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MARE-1 in Milan: an update

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fondazione cariplo

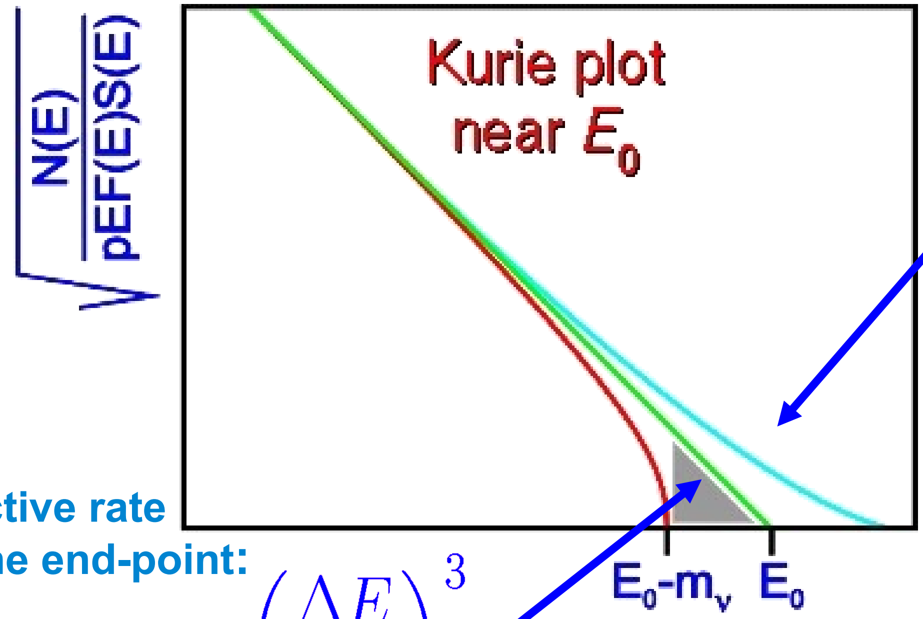
Outline

- Direct neutrino mass measurement
- The calorimetric approach
- MARE: a project for a new Re/ho experiment
- MARE-1 in Milano
- MKDs R&D @ Milano Bicocca

Direct neutrino mass measurement

neutrino oscillations evidence → $m_\nu \neq 0$
BUT oscillation experiments give only Δm^2!

direct neutrino mass measurement



effective rate at the end-point:

$$F_{\Delta E}(0) \approx \left(\frac{\Delta E}{E_0}\right)^3$$

effect of:
- **energy resolution**
- **background**
- **Pile up**

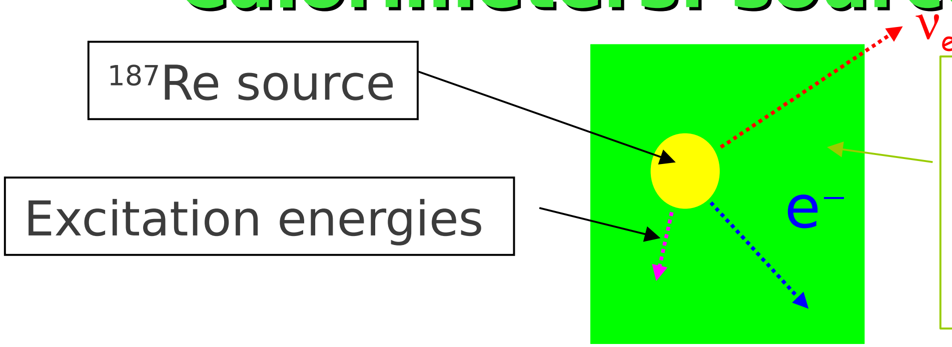
$$K(E_\beta) = (E_0 - E_\beta)\sqrt[4]{1 - \frac{m_\nu^2}{(E_0 - E_\beta)^2}}$$

$m_\nu = (\Sigma m^2_i |U_{ei}|^2)^{1/2}$

2 eV → ^3H (E_0=18.6keV) & spectrometers
15 eV → ^{187}Re(E_0=2.47keV) & calorimeters

The calorimetric approach

- **Calorimeters: source ⊆ detector**



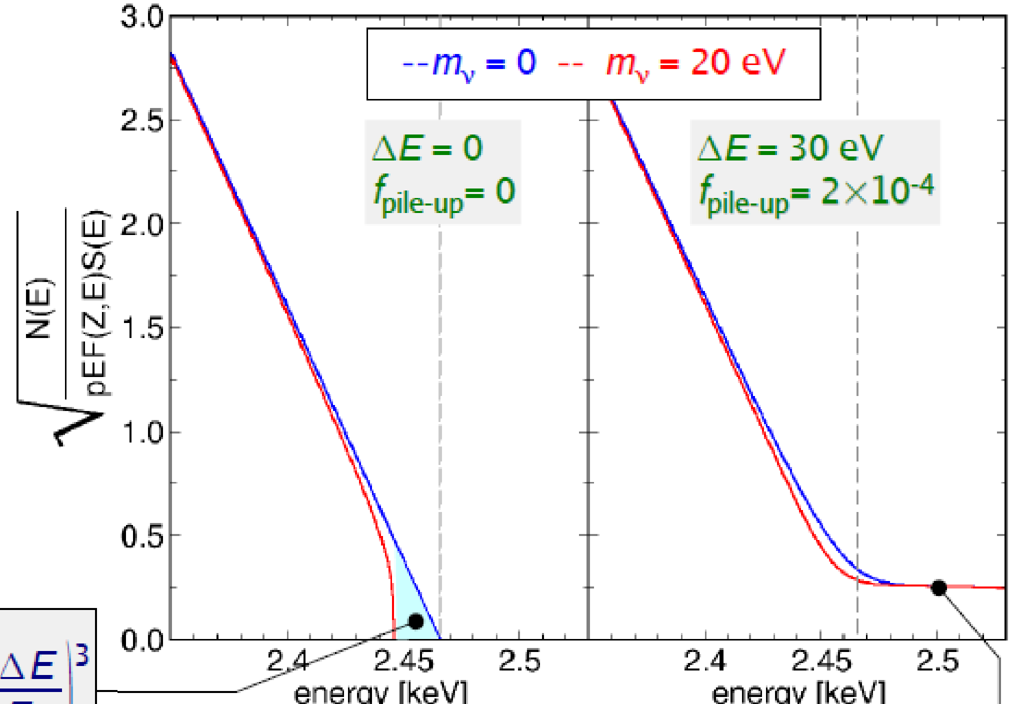
β calorimeter
ideally measures all the energy *E* released in the decay except for the ν_e energy

General experimental requirements:

- High statistics at the beta spectrum end-point
- high energy resolution ΔE
- high Signal to Noise ratio
- small systematic effects

Calorimeters measure the **entire spectrum** at once:

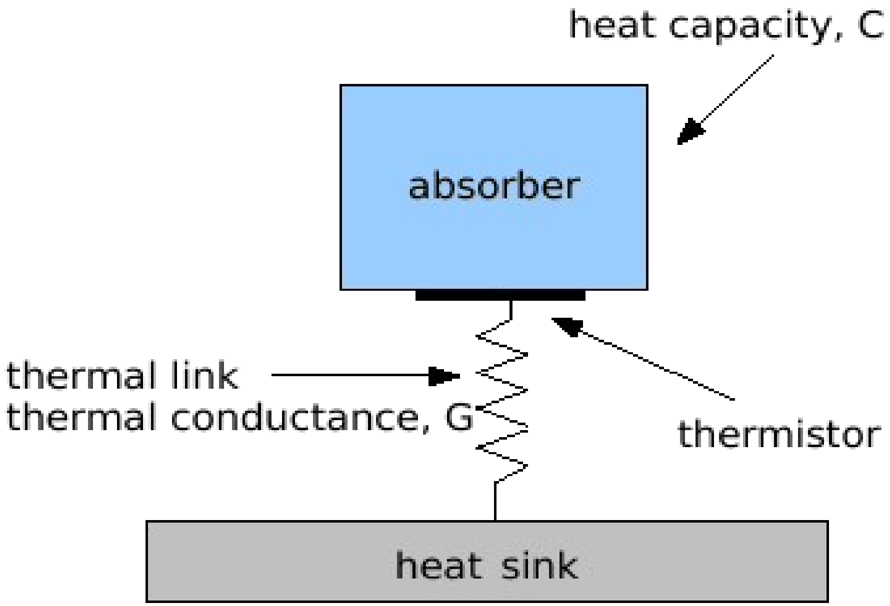
- low E_0 β decaying isotopes for more statistics near the end-point
- best choice ^{187}Re:
  - E_0 = 2.5 keV, τ½ = 4×10^{10} y
- other option ^{163}Ho EC:
  - E_0 ≈ 2.6 keV, τ½ ≈ 4600 y

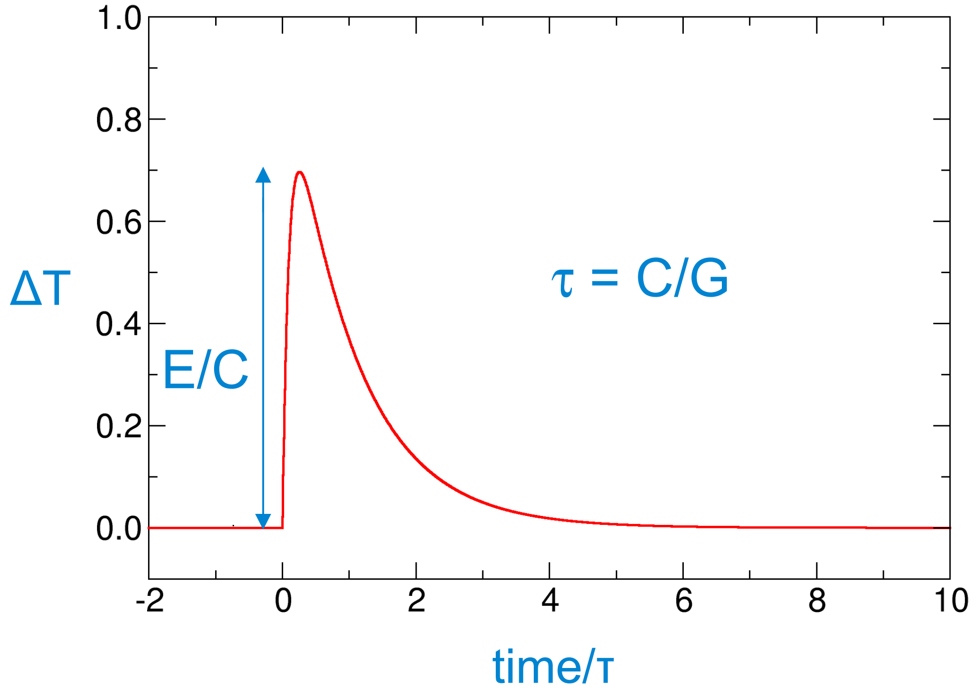


$$F(\Delta E) \approx \left(\frac{\Delta E}{E_0}\right)^3$$

pile-up fraction: $f_{pile-up} = \tau_R A_\beta$

Cryogenic detectors as calorimeters





Detection Principle:

- $\Delta T = E/C$ where C is the total thermal capacity
  - low C: $C \sim (T/\Theta_D)^3$ in superconductors below T_C & dieletric
    - low T (10 ÷ 100 mK)
- ultimate limit to energy resolution:
  - statistical fluctuation of internal energy $\Delta E = (k_B T^2 C)^{1/2}$
- detect all deposited energy, including short-lived excited states (100 μs)
- achieve very good energy resolution in the keV range

MARE - A project for a new Re/Ho experiment

Goal: a sub-eV direct neutrino mass measurement complementary to the KATRIN experiment

MARE 1

- activities aiming at isotope/technique selection (^{187}Re or ^{163}Ho options)
- activities using medium sized arrays to improve ^{187}Re measurement understanding and possibly calorimetric m_ν limit
- detector and absorber coupling R&D activities

~ 100 detectors → 2-4 eV m_ν sensitivity

MARE 2

- very large experiment with a m_ν statistical sensitivity close to KATRIN but still improvable
- requires new improved detector technologies

MARE: Microcalorimeter Arrays for a Rhenium Experiment

Università di Genova e INFN Sez. di Genova, Italy
Univ. di Milano-Bicocca, Univ. dell'Insubria e INFN Sez. di Milano-Bicocca, Italy
Kirkhhof-Institute Physik, Universitat Heidelberg, Germany
University of Miami, Florida, USA
Wisconsin University, Madison, Wisconsin, USA
Universidade de Lisboa and ITN, Portugal
UniversitÃ di Roma “La Sapienza” e INFN Sez. di Roma1, Italy
Goddard Space Flight Center, NASA, Maryland, USA
PTB, Berlin, Germany
FBK, Trento e INFN Sez. di Padova, Italy
NIST, Boulder, Colorado, USA
SISSA - Trieste, GSI Darmstad, JPL/Caltech, CNRS Grenoble, ...

http://crio.mib.infn.it/wig/silicini/proposal/

MARE 1

MARE-1: collection of activities aiming at isotope/technique selection

- ^{187}**Re** – high statistics measurement
  - asses systematics
  - test large arrays
  - lower limit to few eV
- ^{163}**Ho** – high statistics measurement – R&D for ^{163}Ho production
  - measure Q_{EC}
  - study spectrum shape
  - asses systematics

Different techniques:

- TES – Transition Edge Sensor
- MMC – Magnetic MicroCalorimeter
- MKID – Microwave Kinetic Inductance Detector

↳
- **multiplexed readout**
- **large arrays**

MARE-1 in Milan / Re option

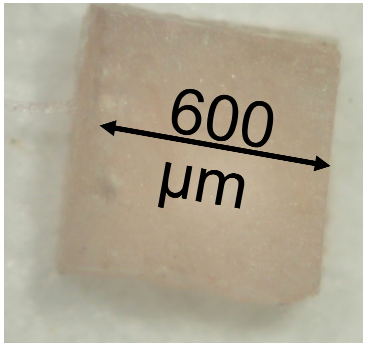
MARE-1 in Milan: Milano/FBK/Wisconsin/NASA

- $m_{\nu e} < 2$ eV/c^2
- 10^{10} events - 300 sensors
- 8 arrays of Si:P thermistors with $AgReO_4$ absorbers
- energy resolution 25 eV @ 2.6 keV

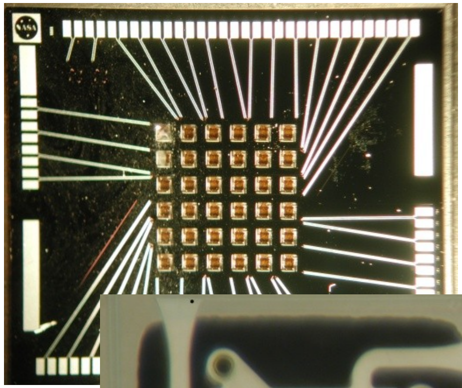
The first phase is needed:
- because it's the only possible one with present technology
- To investigate systematics in thermal calorimeters

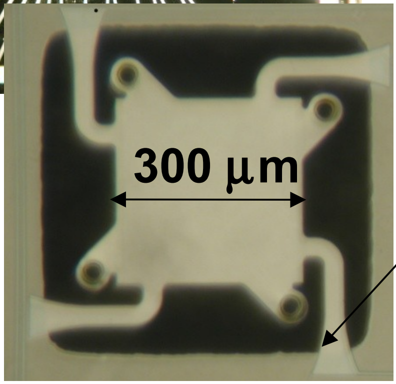
↳ **very important to cross-check spectrometer results**

