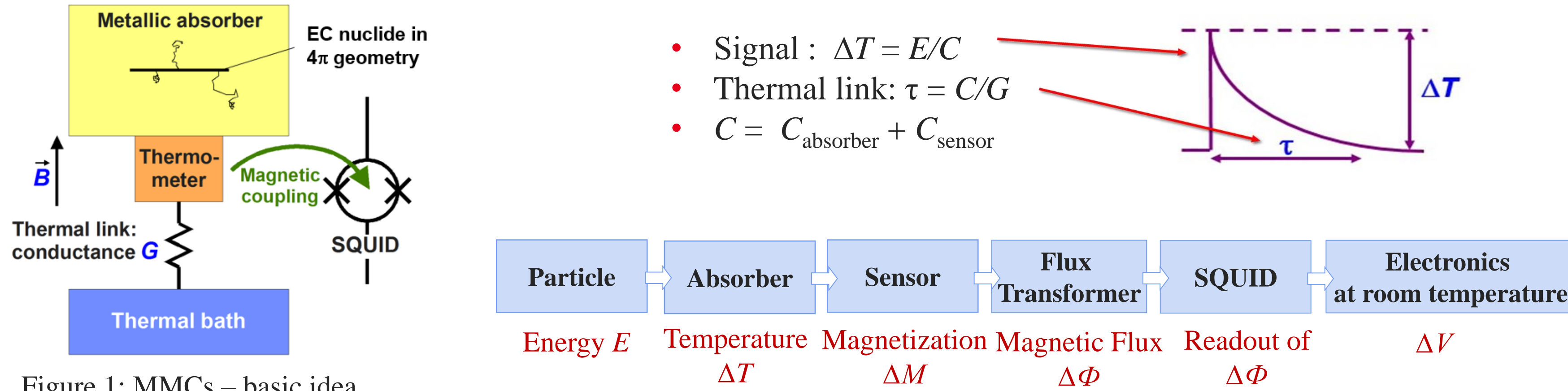


Figure 2: MMC readout by DC SQUID magnetometer via a superconducting flux transformer.

