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A microcalorimeter measurement of the neutrino mass, studying ^{187}Re single β decay and ^{163}Ho electron-capture decay

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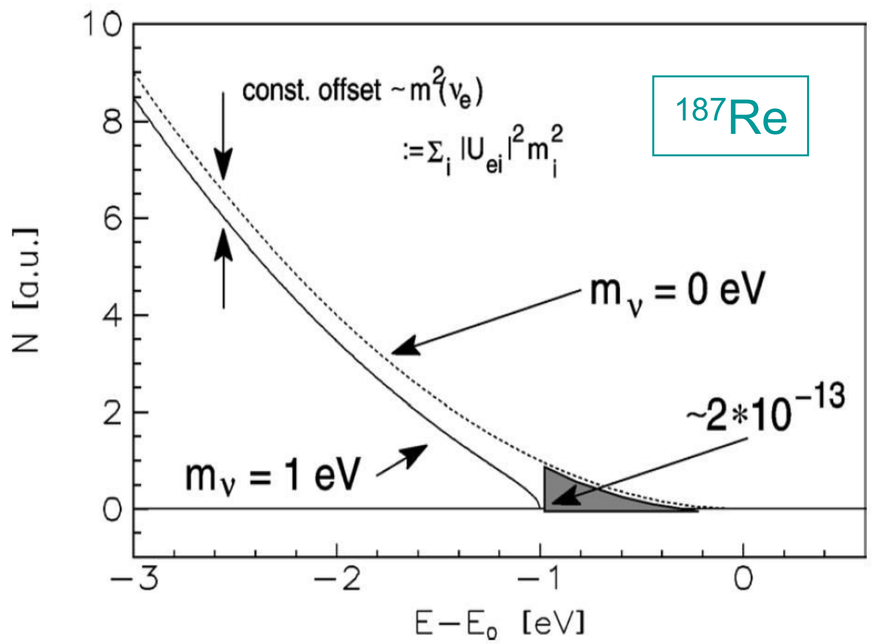
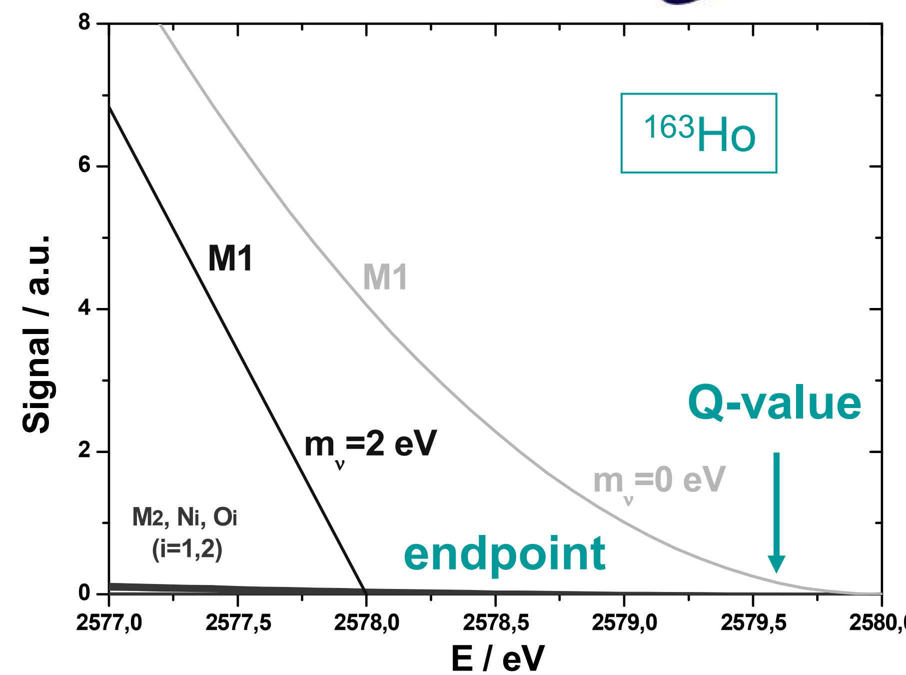
^{187}Re β decay and ^{163}Ho EC decay





