Measurement of Nuclear Decay Data for Beta Decay and Electron Capture using Metallic Magnetic Calorimeters

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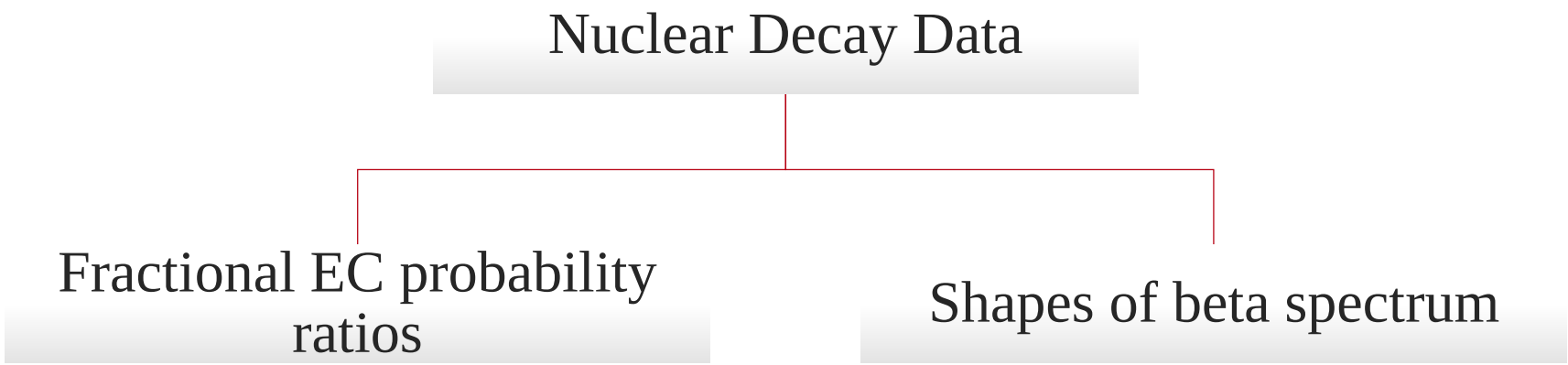
Motivation for the subject

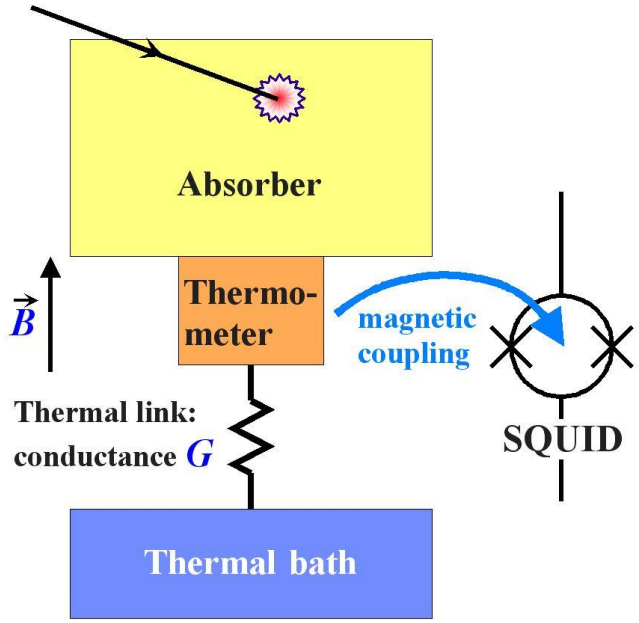


Applications

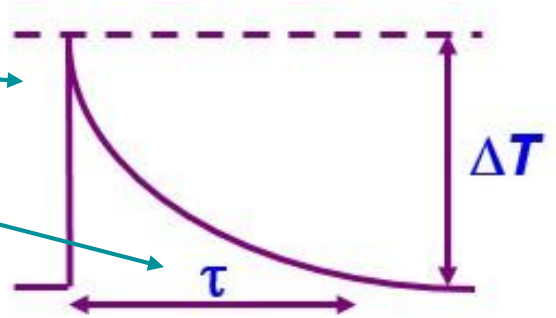
- Ionizing radiation metrology
- Nuclear Industry
- Fundamental Research
- Medical care etc.

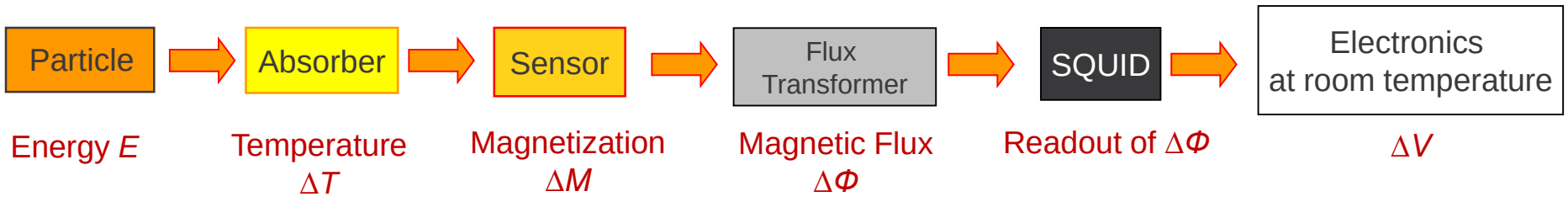
- Calorimetric energy spectrum
- **European "EMPIR" projects**: MetroBeta (2016 - 2019)
  MetroMMC (2018-2021)
  PrimA-LTD (2021-2024)

Metallic Magnetic Calorimeters (MMCs)