Absorber and source preparation

I. Electrodeposition Method

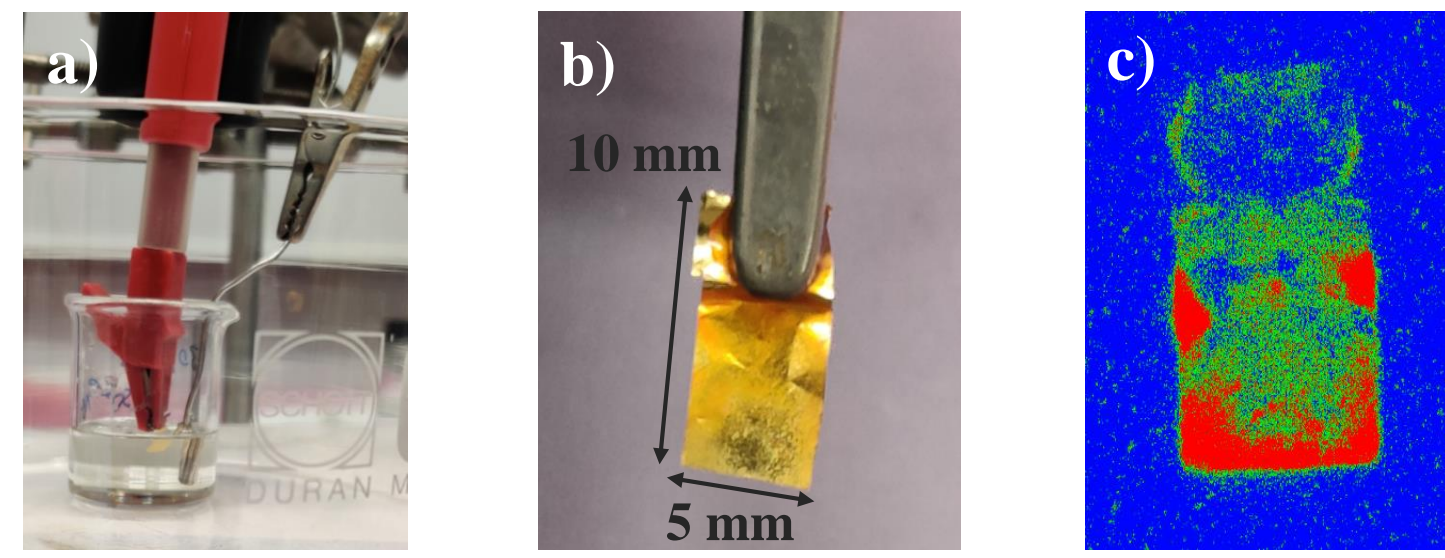


Figure 3: a) Electroplating setup b) Source foil after plating c) Autoradiography of the source foil.