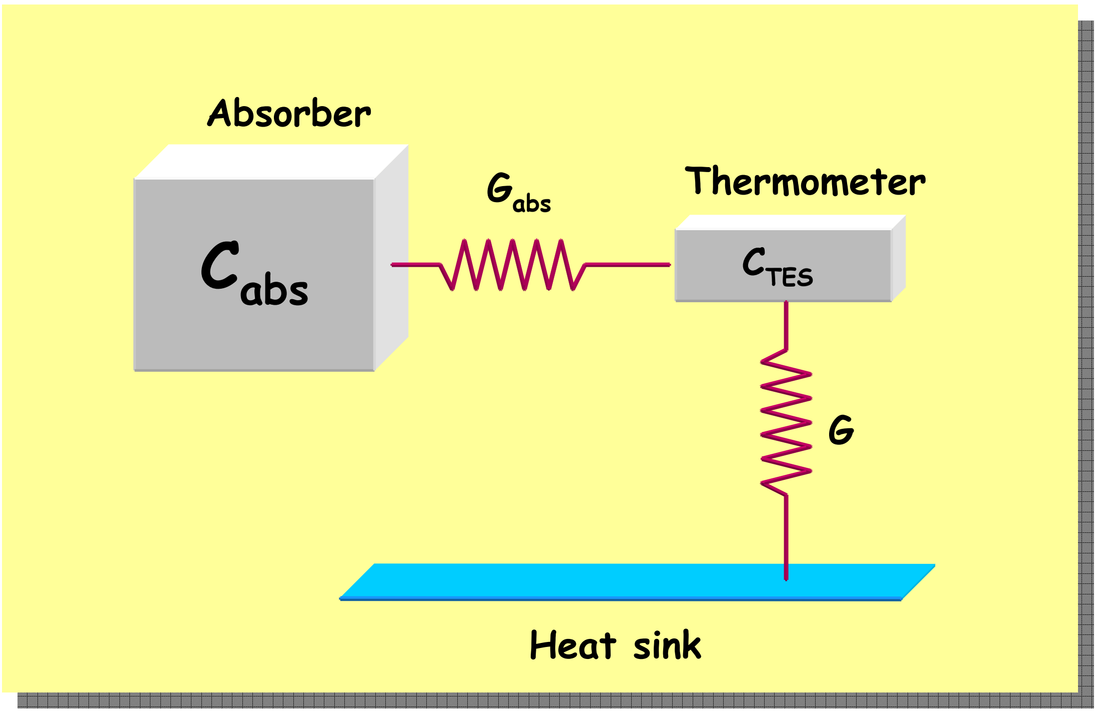
The effect due to the massive neutrino is maximum at the endpoint E_0.

In order to get a good resolution we need decays with **low endpoint energy**

$^{187}Re \longrightarrow Q = 2.6KeV$
$^{163}Ho \longrightarrow Q = 2.8KeV$
} **good candidates!**

In both cases the events fraction under the endpoint scales with $(m_\nu c^2)^3$

A μ-calorimeter measurement



Components of the μ- calorimeter:

- **Absorber:** here the decay process takes place, thus the absorber must contain ^{187}Re or ^{163}Ho and must absorb the electrons emitted;
- **Thermometer**: is the sensor that we use to detect the energy released by the decay;
- **Heat sink**: it restores the thermal equilibrium after the occuring of each event;