MARE-1 detectors

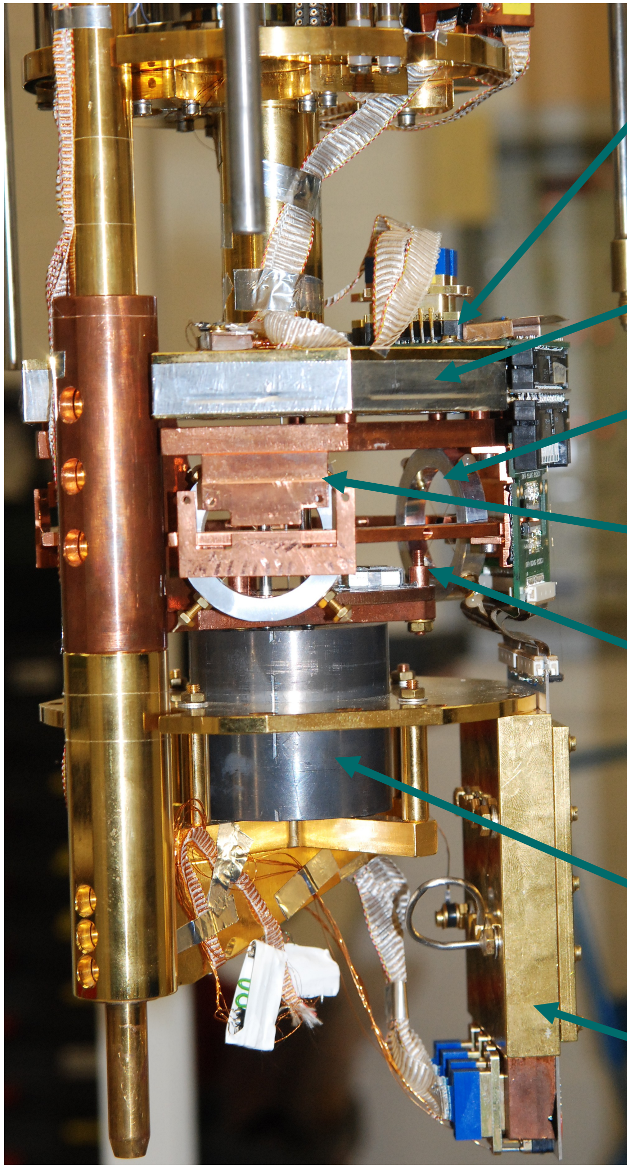


- ^{187}Re β-decay
  - $^{187}Re \rightarrow {}^{187}Os + e^- + \nu_e$ E_0=2.47 keV
  - i. a. 63% and τ=42.3 Gy
- Single crystal of silver perrhenate ($AgReO_4$)
  - mass ~ 500 μg per pixel (A_β~ 0.3 decay/sec)
  - regular shape (600x600x250 μm^3)
  - low heat capacity due to Debye law
- 6x6 array of Si:P semiconductors (NASA-GSFC)
  - pixel: 300x300x1.5 μm^3
  - high energy resolution
  - developed for X-ray spectroscopy with HgTe absorber (ASTRO-E2)