II. Micro-drop deposition on gold nanofoam

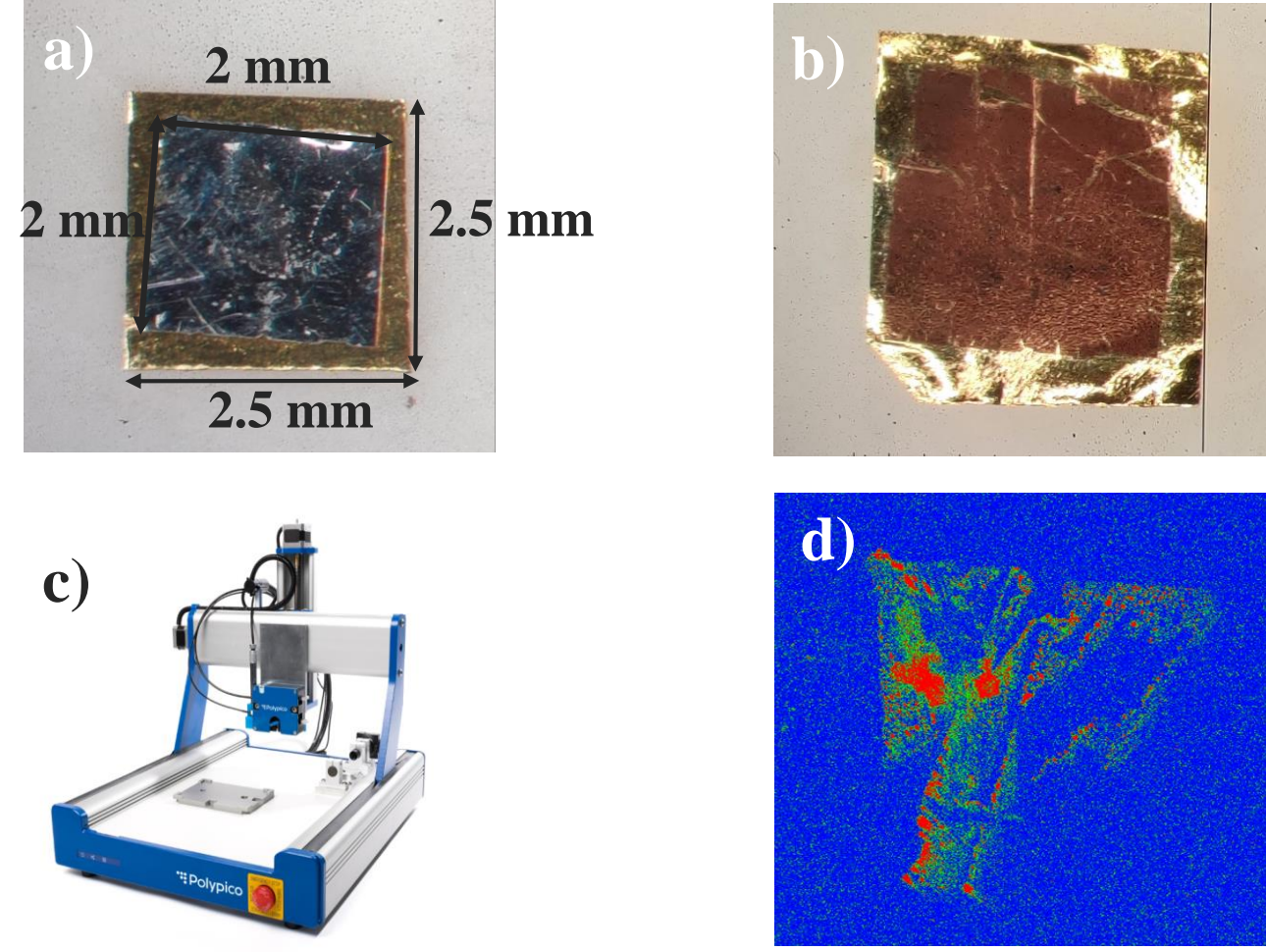


Figure 4: a) AuAg alloy on Au foil b) Micro-drop deposition on gold nanofoam c) Micro-drop dispenser d) Autoradiography of the source foil.

- Figure 4a: $\text{Au}_{0.3}\text{Ag}_{0.7}$ (wt%) alloy ($2 \times 2 \times 0.006 \text{ mm}^3$) diffusion welded on gold foil ($2.5 \times 2.5 \times 0.01 \text{ mm}^3$).
- Figure 4b: Gold nanofoam by dealloying through wet etching with 20% HNO_3 for 2 hours at 50°C , dissolving silver, and forming nanoporous gold.
- Figure 4c: Micro-drop dispenser setup. For a 3 Bq activity, the drop volume was 41 nL (1216 drops); for 4 Bq, it was 55 nL (1671 drops).
- Figure 4d: Autoradiography of one of the sources.

Experiment setup:

Decay energy spectrometry (DES)

- In DES measurement mode, the source is fully enclosed between the two absorber halves (Figure 5a) to have a 4π detection geometry (Figure 5b).
- The decay energy from the source, except the neutrino, is thermalized inside the absorber. The obtained energy spectrum shows a single peak for each capture electron shell.