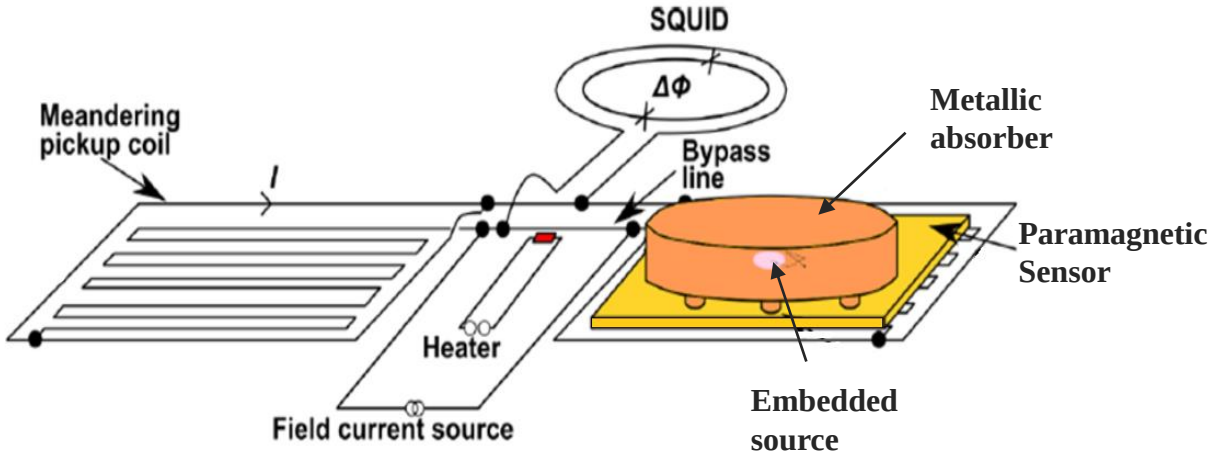


- **Signal:** $\Delta T = E/C$
- **Thermal link:** $\tau = C/G$
- $C = C_{absorber} + C_{sensor}$
- $\Delta M = \frac{\partial M}{\partial T} \Delta T$





Schematic view of the MMC read out by a DC-SQUID

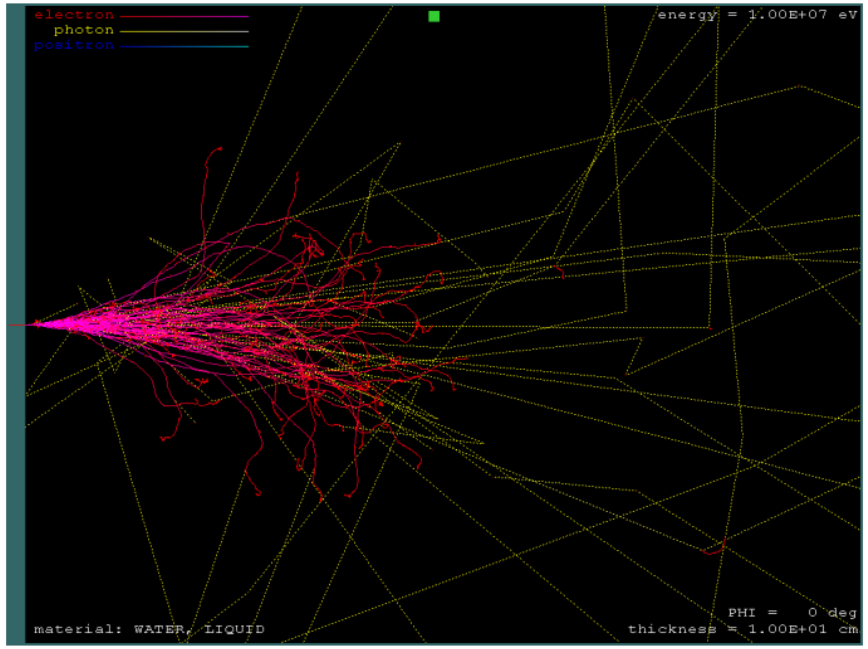


- **Flux transformer**: closed superconducting circuit formed by a readout coil and the input coil of a current sensor SQUID
- **Superconducting readout coil:** niobium thin film structure in a meander shape.
- **Thermometer:** thin (few µm) film of Au:Er or Ag:Er
- easy to scale, to match $C_{thermometer}$ to $C_{absorber}$

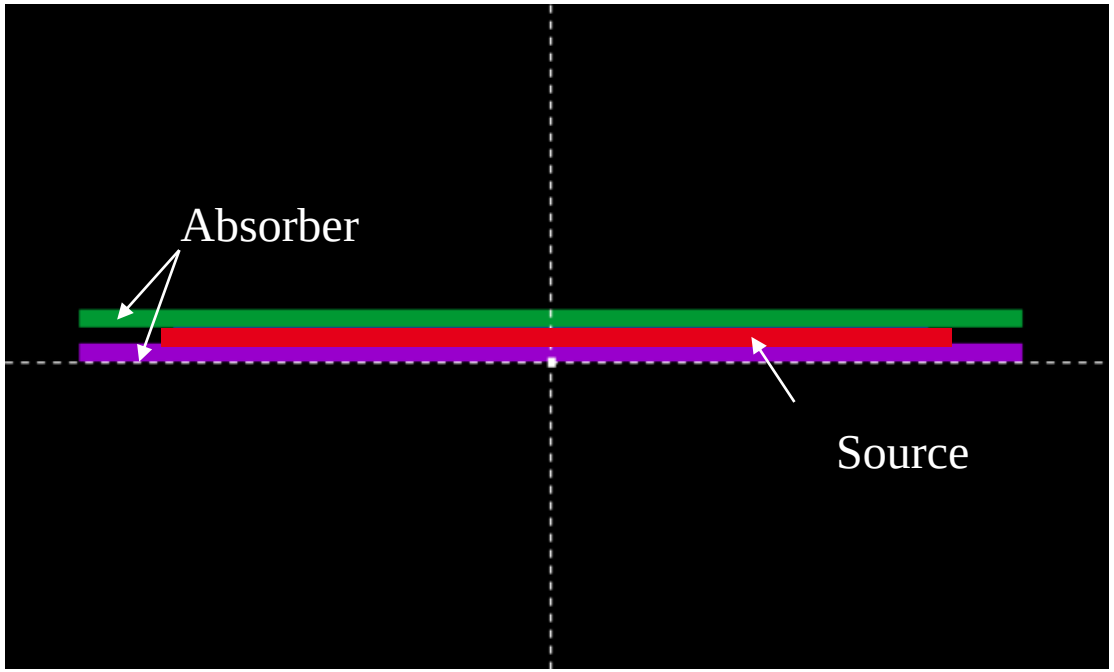
Preparation for the experiment

Optimization of detector geometry

Monte Carlo simulations (PENELOPE) to calculate the detection efficiency for optimizing absorber-source geometry.



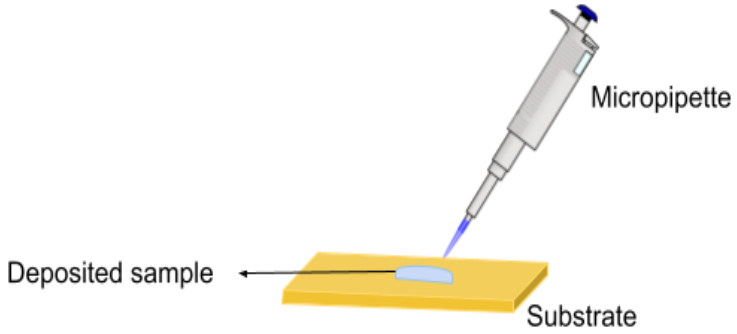
Simulations for minimal required absorber thickness and to calculate $C_{absorber.}$



Simulated 4π source absorber geometry.