Cryogenic set-up of MARE 1 @ Milano Bicocca



Load Resistence 50 MΩ

Detector holder

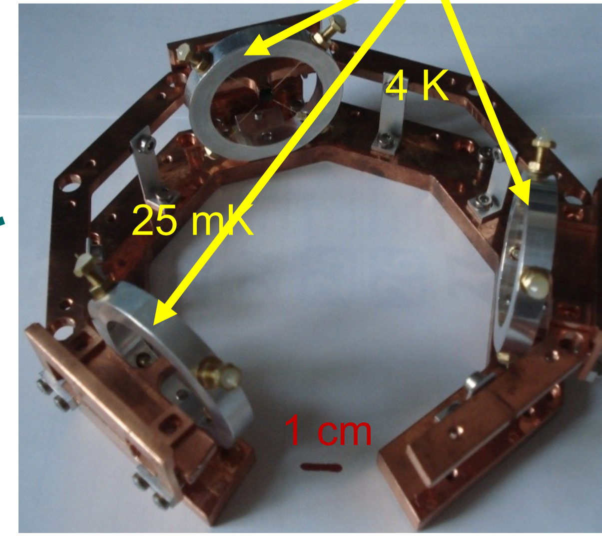
Calibration source ^{55}Fe

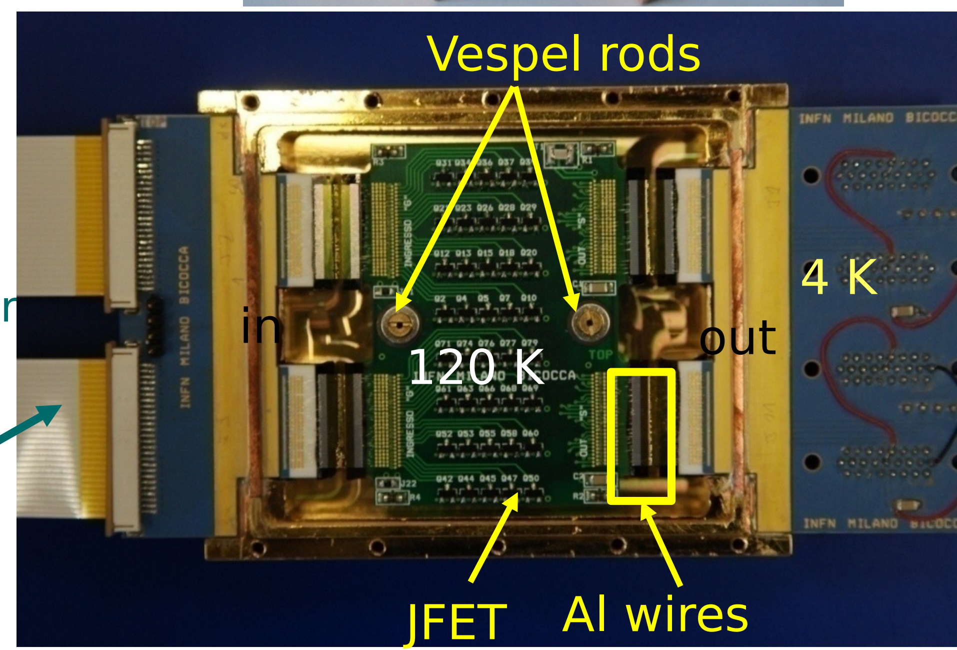
Calibration targets

Pb shield for calibration source

JFET box

Kevlar crosses



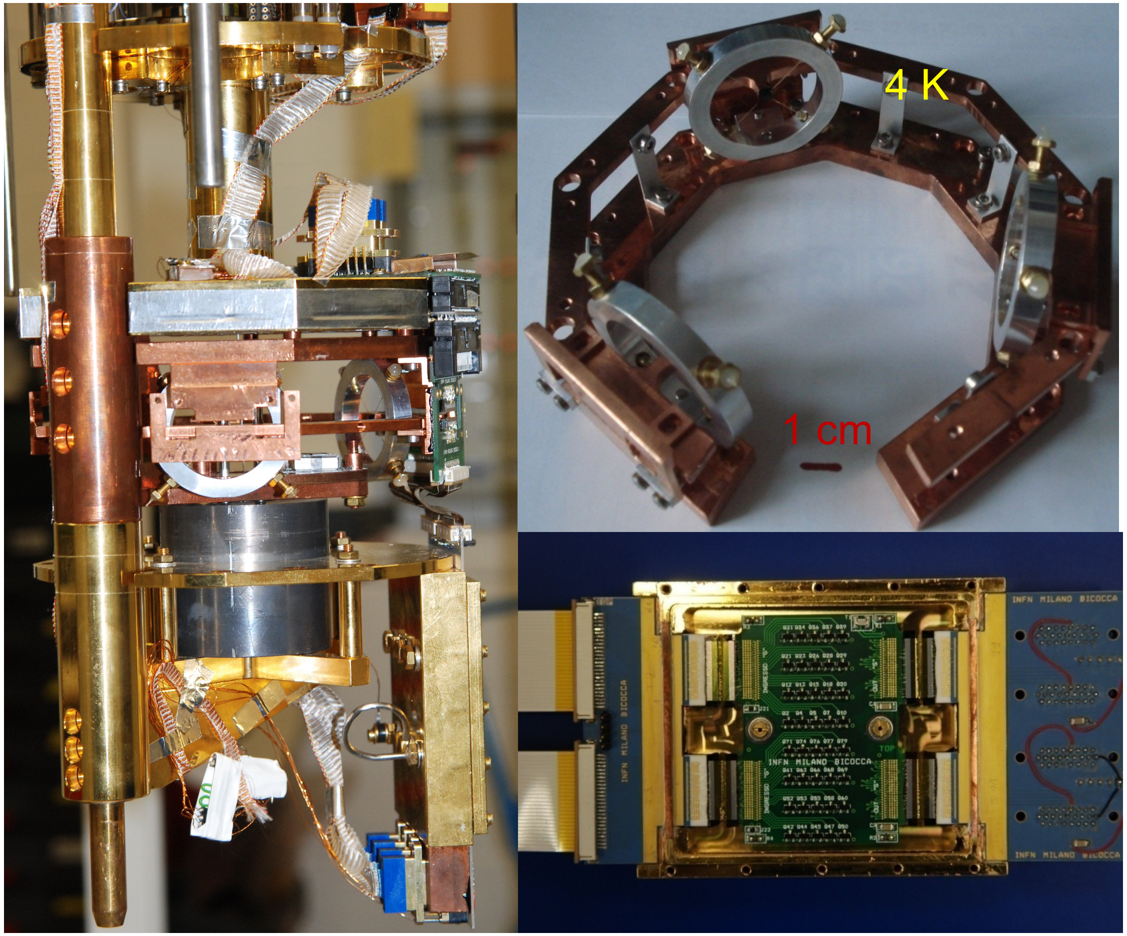


MARE 1 @ Milano-Bicocca

All the problems concerning the cryogenic set-up have been solved.

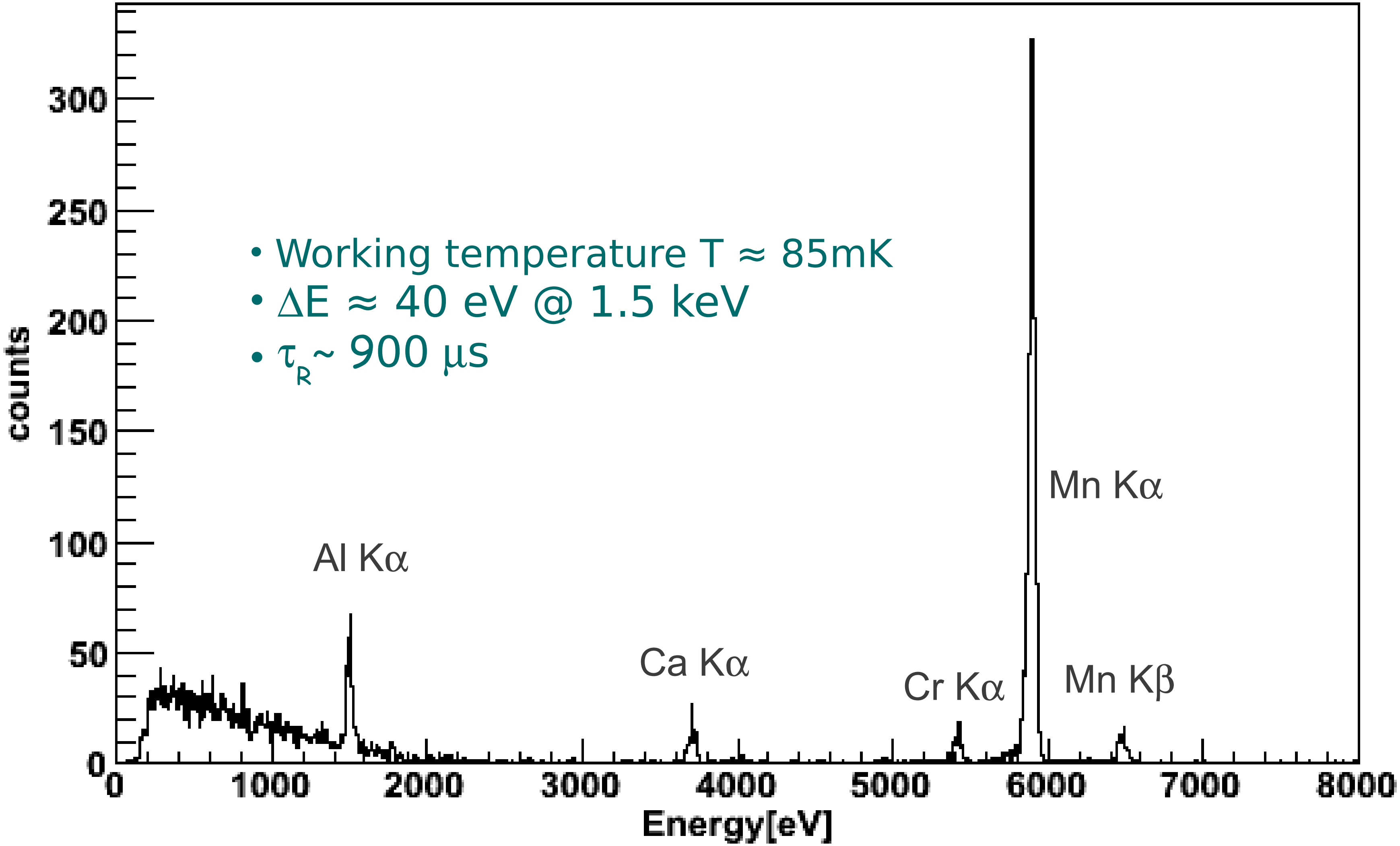
Thanks to the improvements added to the cryogenic set-up the detector target performances have been achieved.