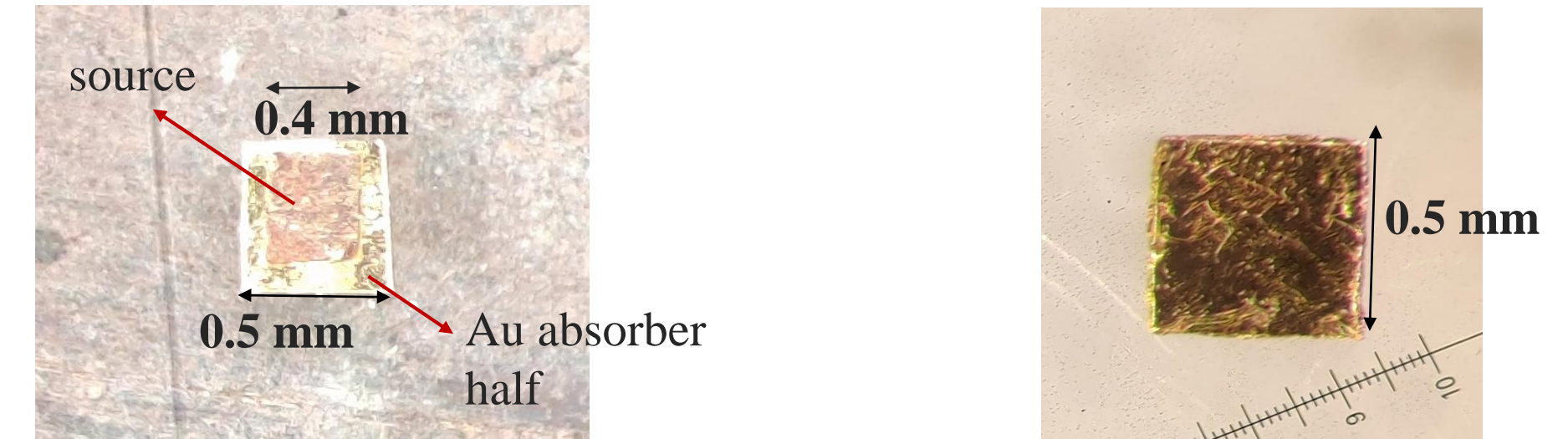


Figure 5: a) Source foil on one half of Au absorber b) Complete absorber-source ensemble.