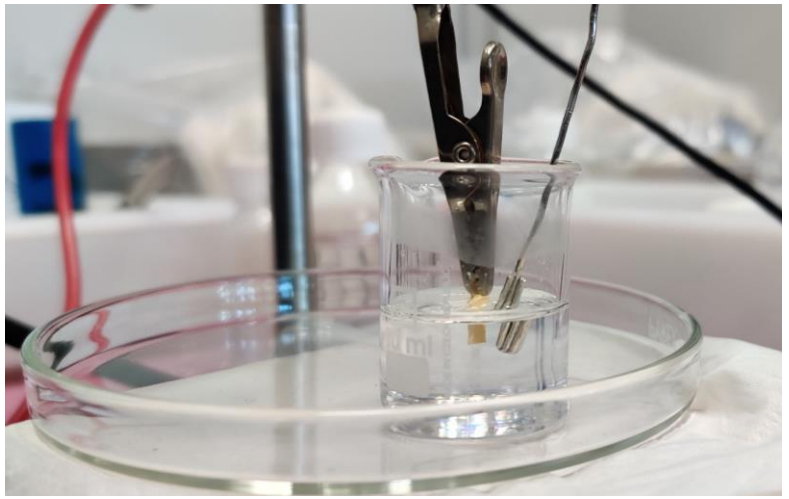
Source Preparation techniques

- **Manual drop deposition:**



- **Micro-drop dispenser:**

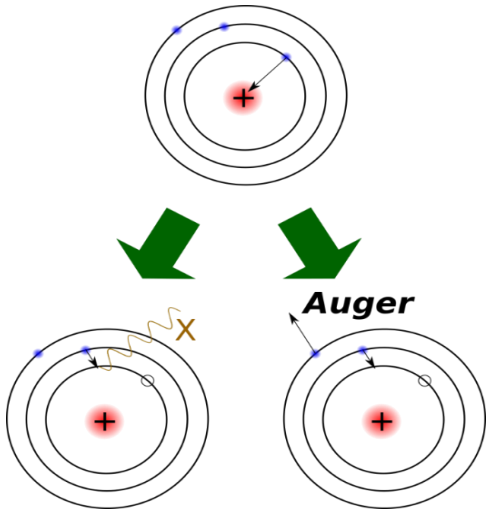
- **Electrodeposition**



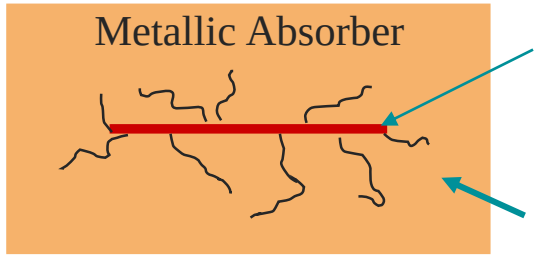
- Deposition of droplet volumes ≥ 50 pL
- Volume accuracy ± 2%
- Placement accuracy ~ 100 µm

Fractional Electron Capture Probabilities

Electron capture



Atomic rearrangement

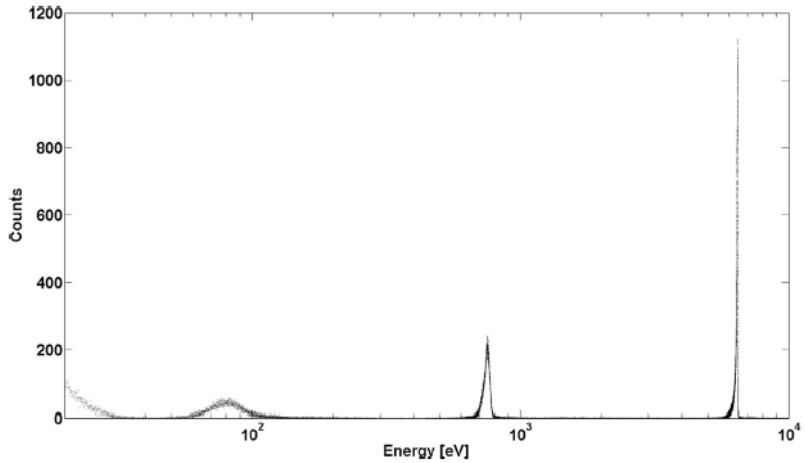


4π absorber-source geometry

Radionuclide source

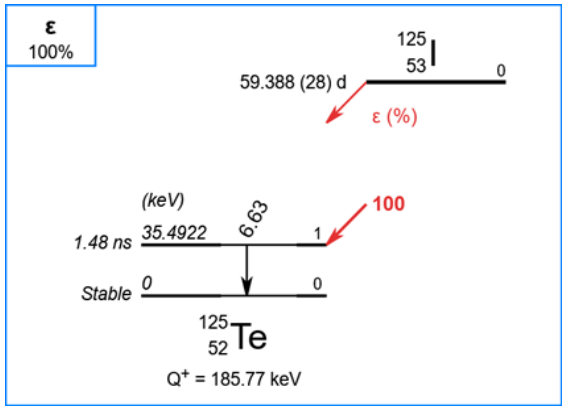
Metallic absorber formed by diffusion welding of two metal foils with source in between.

- Electron capture on K, L, M, N… shells; probabilities P_K, P_L, P_M, P_N …
- Atomic rearrangement →
  Binding energy of the captured electron liberated in a cascade of X-ray and/or Auger electron emissions.
- Integrate sum energy of the cascade →
  line spectrum with one single line per shell.