- First spectra acquired
- Completed assembly of the first array



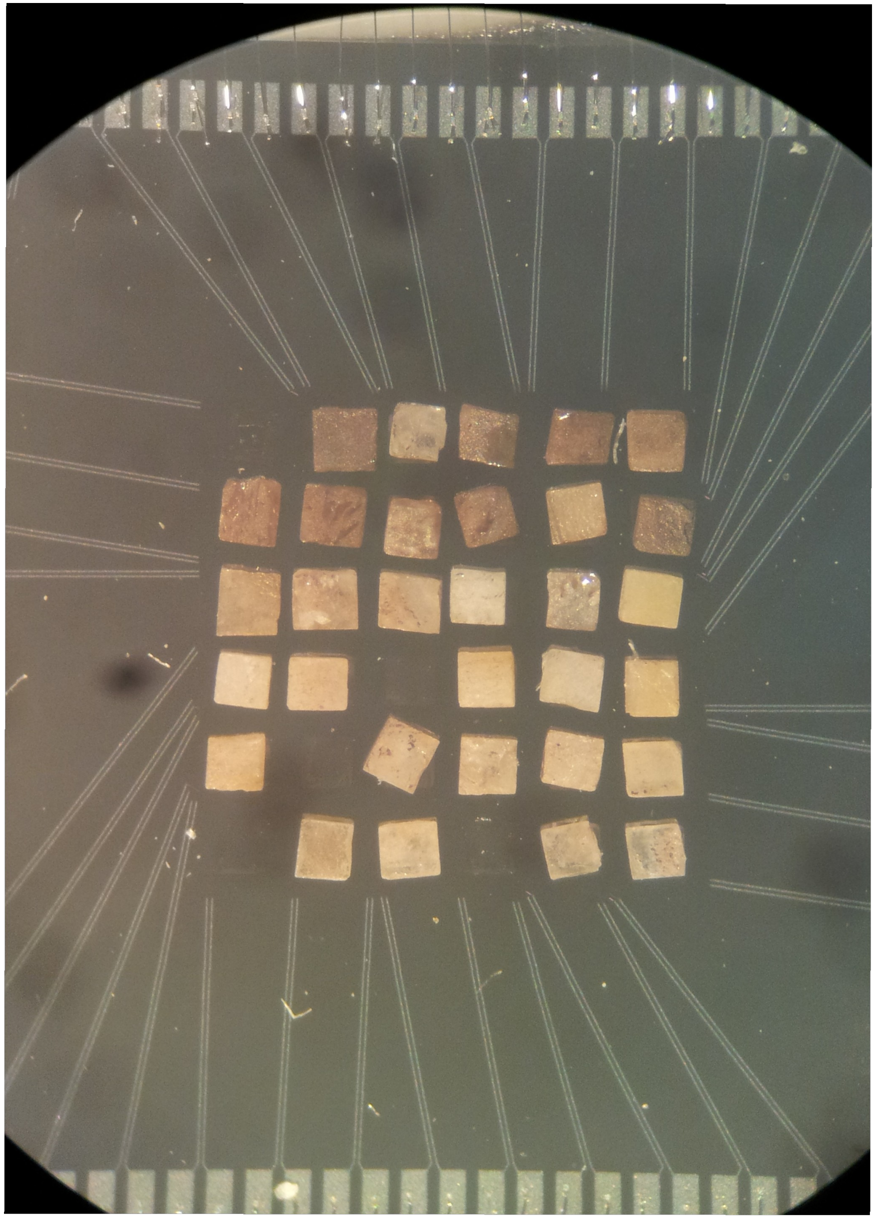
MARE 1 @ Milano-Bicocca

first spectrum acquired after the improvements added to MARE-1 cryogenic set-up



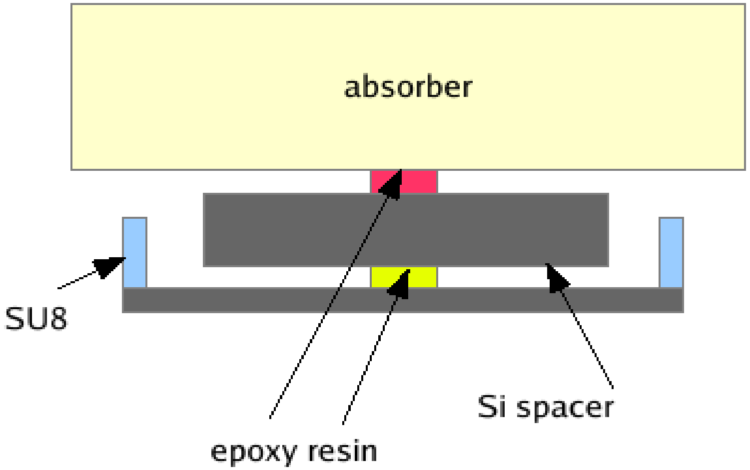
Measured 7 pixels: ΔE_{ave}~30eV @ 1,5keV

First array of MARE-1



Thermal coupling

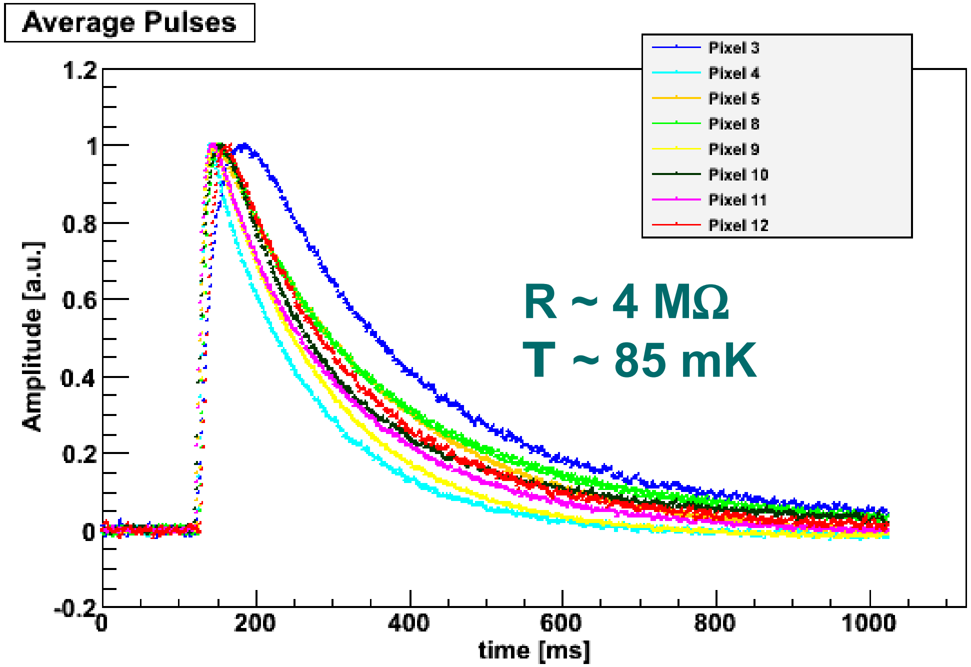
- **Araldit or ST1266:** thermistor/spacer
- **ST2850:** spacer/$AgReO_4$

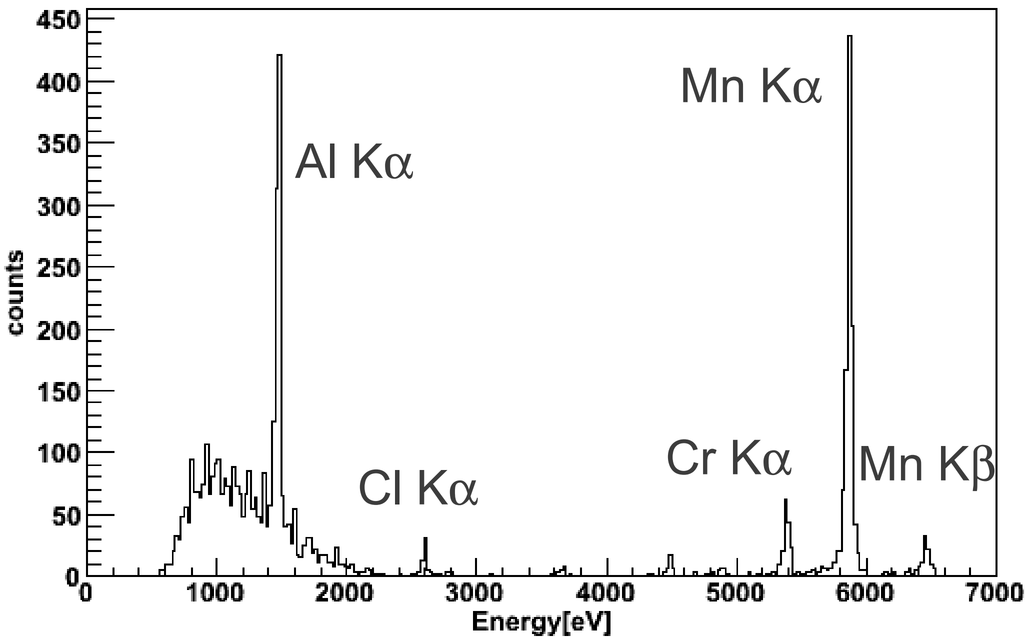


- 6 silicon spacers are attached with **Araldite Normal**
- 10 with **Araldite Rapid**
- 15 with **ST1266**

First array of MARE-1

A run aimed to test the performance of this setup is ongoing, after which the absorbers will be glued also on the second array. With two arrays, a sensitivity of 4.5 eV at 90% C.L. is expected in three years running time.

