The Future of Neutrino Mass Measurements: Terrestrial, Astrophysical, and Cosmological Measurements in the Next Decade

Seattle

February 8-11, 2010

MARE in Milan

Talk presented by Elena Ferri*

E. Ferri*, C. Arnaboldi*, C. Kilbourne▪, S. Kraft Bermuth•, A. Nucciotti*, G. Pessina* and D. Schaeffer*

* University of Milano-Bicocca and INFN Milano-Bicocca, Italy
▪ Goddard Space FlightCenter, Nasa, USA
• Institut fur Physicik, Johannes-Gutenberg-Universitat Mainz, Germany

Outline

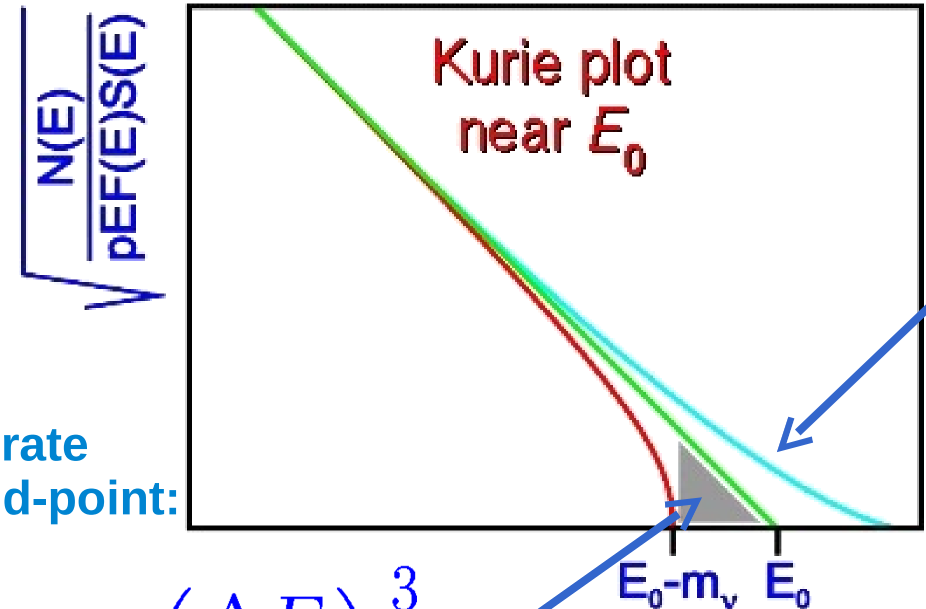
- Physics motivation
- Microcalorimeter
- The MARE experiment
- MARE-1 in Milan: Source, Absorber & Thermistors
- Cryogenic set-up
- Detectors
- Conclusion

Physical motivation

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**

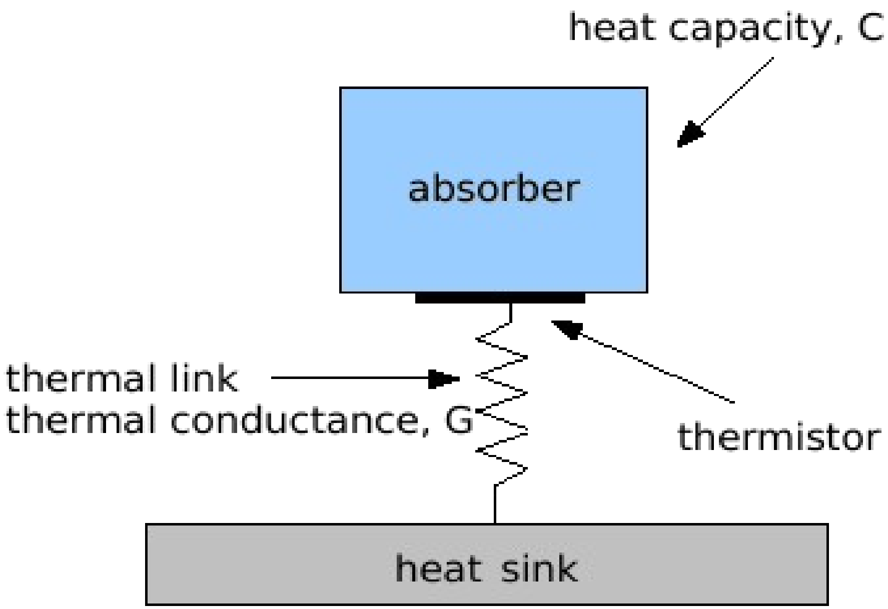
$$K(E_\beta) = (E_0 - E_\beta)\sqrt[4]{1 - \frac{m_\nu^2}{(E_0 - E_\beta)^2}}$$