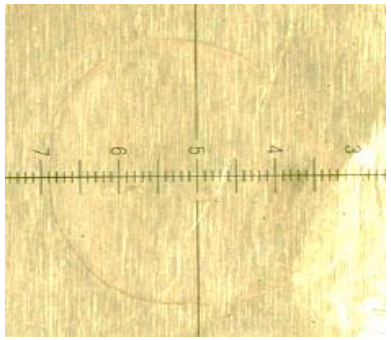


Measurement of fractional electron capture probabilities for ^{125}I

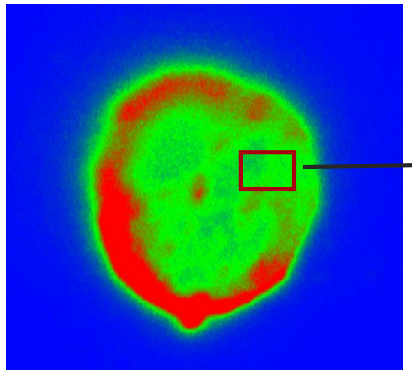
- $^{125}_{53}I + ^{0}_{-1}e \rightarrow ^{125}_{52}Te + \nu_e$ → escapes
- Daughter nucleus in excited state → gamma deexcitation
- 4π detection geometry → integration of Auger electrons/X-rays / gamma energy
  → one line for each electron shell in energy spectrum



Decay Scheme I-125



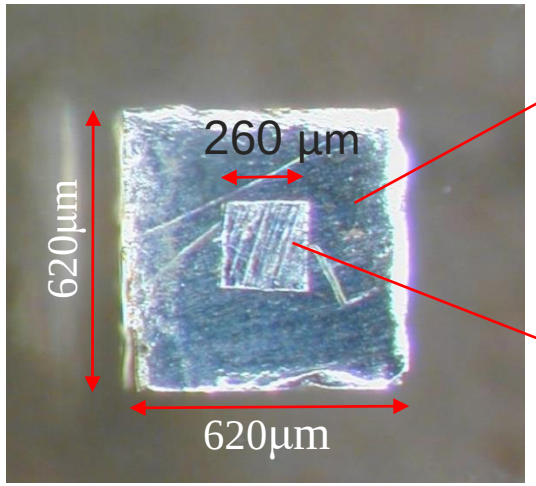
The $AgNO_3$ solution containing I-125 solution was drop deposited on silver foil resulting in the formation of AgI.



The area from which source of required activity of few bq was taken.

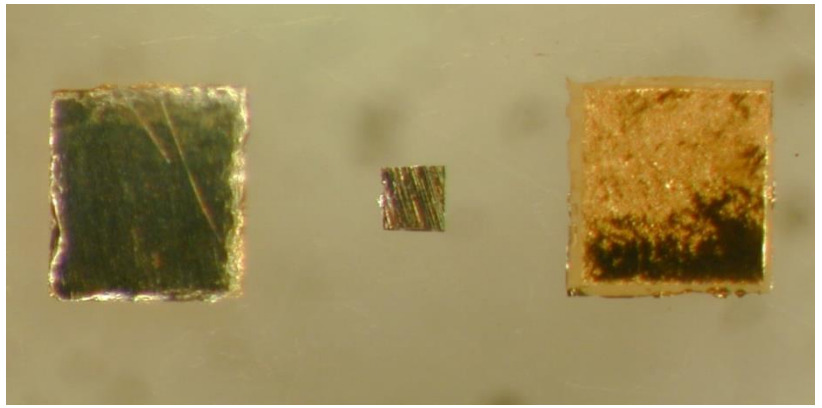
Autoradiographic image of source having 19.2 kBq activity.

Detector Assembling

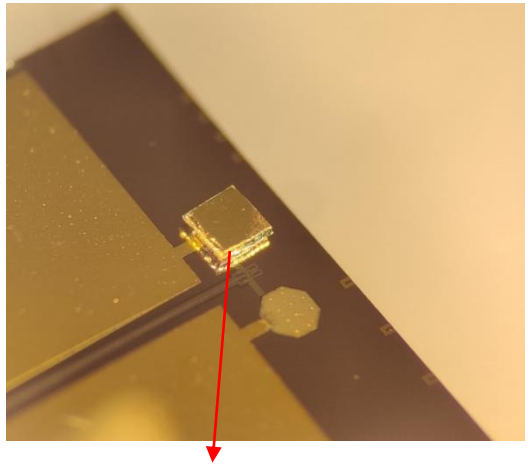


Gold absorber with AuAg alloy foil on one side.

Source placed on one half of absorber.



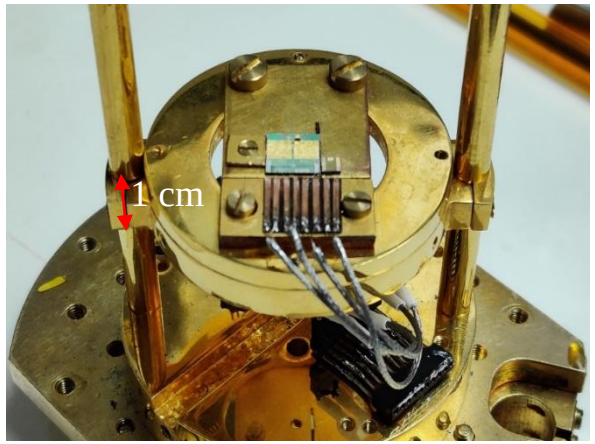
Two absorber halves with the source in the middle.



Complete absorber (after diffusion welding) on M size MMC chip i.e. optimized for C_{abs} = 0.11 nJ/K @ 20 mK.