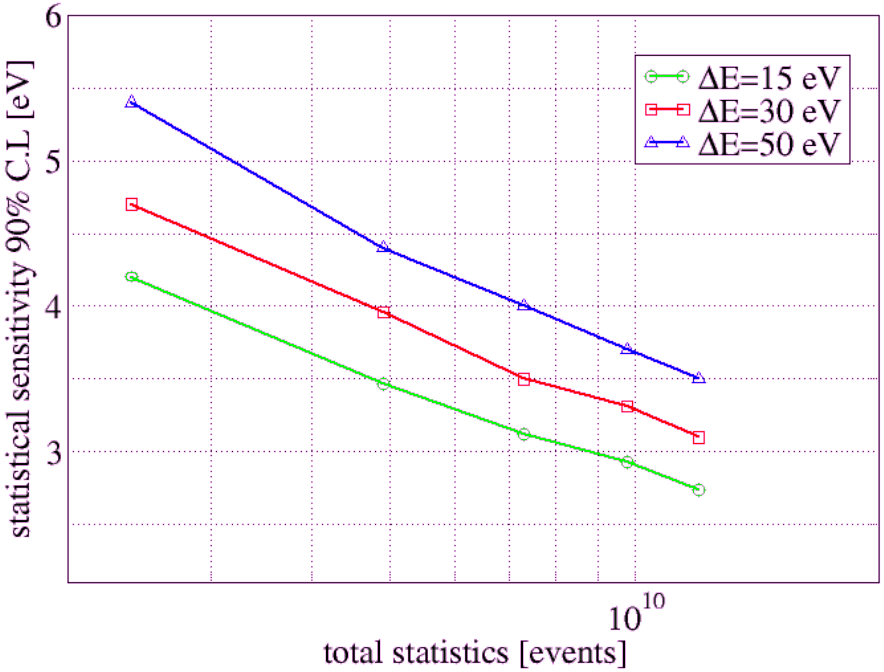




- Working temperature T ≈ 88mK
- $\Delta E \approx 24$ eV @ 1.5 keV
- $\tau_R \sim 1$ ms

MARE 1 in Milano: sensitivity

MonteCarlo approach



- setup designed to host up to 8 arrays
- 288 $AgReO_4$ crystals
- start with 2 arrays (72 ch.)
- gradual deployment

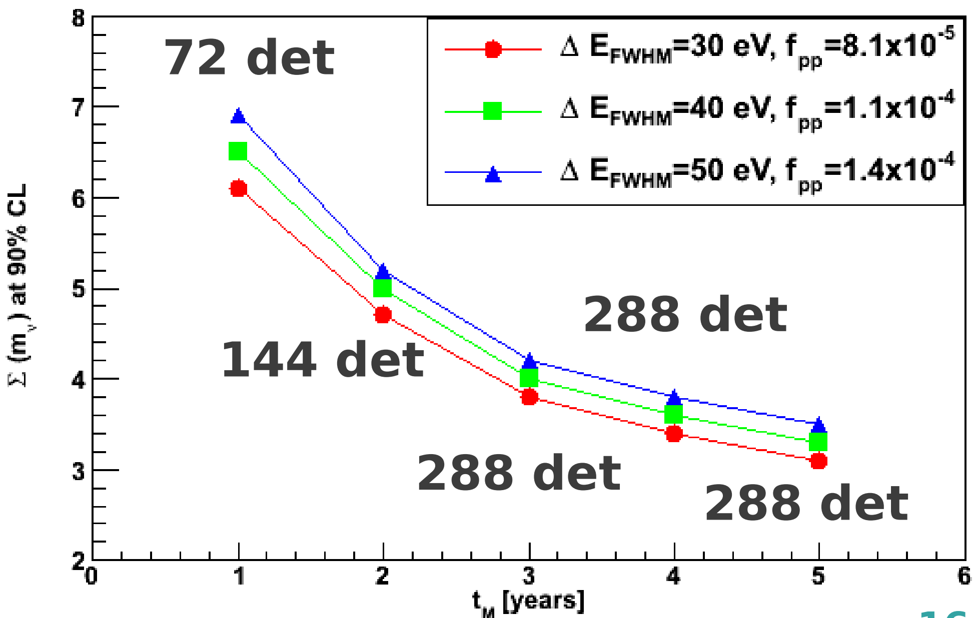
Since only two arrays are available up to now, it is useful to estimate the sensitivity on neutrino mass over the years by increasing the detectors number from year to year.

Detectors

ΔE_{FWHM} ~ 50 eV and τ_R ~ 500 μs
1 year and 72 channels → $\Sigma(m_\nu)$ ~7eV
3 years and 288 channels → $\Sigma(m_\nu)$ ~ 4.2eV

ΔE_{FWHM} ~ 30 eV and τ_R ~ 300 μs
1 year and 72 channels → $\Sigma(m_\nu)$ ~6eV
3 years and 288 channels → $\Sigma(m_\nu)$ ~ 3.8eV

Analytic approach (1st order)