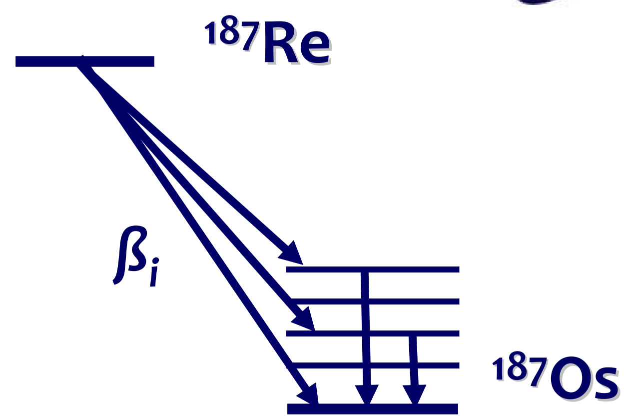
^{187}Re single β decay

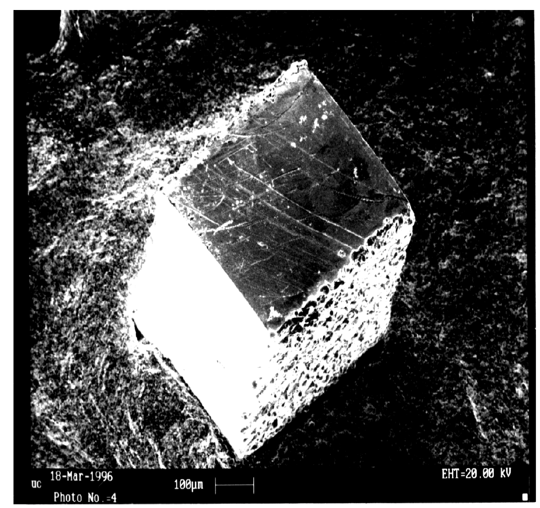
Advantages:

- Only the ν escape: direct measurement of the electron spectrum;
- No model dependent corrections for atomic and molecular final states
- No corrections for nuclear recoil energy and electron energy losses

Disadvantages:

- The β source is inside the μ-calorimeter, the amount of interesting events is a very small part of the whole spectrum
- The Re half life is very long: 4.5 10^{-10} years, that means low statistics.





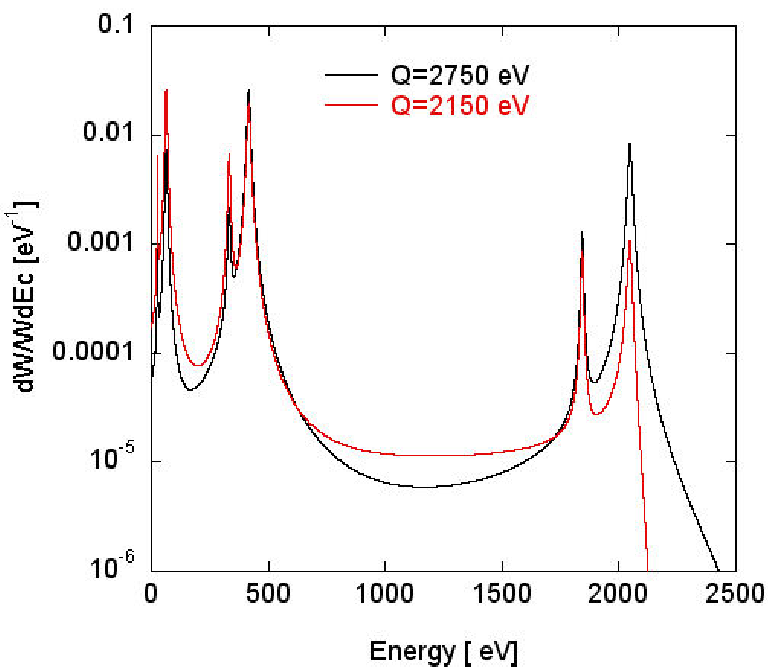
Natural metallic Re contains 63% of ^{187}Re;
Expected activity of 1mg of Re is 1Bq

^{163}Ho electron-capture decay

The most attractive method is based on the “kink” search at the energy spectrum endpoint:

$$\frac{dW}{dE_C} = M^2 (Q - E_c)\sqrt{(Q - E_c)^2 - m_\nu^2} \cdot \sum \varphi_o^2 \frac{\Gamma}{(E_C - E_H)^2 + \Gamma^2}$$