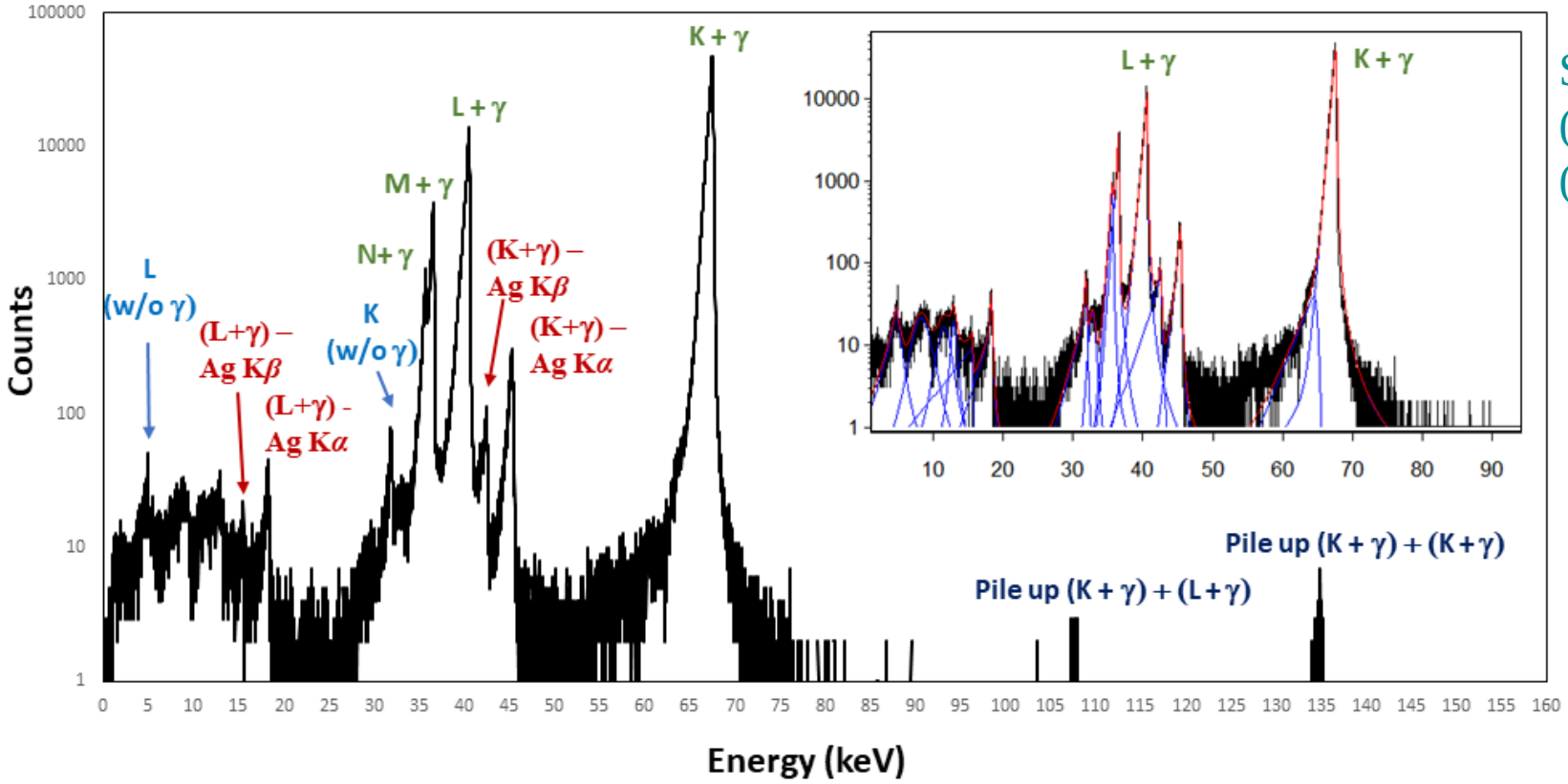
Detector characteristics:

- Embedded source activity ~ 4 Bq
- Gold absorber dimensions= 620×620×149 µm^3
- Source dimensions= 260×260×6 µm^3



Detector Holder with complete MMC chip.

Total emission spectrum of ^{125}I

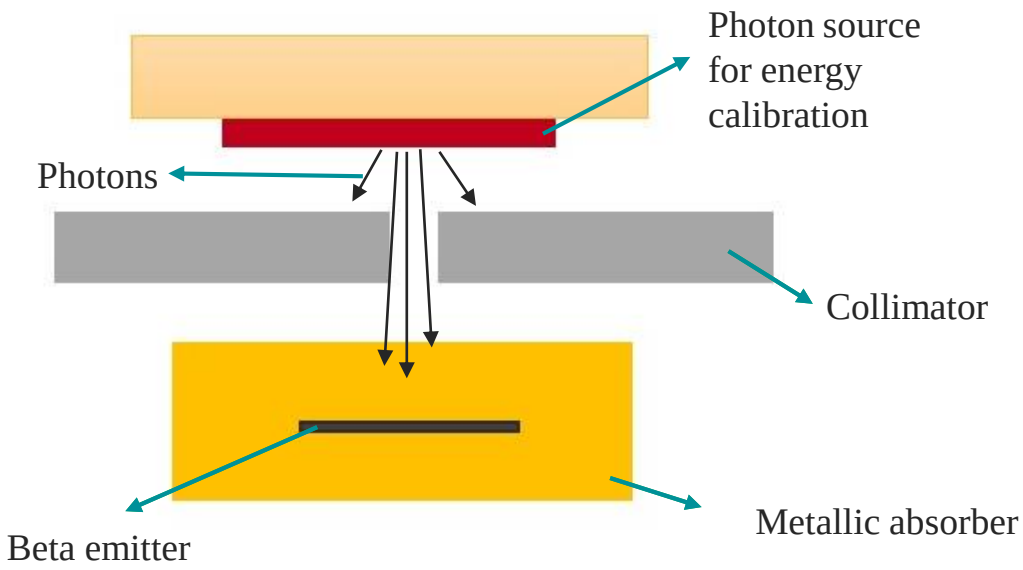


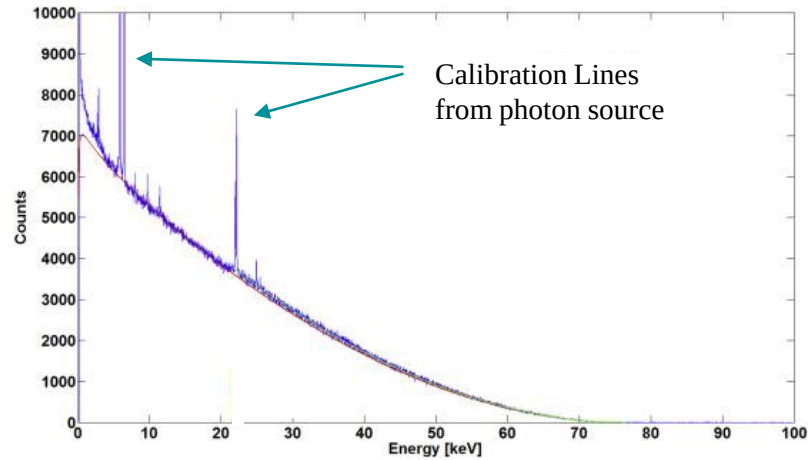
Spectral Resolution (**K+γ**) = 200 eV (FWHM) @ 67 keV

Fractional EC ratios	Experimental	Beta Shape	Literature
P_L/P_K	0.2388 (26)	0.19470 (29)	0.23(0.03)
P_M/P_K	0.0570 (16)	0.04467 (22)	-
P_N/P_K	0.0157 (21)	0.01012 (10)	-

Beta Spectrometry with MMCs

Basic setup





Energy spectrum for beta decay.