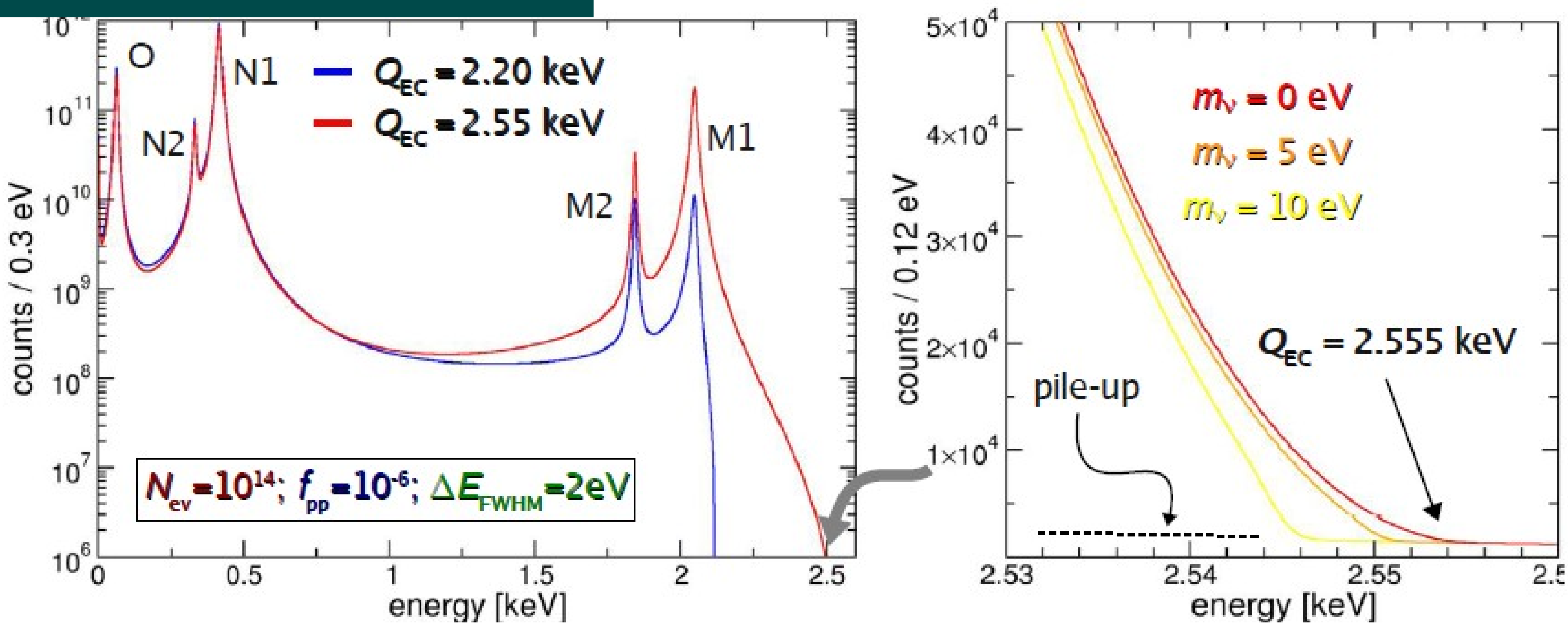


MARE extensions: ^{163}Ho EC measurement

$^{163}Ho + e^- \Rightarrow {}^{163}Dy^* + \nu_e$

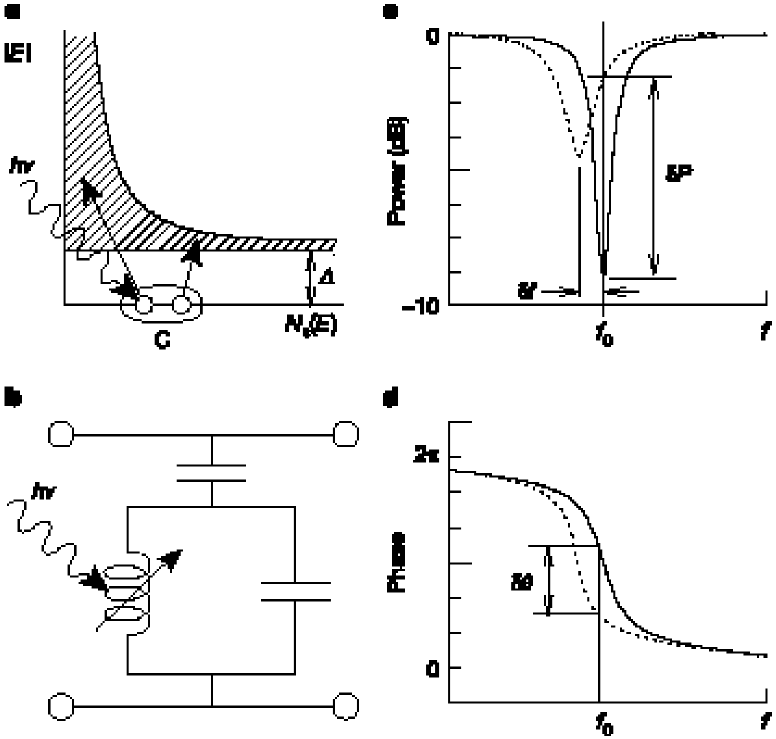
electron capture from shell ⩾ M1

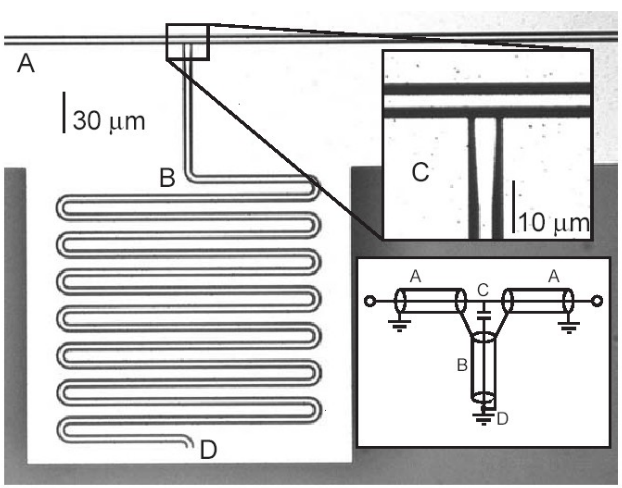
A. De Rujula and M. Lusignoli, Phys. Lett. B 118 (1982) 429



- Calorimetric measurement of non-radiative Dy atomic de-excitations
- Breit Wigner M,N,O lines have an end-point at the Q value
- rate at end-point may be as high as for ^{187}Re but depends on Q_{EC}
    - Q_{EC}? Measured: $Q_{EC} = 2.3 \div 2.8$ keV. Recommended: $Q_{EC} = 2.555$ keV
- $\tau_{1/2} \approx 4570$ years: few active nuclei are needed
    - can be implanted in any suitable microcalorimeter absorber
- ^{163}Ho production by neutron irradiation of ^{162}Er enriched Er

fondazione cariplo





- resonator exploiting the *T* dependence of inductance in a superconducting film
  - **detectors** suitable for large absorbers
  - **Good time resolution** (low pile-up f_{pp})
  - **high energy resolution**
  - **multiplexing** for very large number of pixel

Sensitivity

$\Delta E = 5$ eV

$t_M = 36000$ detectors x 3 years

$A_\beta = 20$ c/s/det

$\tau_{rise} = 1\ \mu s \Rightarrow m_\nu < 0.2$ eV

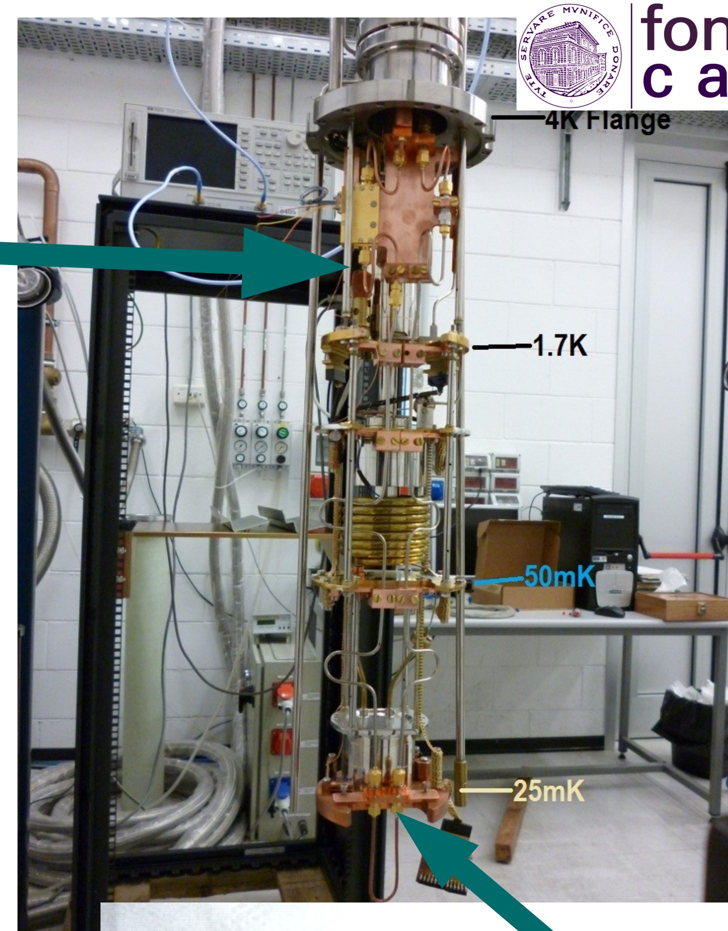
$\tau_{rise} = 100\ \mu s \Rightarrow m_\nu < 0.4$ eV