A. De Rujula, Phys. Lett. 9 (1982)

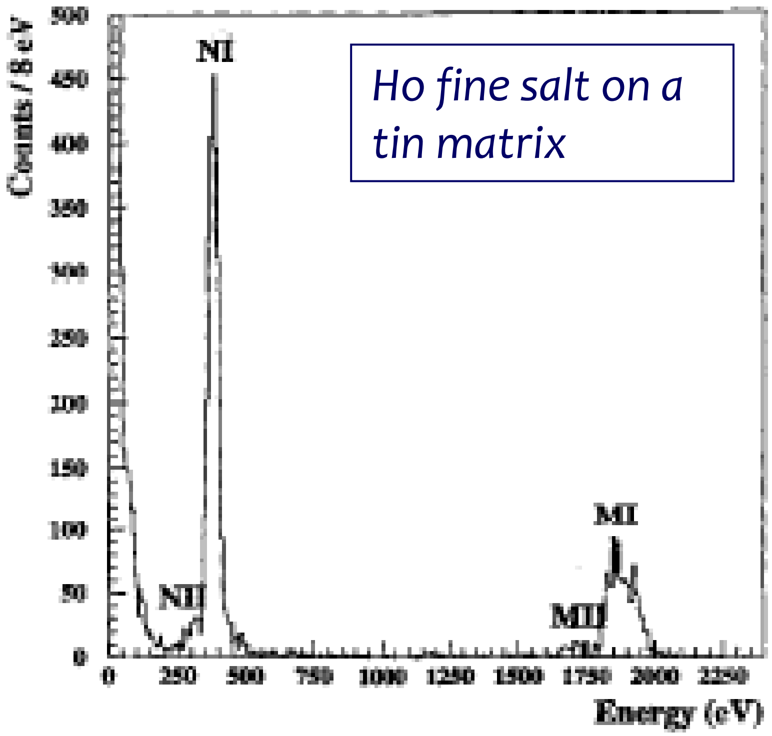


E_c capture energy
E_H ionization orbital energy
Q endpoint energy
m_n neutrino mass
M nuclear matrix coefficient
φ_o wave function on nucleus
Γ is the capture line FWHM

Natural holmium is ^{165}Ho and it is stable. ^{163}Ho required purification and implantation in a suitable support

^{163}Ho electron-capture decay

Calculated energy spectrum shape, for finite m_ν values, of the spectrum endpoint similar to the one for the beta-decay of ^{187}Re



Key advantages of Ho respect to Re:

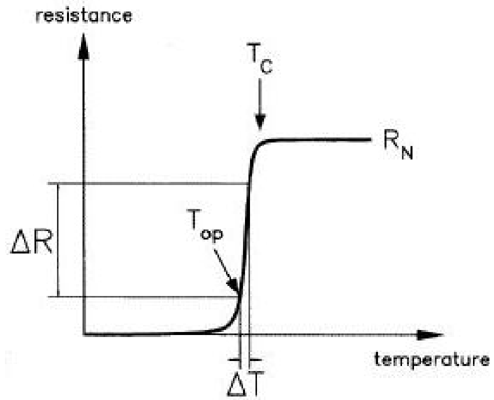
^{163}Ho half-life time is 4.5 10^{-3} years, 7 order lower than ^{187}Re;

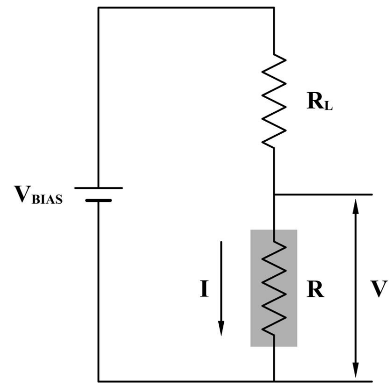
Q value measured in Genoa: 2.80 ± 0.05 keV;

Capture lines can be employed for the detector self calibration and for monitoring its linearity;

Absolute fraction values are very similar to the ones calculated for ^{187}Re.
Q dependence of the event fraction in Q-m_ν still lacks the precise knowledge of Q (affected by a large systematic uncertainty)

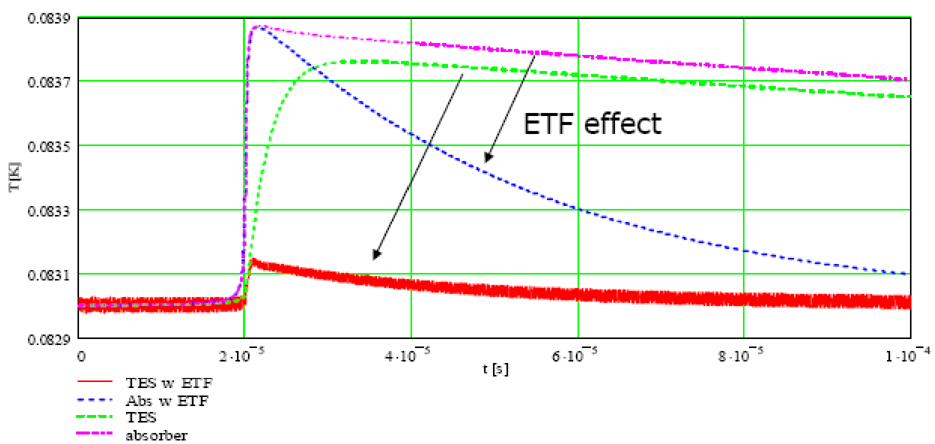
Transition Edge Sensors (TES)