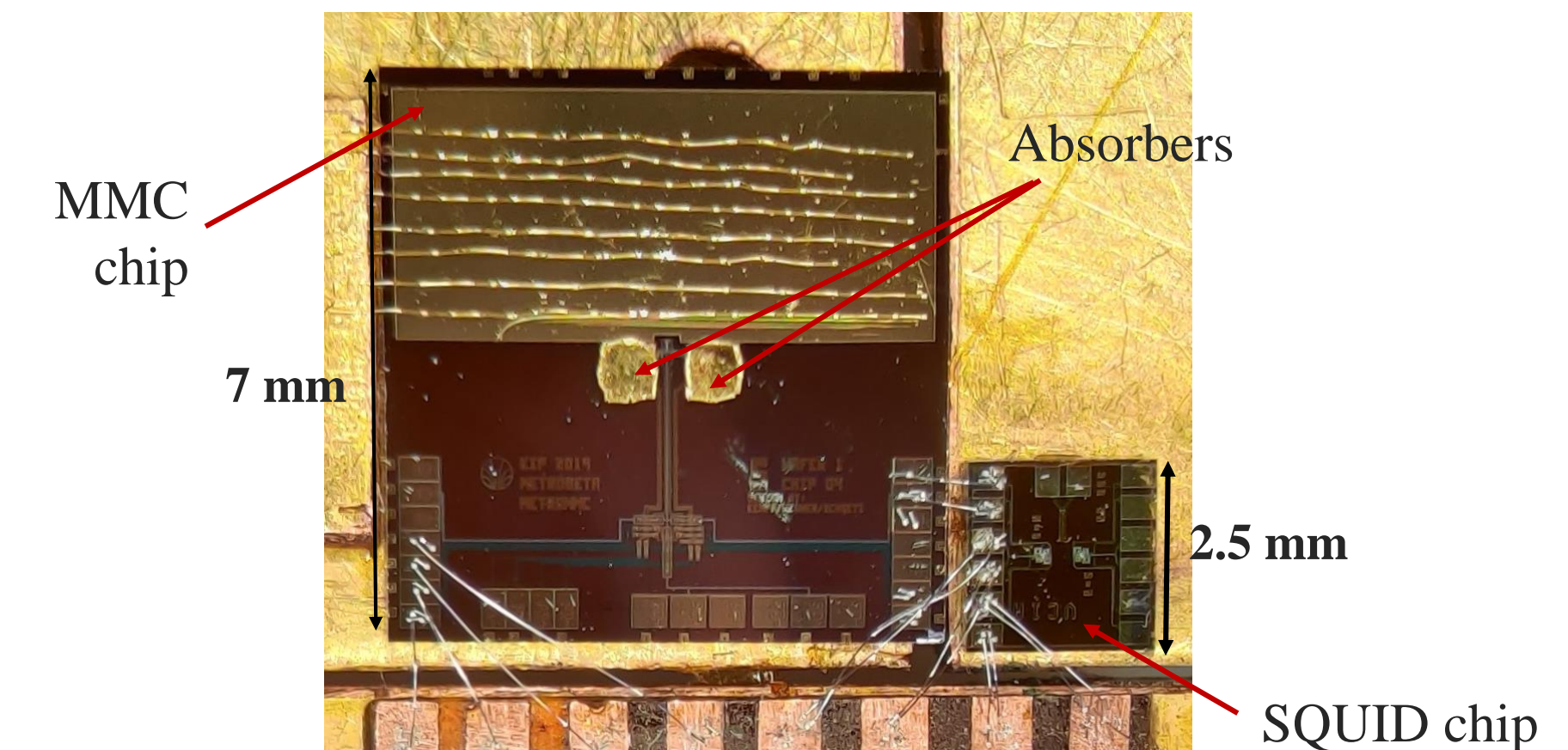


Figure 6: MMC detector setup.

Spectrum analysis and results

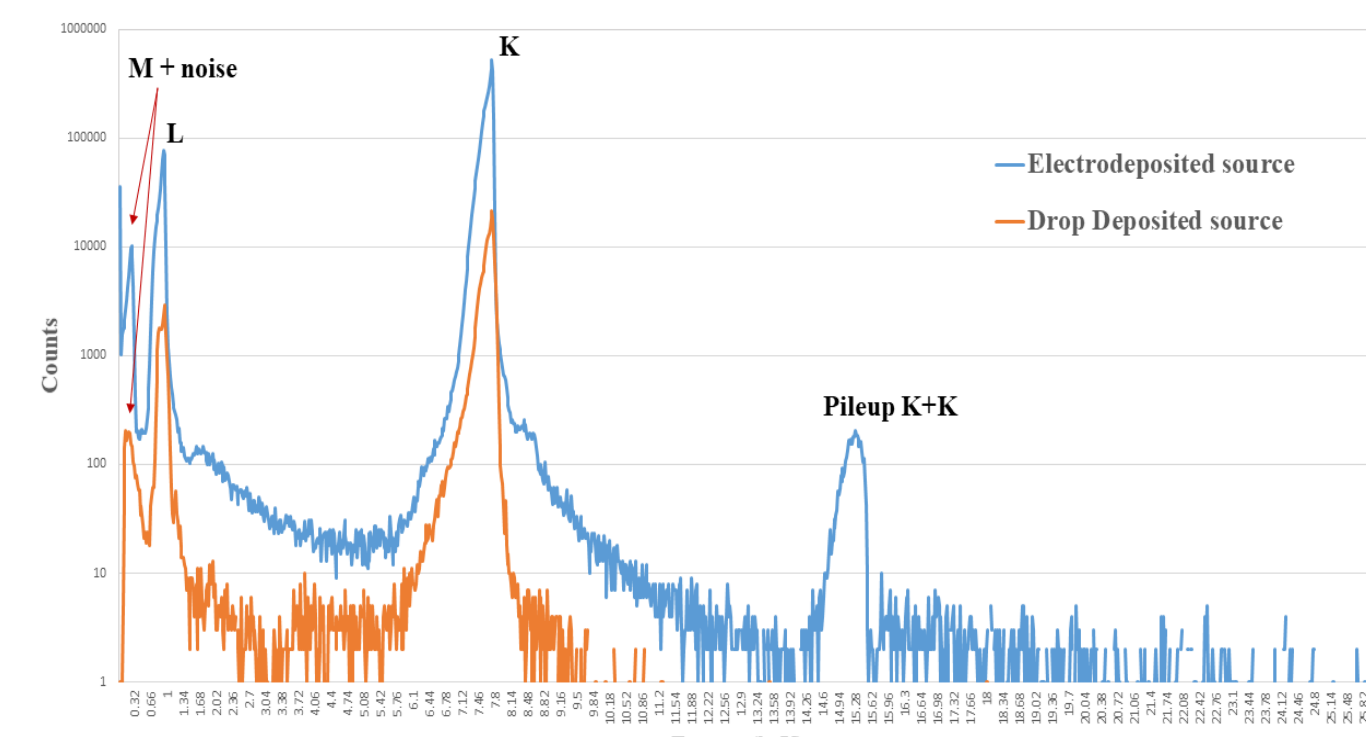


Figure 7: Comparison of both source's total energy spectra of ^{59}Ni .