application to bulky absorber still requires further efforts

MKIDs for ^{163}Ho EC decay end point measurement

fondazione cariplo

4-12 GHz
cryo amp

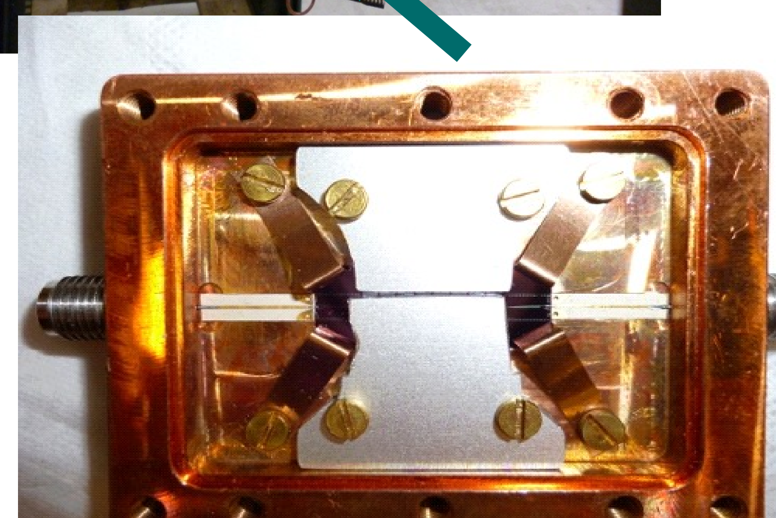


So far tested stoichiometric TiN (T_c=4,6K) films and Ti/TiN multilayer (produced by FBK), which behaves like a sub-stoichiometric TiN film (T_c=1,6K)

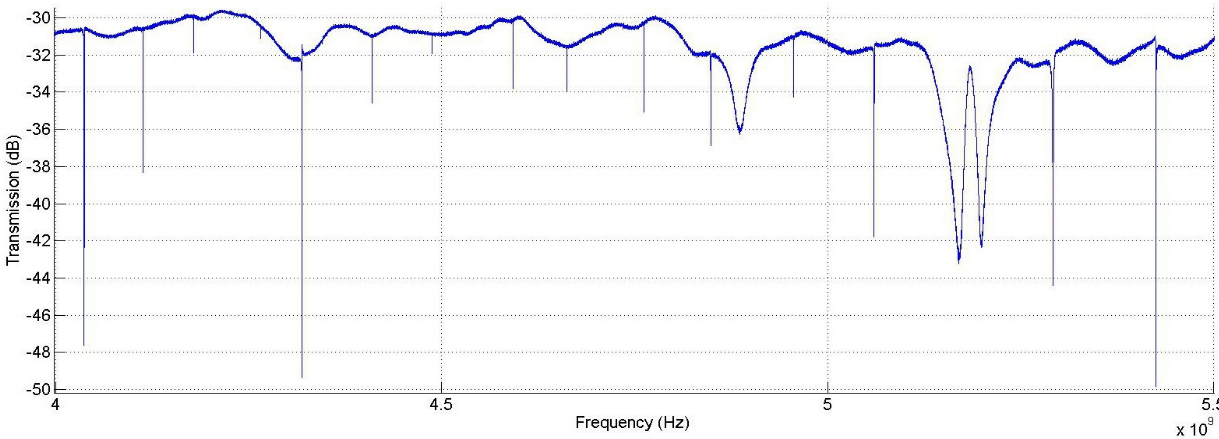
Gap parameter:
- TiN 0.8 meV
- Ti/TiN 0.26 meV

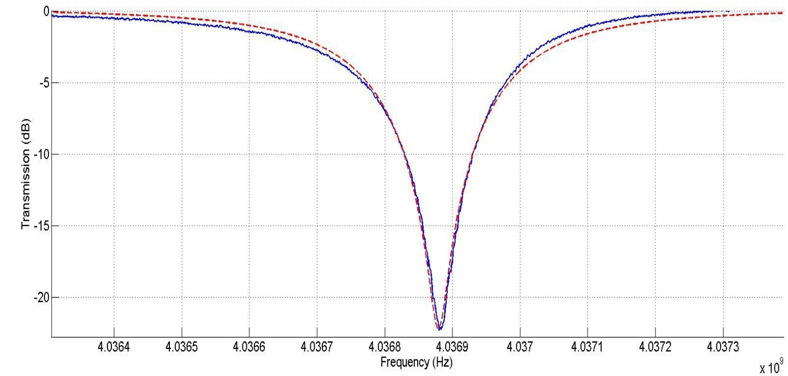
The devices were tested with ^{55}Fe (6keV) and Al X-ray (1,5keV) and the first pulses were acquired

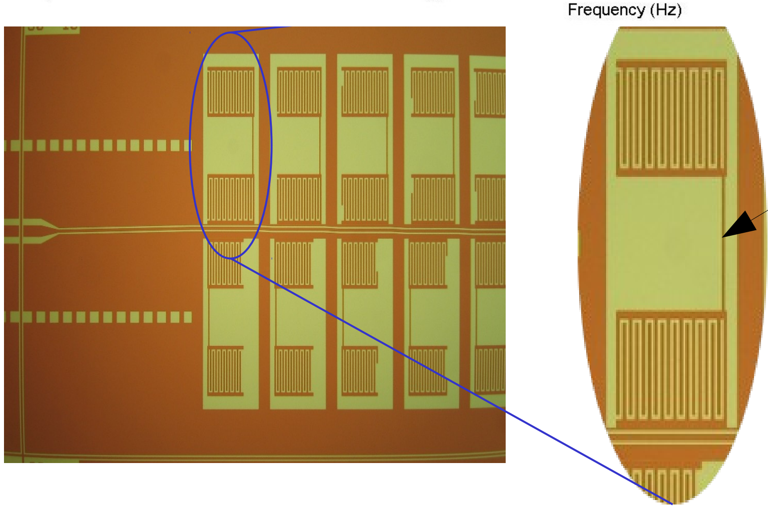
Not resolving yet because of events interacting in the Si substrate under the superconductor



MKIDs for ^{163}Ho EC decay end point





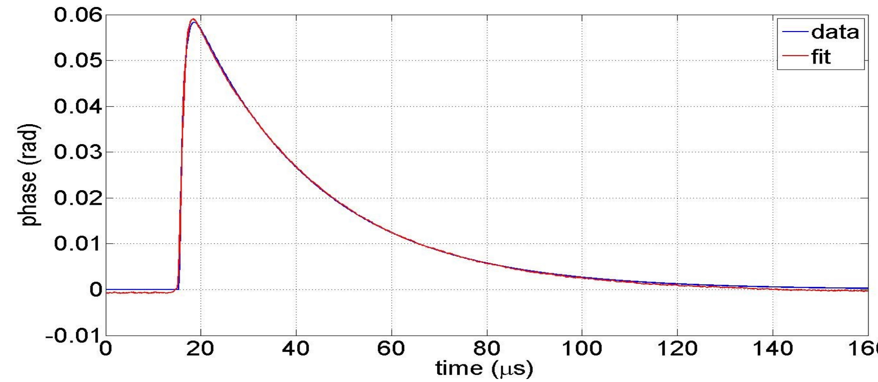


The ^{163}Ho will be embedded in the center of the inductive part of the resonator, deep enough to ensure low escape probability. A thickness of <500nm will be enough

10^{12} Ho nuclei are needed for a count rate of 10 Hz

theoretical resolution

$$\Delta E_{th} = 2keV/N_{qp}^{1/2} = 1.5\ eV$$



This work is supported by Fondazione Cariplo through the project ”Development of Microresonator Detectors for Neutrino Physics” (grant 2010-2351).

Conclusion

First array of MARE-1 has been assembled

→ 31 thermistors are equipped with AgReO4 absorbers

The goal performances of the detectors have been achieved

→ first spectra were acquired obtaining a resolution of ~28eV @ 1,5keV

The next step will be to assemble the detectors on the second array

→ start of data taking in the next months

In the meanwhile new detector technology under investigation

→ Ho EC measurement with MKDs