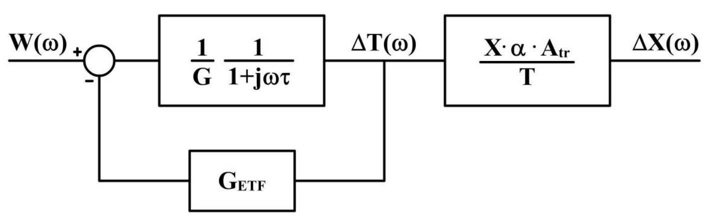




The sensor is made of a thin Ir film operated at a temperature T_{op} at the base of the superconducting transition (Ir bulk T_c=112mK, type I S/C)

A voltage bias allows to relate the temperatures variations to current variations.





Some useful parameters:

Thermal sensitivity $\frac{dR}{R} = \alpha \frac{dT}{T}$

Electrothermal feedback $G_{ETF} = \frac{P}{T}\frac{R - R_L}{R_L + R}\alpha$

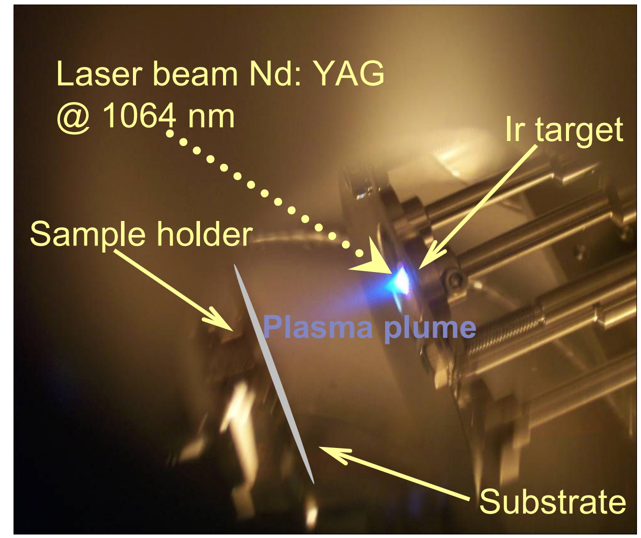
Intrinsic limit $\Delta E_{rms} = \sqrt{k_B T^2 C}$

Current variations $\Delta I = -I \frac{\alpha}{T}\frac{R}{R_L + R}\Delta T$

Thermalization time: $\tau = C/(G_{TES}+G_{ETF})$

TES fabrication process

- **Substrate is a membrane of Si_3N_4 on a Si chip**
- **Ir thin film is grown by pulsed laser deposition**
- **Au thin film evaporation by e-gun**
- **Patterning with microlithography**
- **Electrical contacts are made of a thin Al film**

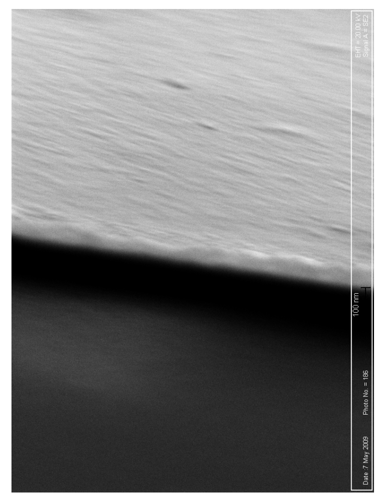


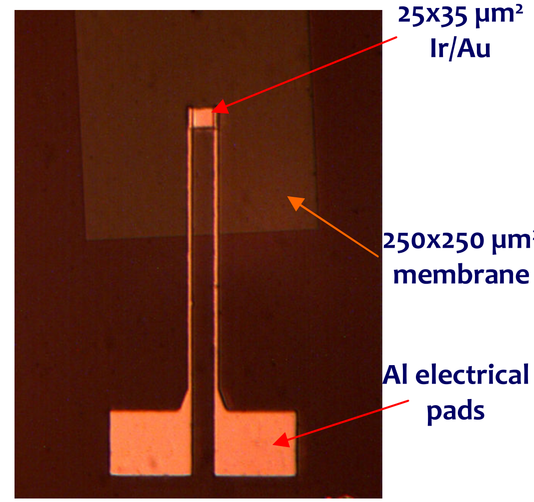
The Ir/Au bilayer is obtained in UHV conditions at room temperatures.