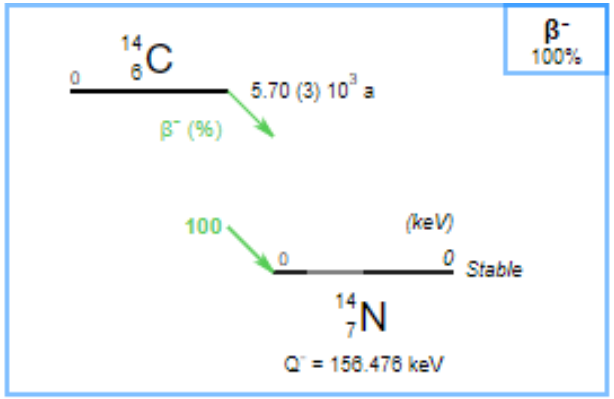
Additional external X-ray / gamma source

→ Energy calibration
→ Check linearity

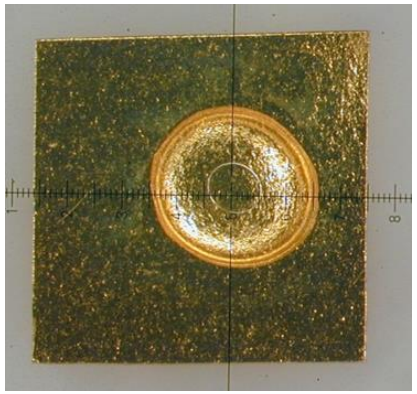
Measurement of beta spectrum of ^{14}C

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \overline{\nu_e}$$ escapes

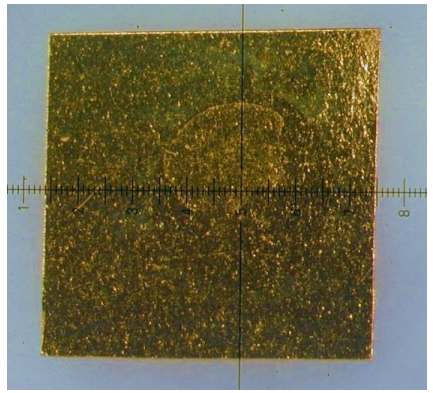
- **Source preparation-** drop deposition from a carrier-free solution on 25 µm thick Au foil.
- ^{14}C bound in an organic molecule (1,3- thiazole)
  - volatile
  - no diffusion welding; foil only folded over



Decay scheme ^{14}C



Drop deposition on the 25 µm thick Au foil.

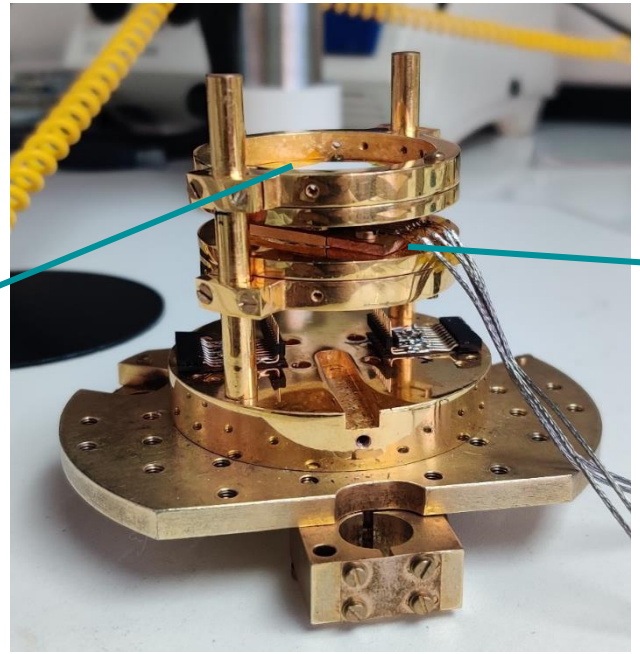


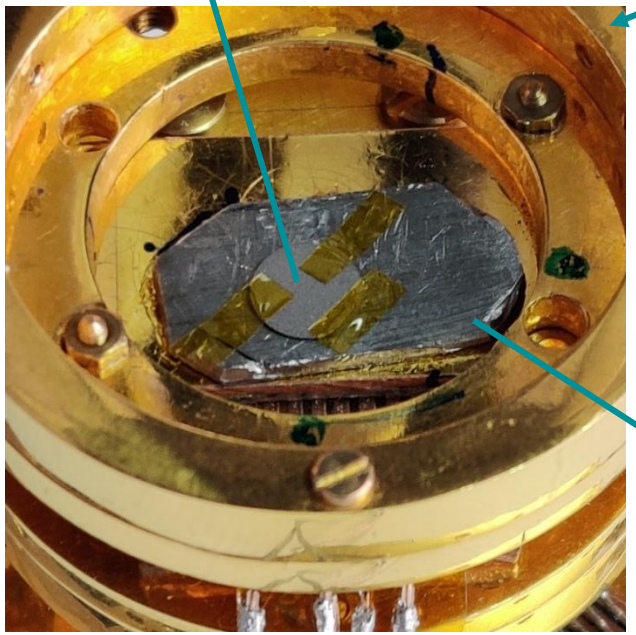
After drying, barely visible deposit, means thin, homogeneous deposit.

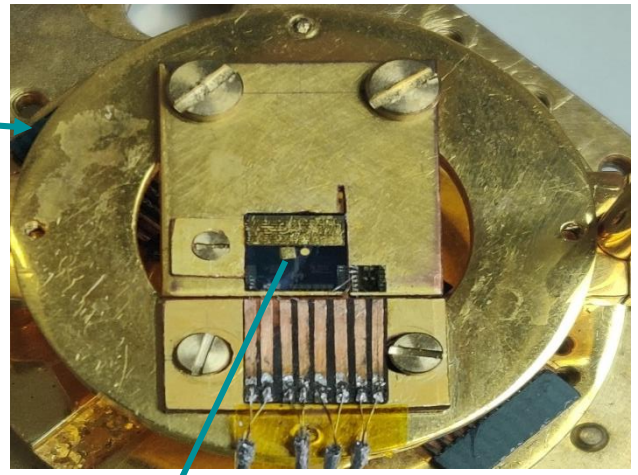
Detector characteristics

Detector setup

Be window of thickness 0.25 mm to stop conversion electrons







Gold Absorber – 1 mm×1 mm× (2 × 25μm)