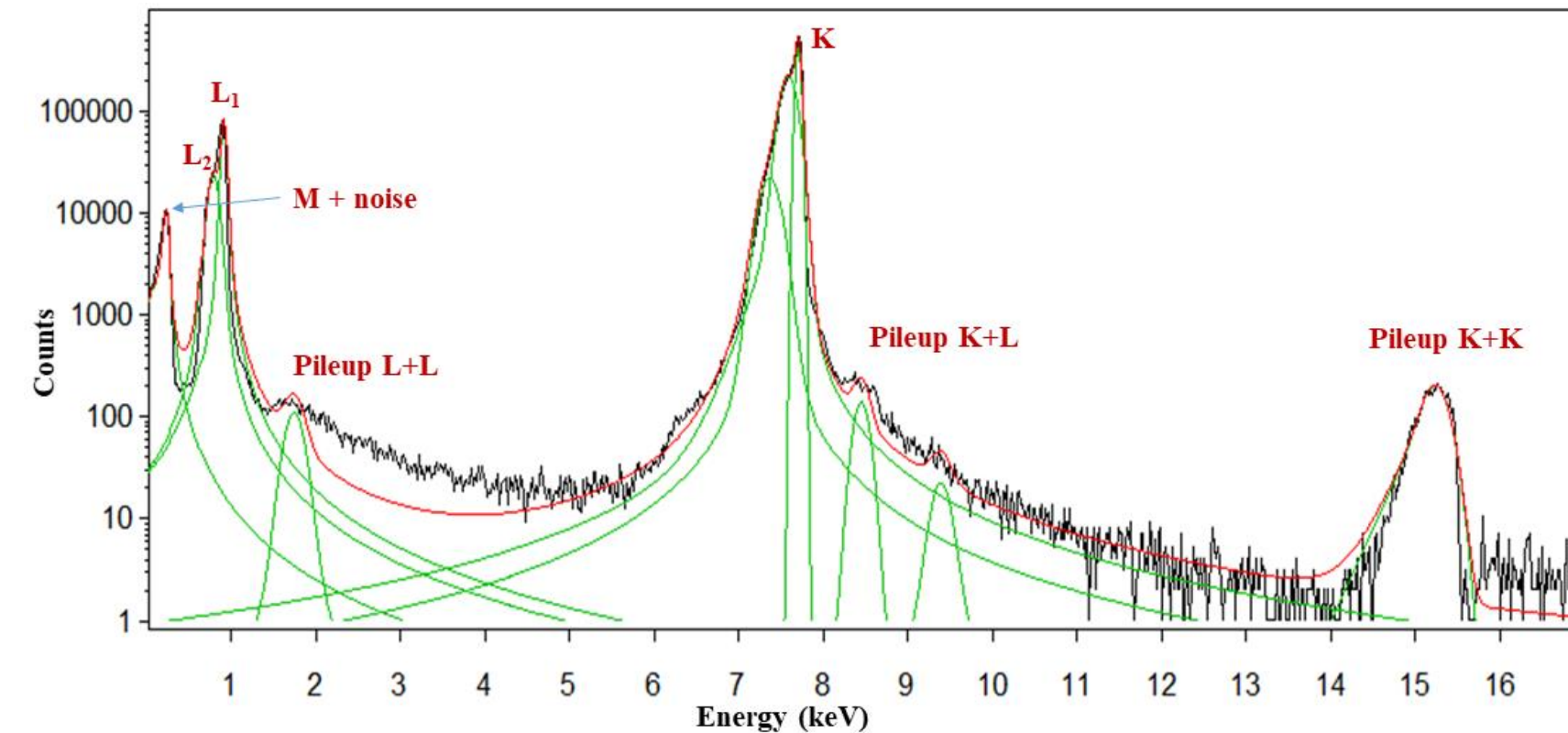


Figure 8: The fitted energy spectrum of electrodeposited ^{59}Ni .