Relative thickness of the layers can be tuned in order to lower Ir T_c by proximity effect.

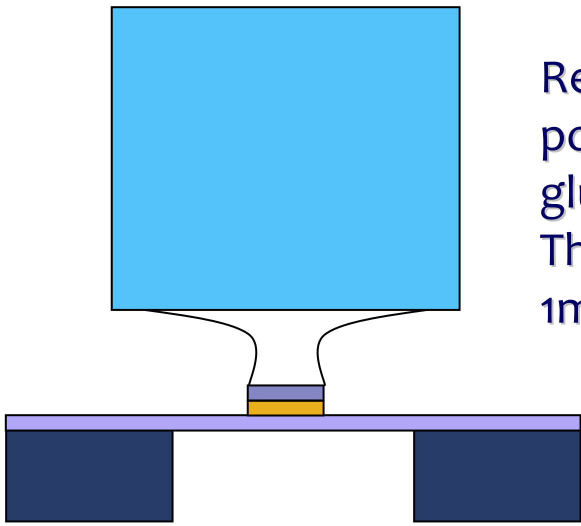
Final detectors are characterized by AFM and SEM analysis, R(T) four wire measurement and noise spectrum acquisition.

The low working temperatures are achieved by a dilution He3/He4 refrigerator, EM shielded by a box with attenuation of 60dB.

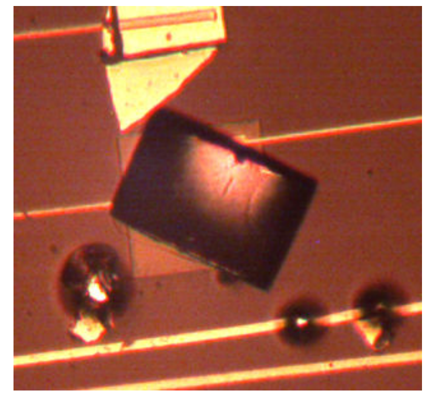


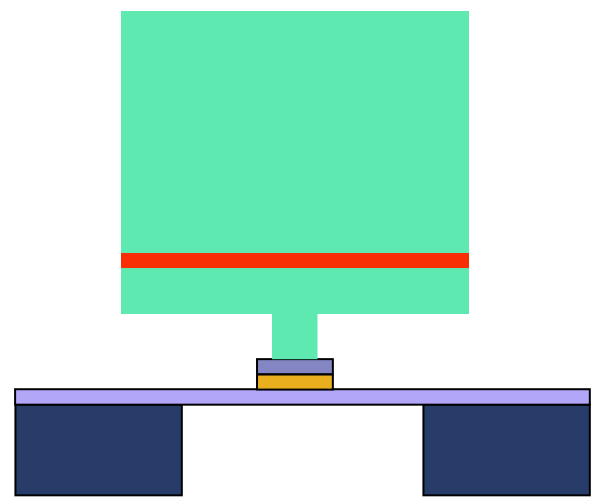


Absorbers



Re single crystal cube positioned with epoxy glue on the TES
The mass required is of 1mg at least.