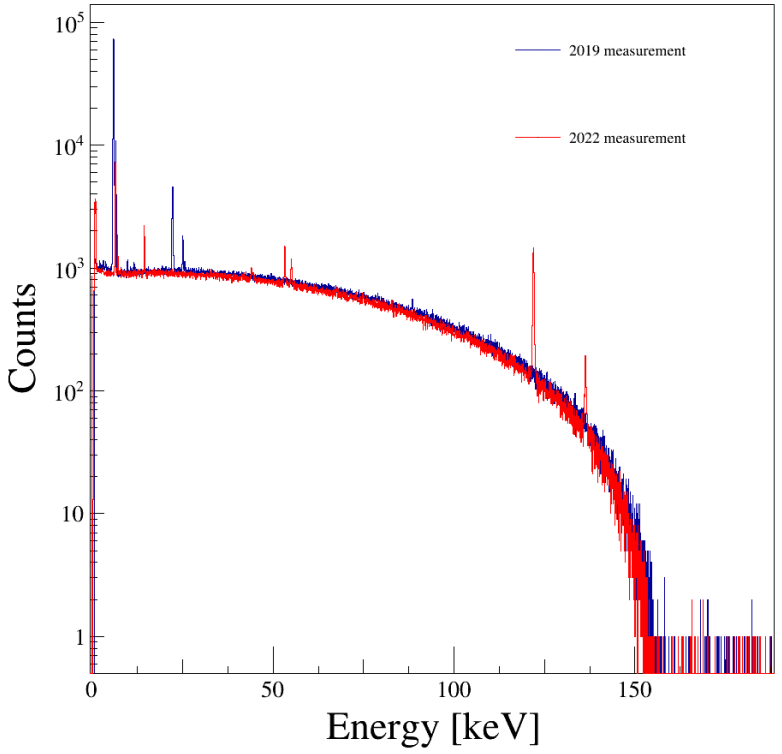
C_{abs} = 67 pJ/K @ 20 mK.

Lead collimator of thickness 1 mm

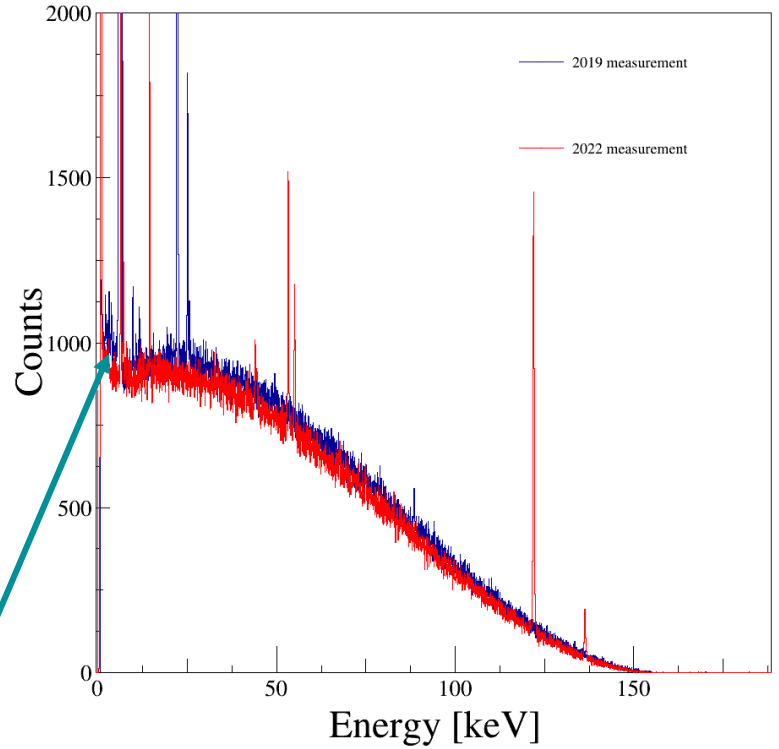
Calibration Source - ^{57}Co (2.5 kBq)