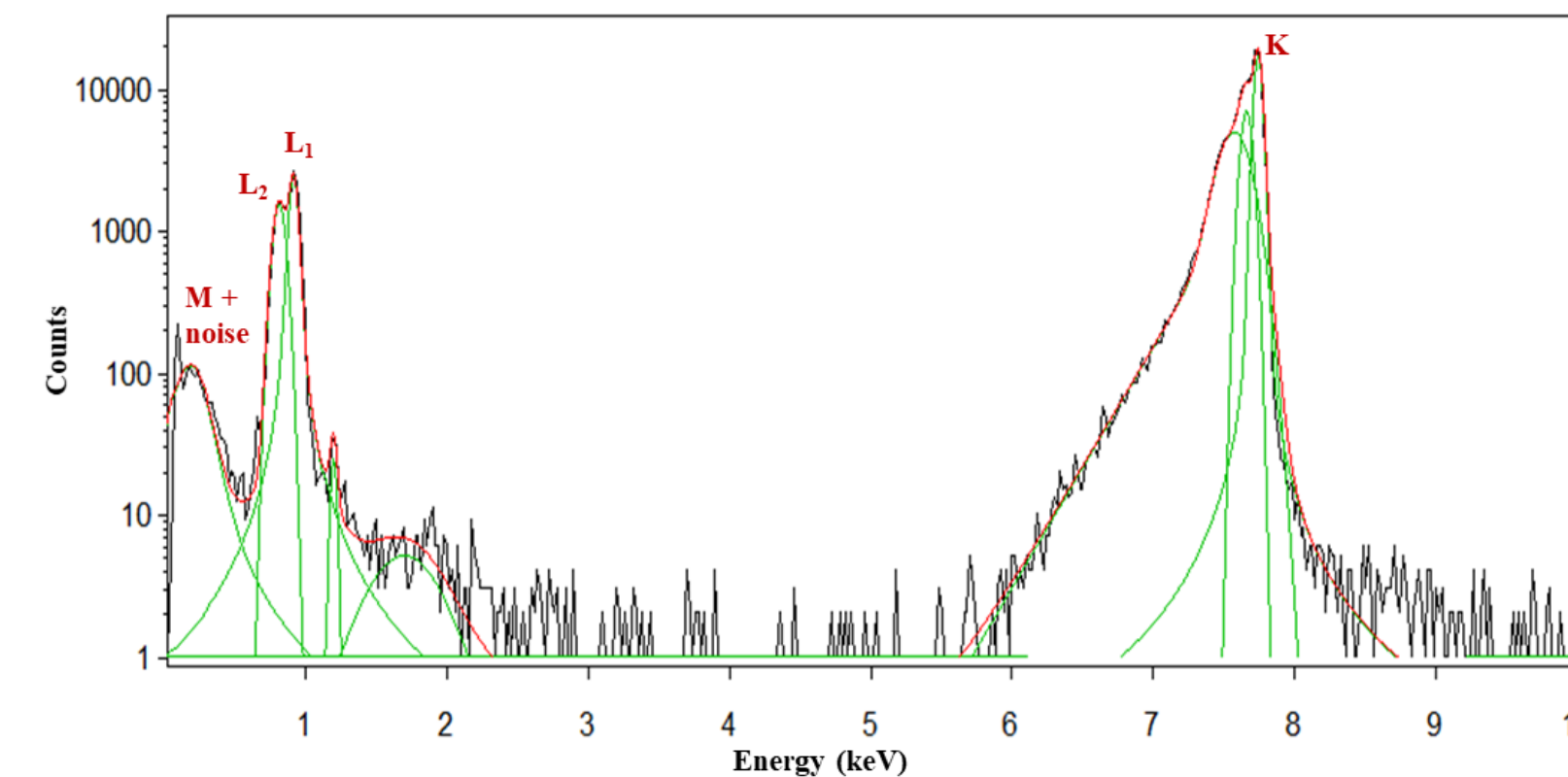


Figure 9: The fitted energy spectrum of drop deposited ^{59}Ni .