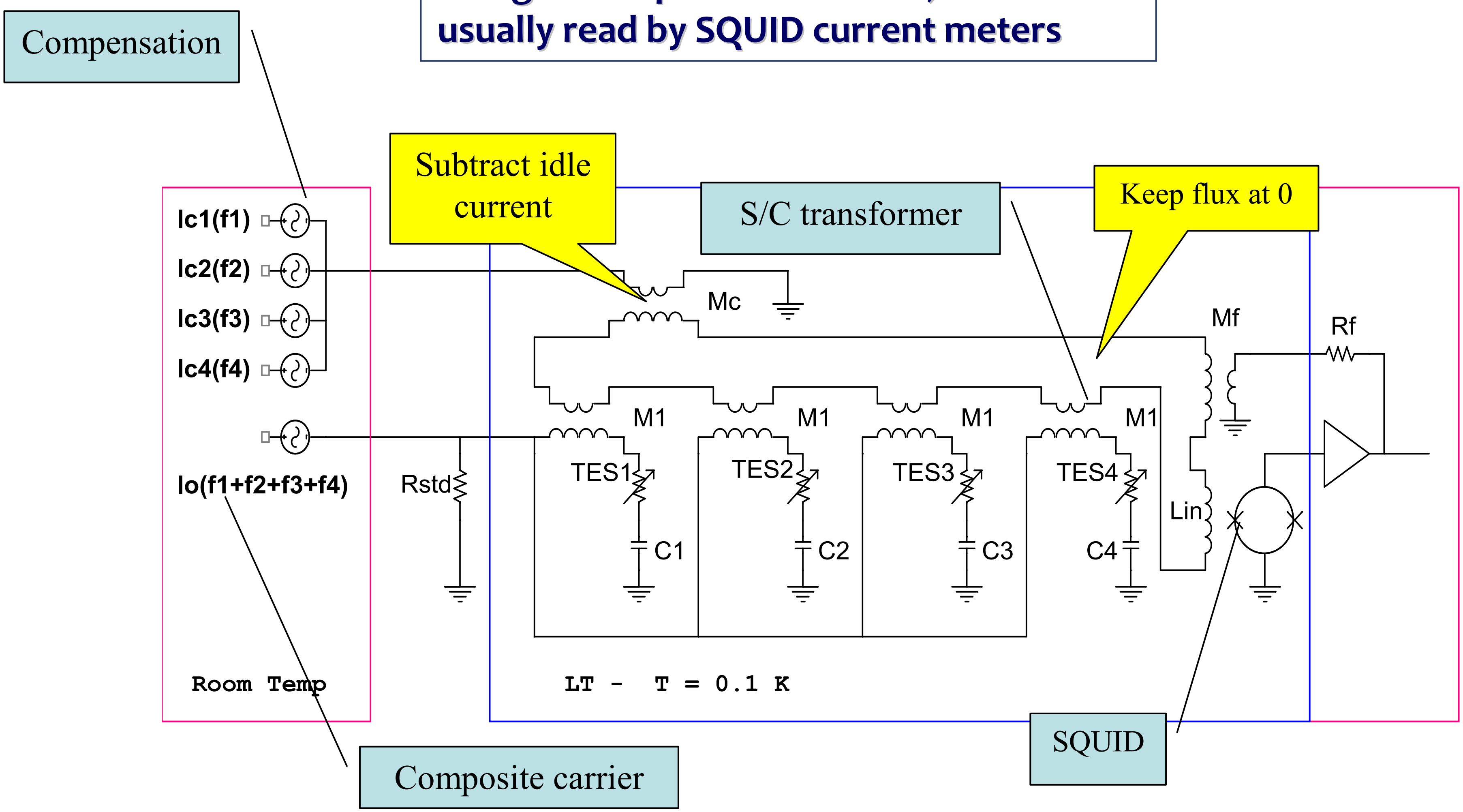




Ho implanted in asuperconducting absorber grown directly on the TES.
The EC energy is finally released as X-rays, Auger electrons or Coster-Kronig transition, thus the absorbed must be a few microns thick (Bi, Sn, Au…)