Beta spectrum of ^{14}C

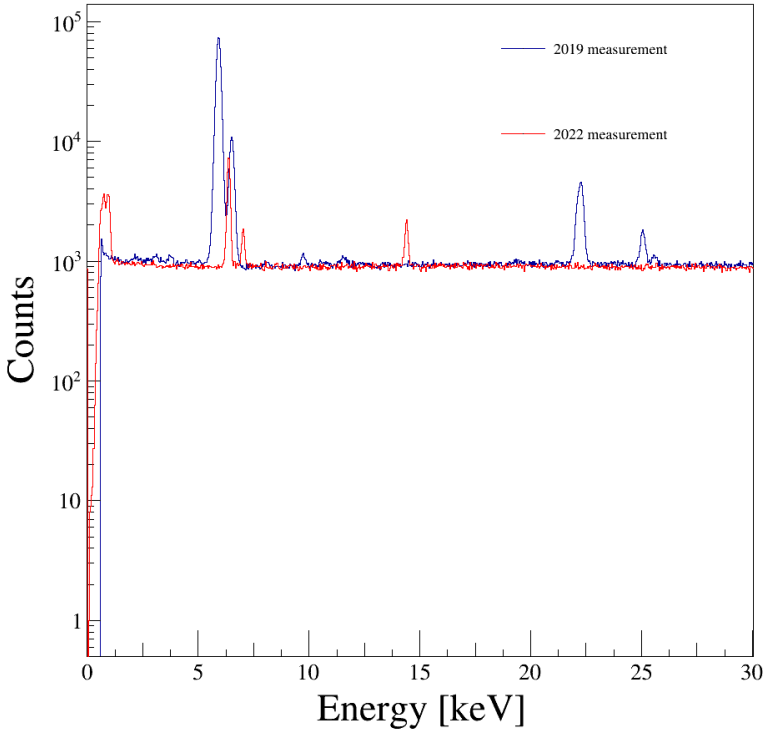
Log Y scale



Linear Y scale



Log Y scale, energy :0-30keV

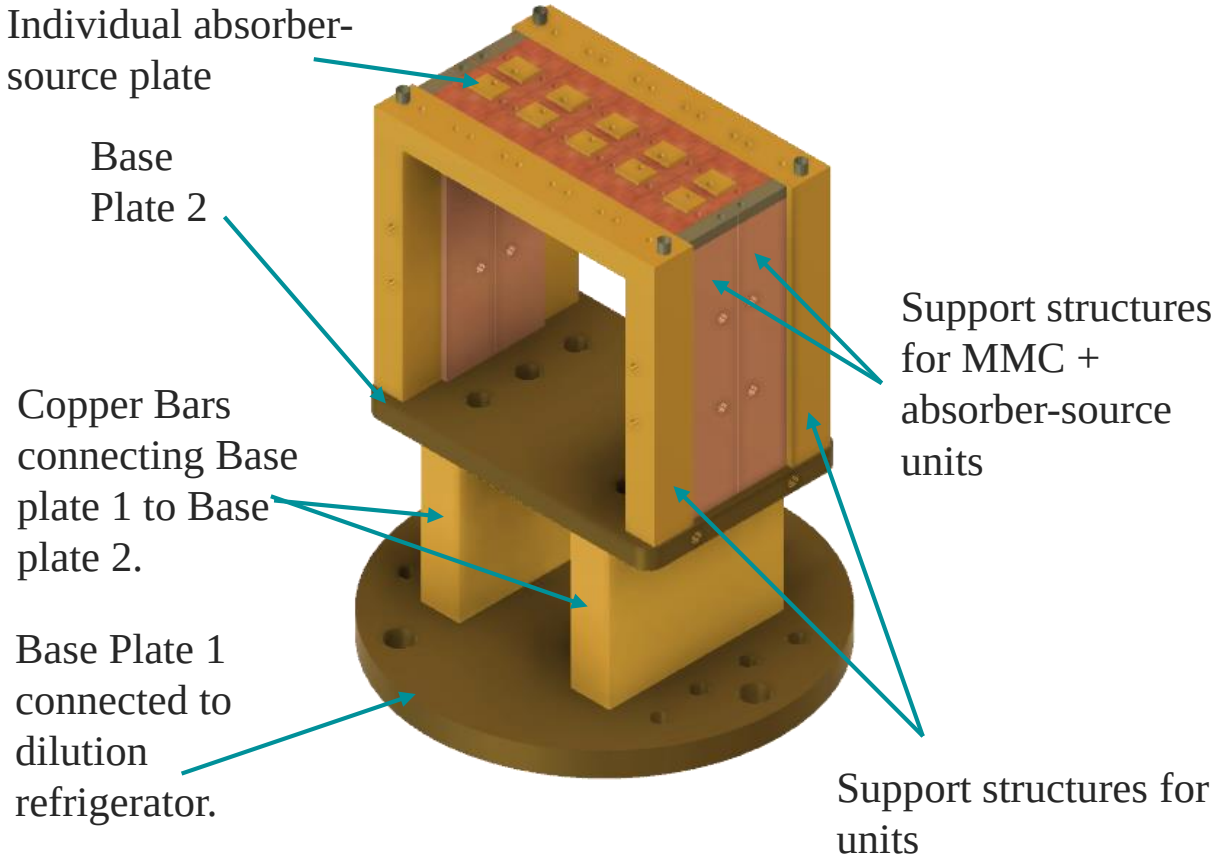


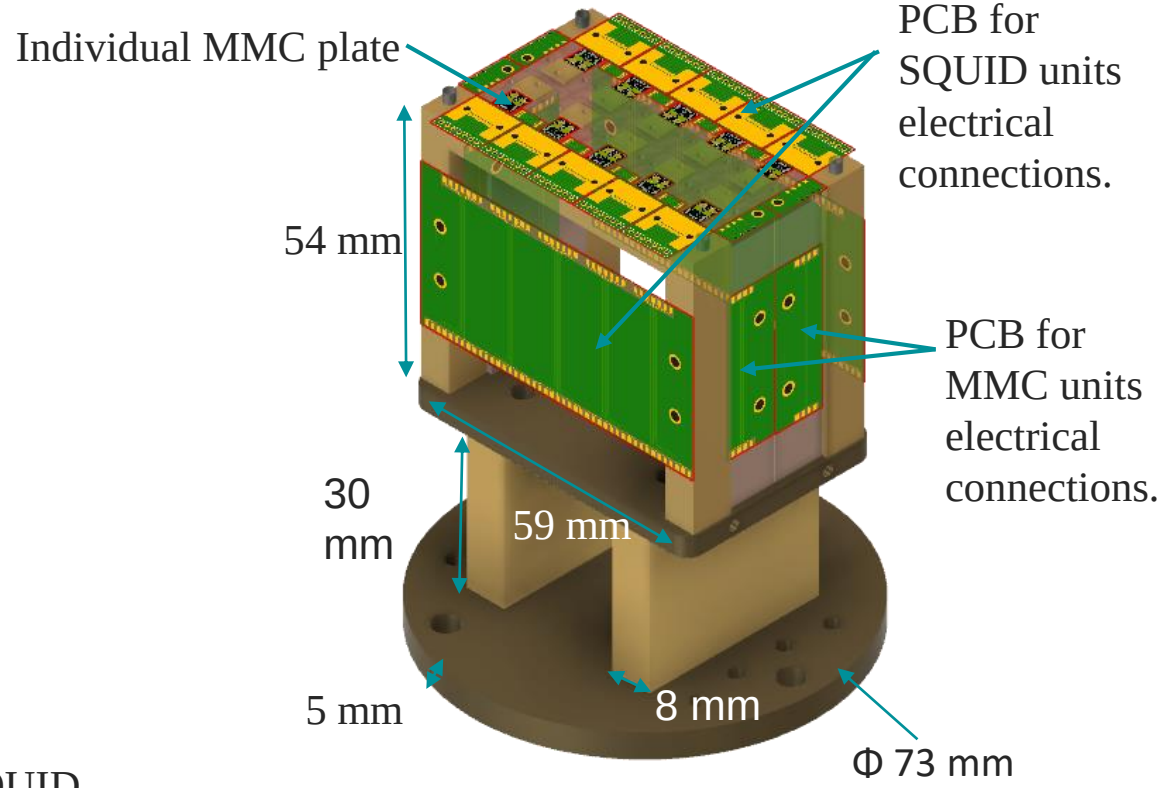
- 2022 measurement: spectral artefact at low *E* due to bad detector performance (2019) disappeared.
- Spectral Resolution (K_α peak) (2022 measurement) = 155 eV (FWHM)
  (2019 measurement) = 200 eV (FWHM)

- The discrete lines are X-ray and gamma ray lines from the external energy calibration source.
- External energy calibration source (2022 measurement) - ^{57}Co
  (2019 measurement) - ^{55}Fe + ^{109}Cd

Perspectives

- Upgraded spectrometer setup for measuring multiple detectors simultaneously to get statistics of the order 10^8 counts.





Thank you for your attention.
Questions?

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