- Fractional electron capture probability ratios

Measurement	P_L/P_K
Electrodeposition	0.1154 (11)
Drop deposition	0.1122 (22)
BetaShape *[3]	0.1159 (26)
Literature	0.1210 (20) [4]

* Theoretical calculation code developed at LNHB.

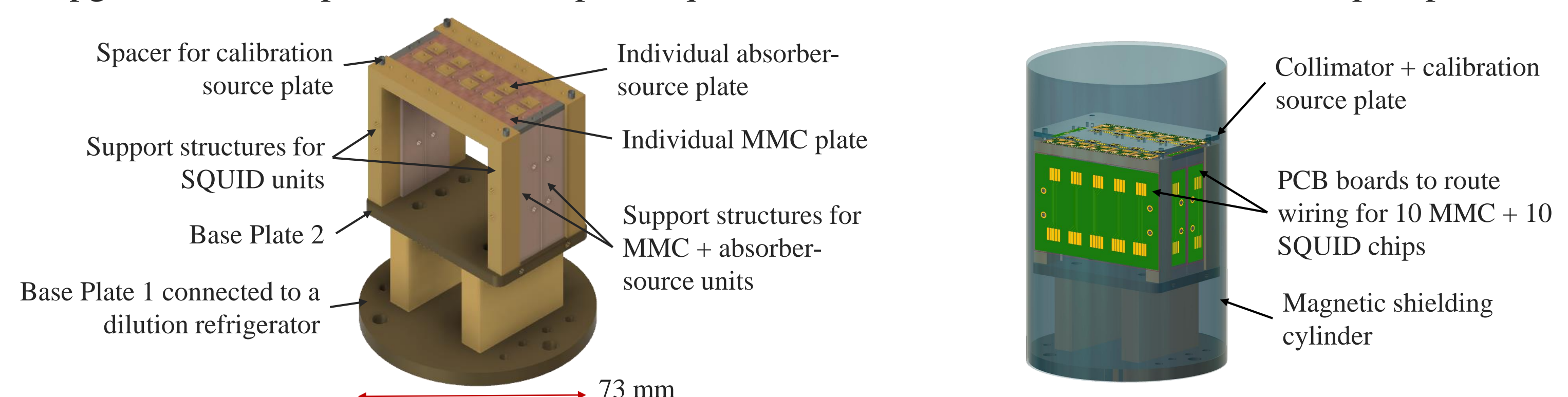
- The ratio of peak areas corresponds to the fractional capture probabilities. The quoted uncertainties comprise the statistical uncertainties and an estimation of the uncertainty due to the data analysis.
- The pulses had a 10-90% rise time of 170 μs in both sources, with exponential decay resulting in a $1/e$ decay time of 400 μs in the electroplated source and 440 μs in the drop-deposited source.
- In drop-deposited sources, due to the loss of a portion of the energy of Auger electrons in the source material causes a low energy tail (0.95% for K peak), less pronounced in electroplated sources (0.38% for K peak).

The fractional electron capture probability ratios from both sources are compatible with each other and the recent BetaShape calculation value.

The follow-up EMPIR project: PrimA-LTD (2021-2024)

- To develop a new primary method for decay scheme independent activity determination, high energy resolution, and statistics that exceed 10^8 events/spectrum.
- High statistics measurements of ^{129}I (beta spectrum shape; branching ratio) and ^{55}Fe (shake-up and shake-off effects) will be performed by the use of multiple detectors.

- Upgraded MMC spectrometer setup to acquire measurement statistics of $>10^8$ events per spectrum.



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