SQUID amplifier for TES arrays

Being low impedance devices, TES's are usually read by SQUID current meters



Our goal: 0.2 eV limit on m_ν

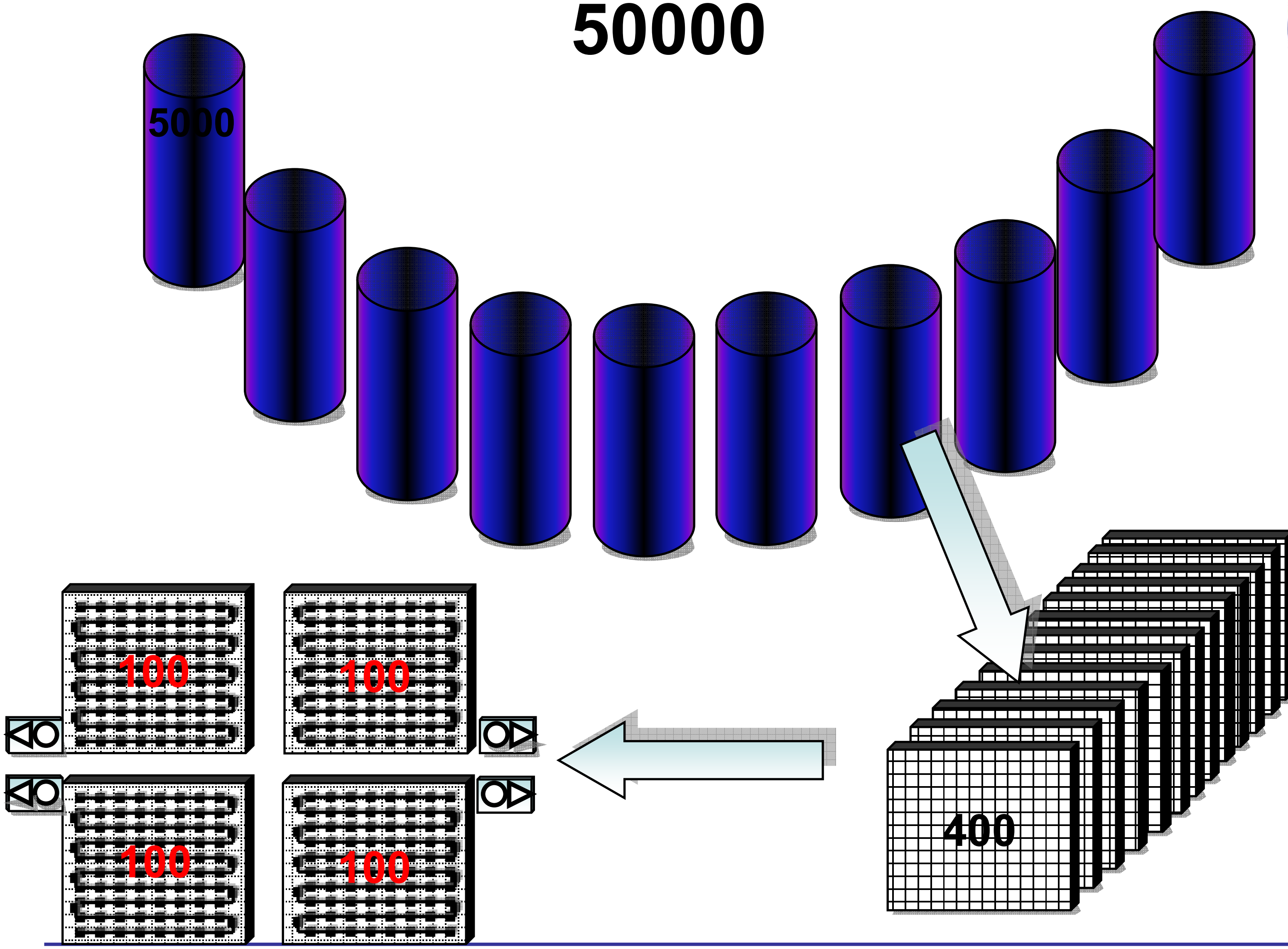
- MARE I (expected resolution of 1eV or fraction)
  - 300 detectors
  - $Tr < 200\ \mu s$
  - 10^{10} events
- MARE II (expected resolution of 0.2eV)
  - 50000 detectors
  - $Tr = 1 - 10\ \mu s$
  - $m = 1 – 5$ mg
  - 10^{14} events , pile up fraction 10^{-5}

At the moment the sensitivity limit is due to statistics; a better result is achievable growing the number of detectors

Conclusions

- A microcalorimetric measurement of the neutrino mass could permit to lower of one order the actual limit of 2eV;
- The huge effort for test and improving the overall technology is needed:
  - ✓ ^{163}Ho EC is a promising alternative tool respect to ^{187}Re β decay, and a technique of implantation with highly purification process is under study;
  - ✓ The fabrication of TES in arrays of several pixel requires the optimization of the reproducibility of thin film superconducting properties over larger areas;
  - ✓ A prototype of the SQUID multiplexing amplifier with 5 channels is now tested in our lab;
- We should be able to integrate 5 Re μ-calorimeters in the same chip and fully characterize the array within the end of the year.

50000



SQUID amplifier for TES arrays