Precision Measurements of Beta Spectra using Metallic Magnetic Calorimeters within the European Metrology Research Project MetroBeta

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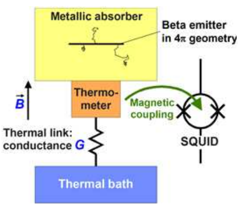
MetroBeta, a recently completed European metrology research project, aimed at the improvement of the knowledge of the shapes of beta spectra, both in terms of theoretical calculation and measurement. The most prominent experimental work package concerned the measurement of the spectrum shapes of several beta emitters by means of metallic magnetic calorimeters (MMCs) with the beta emitter embedded in the absorber. New MMC chips have been designed and optimized for five different absorber heat capacities, enabling the measurement of beta spectra with Q values ranging from few tens of keV up to ~ 1 MeV. Several beta spectra, covering different types of beta transition and a range of Q values between ~ 70 keV and 300 keV, have been measured with high energy resolution, low energy threshold and statistics of up to 10^7 counts: ^{151}Sm (1st forbidden non-unique; Q = 76.3 keV), ^{14}C (allowed; Q = 156.5 keV) and ^{99}Tc (2nd forbidden non-unique; Q = 293.8 keV). Measurements of ^{36}Cl (2nd forbidden non-unique; Q = 709.5 keV) are under way. Improved theoretical calculation methods and complementary measurement techniques completed the project.

Beta spectrometry with metallic magnetic calorimeters



Source embedded inside the detector absorber

- 4π solid angle
- no back-scattering
- energy loss of beta particles in the source:

⇨ **full thermalization of β energy must be ensured**

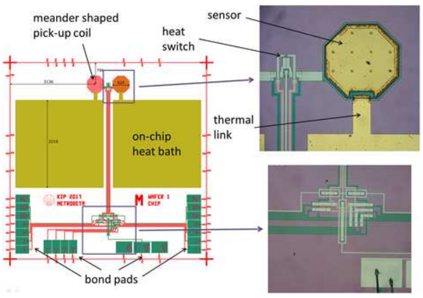
Extensive work on **source & absorber preparation:**

- Electrodeposition
- Micro-drop dispensing system:
  - Droplet volumes < 50 pl
  - Placement accuracy 20 µm
- Absorber array fabrication by milling or laser cutting

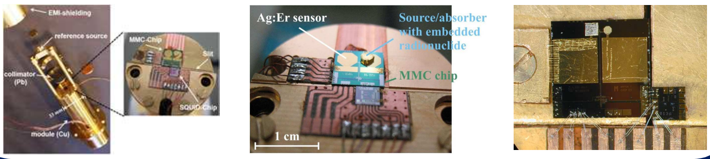
⇨ **See poster # 125**

MMC development

MMCs have been designed to match five different absorber heat capacities corresponding to beta spectra of maximum energies ranging from ~ 20 keV to 700 keV. The designs are based on optimization calculations with the constraints of erbium concentration and sensor thickness being equal for all five designs, in order to be able to fabricate all sensors on one wafer.



Detector integration



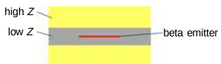
Absorber design for higher energy (≥ 500 keV) spectra

At E_{max} ≥ 500 keV, the measured beta spectra may be distorted by escape of bremsstrahlung from the absorber. The absorber material may have a major influence on this phenomenon.

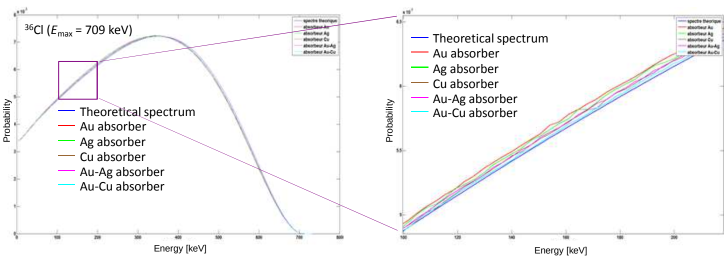
- Bremsstrahlung production increases with atomic number Z of the material ⇨ low Z
- A higher Z material offers a higher absorption probability for the photons
- Absorber heat capacity as a function of electron stopping power

} ⇨ high Z

⇨ Composite absorber with an inner layer of low Z material and an outer layer of high Z material may be best choice



Monte Carlo simulations of monolithic Au, Ag, Cu and Au-Ag, Au-Cu bilayer absorbers:



⇨ strongest spectrum distortion: monolithic Au absorber
⇨ weakest spectrum distortion: Au-Cu bilayer absorber

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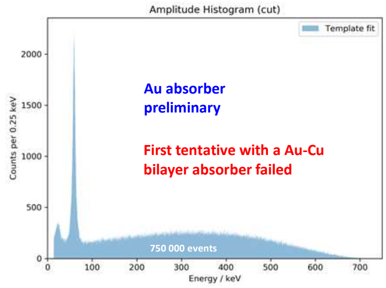
Beta spectra measurements

^{36}Cl

Beta emitter characteristics
- E_{max} = 709.5 keV
- Half life = 302 × 10³ y
- 2nd forbidden non-unique transition
- Pure beta

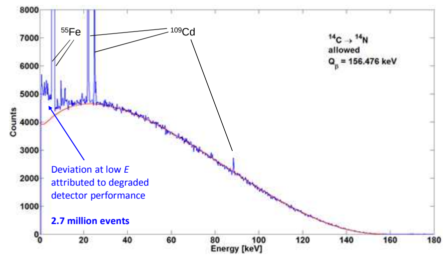
Detector characteristics
- Embedded source activity ~ 2 Bq
- Prepared with micro-drop dispensing system
- Au absorber, 1.6 mm octagon, (2 × 300) µm
- C_{abs} = 1.8 nJ/K @ 20 mK
- Strong vibrations from pulse tube
  → degraded energy resolution (~ 3.6 keV)



^{14}C

Beta emitter characteristics
- E_{max} = 156.476 keV
- Half life = 5700 y
- Allowed transition
- Pure beta

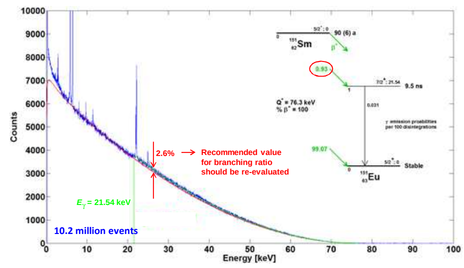
Detector characteristics
- Embedded source activity ~ 7 Bq
- Prepared from carrier-free triazol solution
- Au absorber, 1 mm² × (2 × 25) µm
- C_{abs} = 34 pJ/K @ 10 mK
- Glue between MMC and holder broken
  → strong pile-up
  → degraded energy resolution (~ 200 eV)



^{151}Sm

Beta emitter characteristics
- E_{max} = 76.3 keV
- Half life = 90 y
- 1st forbidden non-unique transitions
- 99.07(4)% decays → ground state
- 0.93(4)% decays → 21.54 keV level

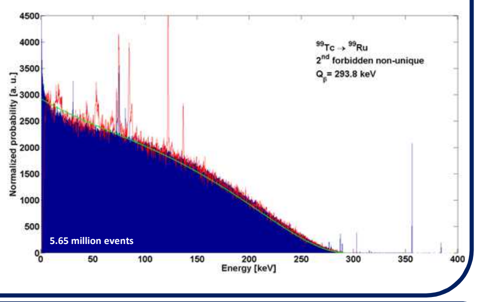
Detector characteristics
- Embedded source activity ~ 8 Bq
- Electroplated on Ag foil
- Ag absorber, (0.9 mm)² × (2 × 15) µm
- C_{abs} = 14.5 pJ/K @ 10 mK
- ΔE = 45 eV @ 6 keV, 70 eV @ 25 keV
- Energy threshold 250 eV



^{99}Tc

Beta emitter characteristics
- E_{max} = 293.8 keV
- Half life = 211.5 × 10³ y
- 2nd forbidden non-unique transition
- Pure beta

Detector characteristics (LNHB)
- Embedded source activity 7.6 Bq
- Electroplated on Au → metallic Tc
- Au absorber, (0.9 mm)² × (2 × 74) µm
- C_{abs} = 175 pJ/K @ 10 mK
- ΔE = 100 eV from 31 keV to 384 keV
- Energy threshold 650 eV
- Excellent linearity



Perspectives

- Beta emitters with more complex decay schemes: determine additional decay parameters e. g. ^{129}I, ^{204}Tl, ^{210}Pb - branching ratios …
- Electron capture decays:
  - fractional capture probabilities
  - photon emission probabilities
  - branching ratios

} **MetroMMC - see poster # 122**