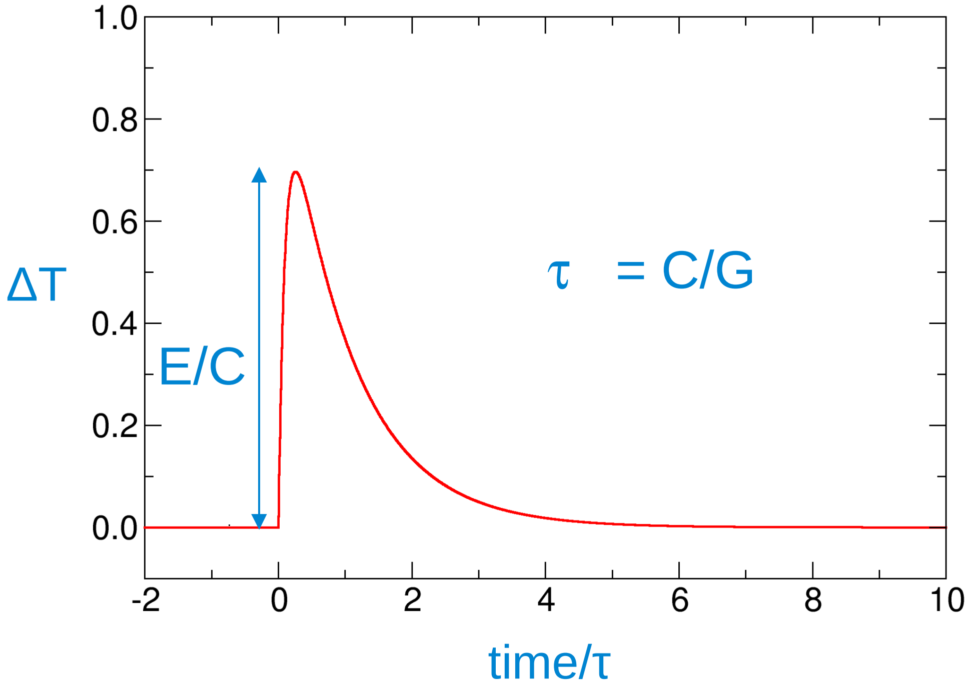
$m_\nu = (\Sigma\ m^2_i |U_{ei}|^2)^{1/2}$

2 eV → ^3H (E_0=18.6keV) & spectrometers

15 eV → ^{187}Re(E_0=2.47keV) & calorimeters

Microcalorimeter





- energy resolution $\Delta E=(k_B T^2 C)^{1/2}$
- low heat capacity
  - Debye law
  - $C \sim (T/\Theta_D)^3$
- detect all deposited energy, including short-lived excited states (100 µs)
- achieve very good energy resolution in the keV range

MARE

- new large scale experiment: 10,000 sensors
- sub-eV sensitivity on neutrino mass

MARE-1: the first step

⇨ $m_{\nu_e} < 2$ eV/c^2

⇨ 10^{10} events - 300 sensors

⇨ 2 independent experiments: Milan and Genoa

MARE-1 in Milan: Milano/Como/IRST/Wisconsin/NASA

⇨ 8 arrays of Si:P thermistors with $AgReO_4$ absorbers

⇨ energy resolution 25 eV @ 2.6 keV

MARE 1 - Sensitivity

$$\Sigma_{90}(m_\nu) \approx 1.13\sqrt{\frac{2\Delta E E_0^3}{N_{ev}} + 0.3\frac{f_{pp}E_0^5}{N_{ev}\Delta E}}$$

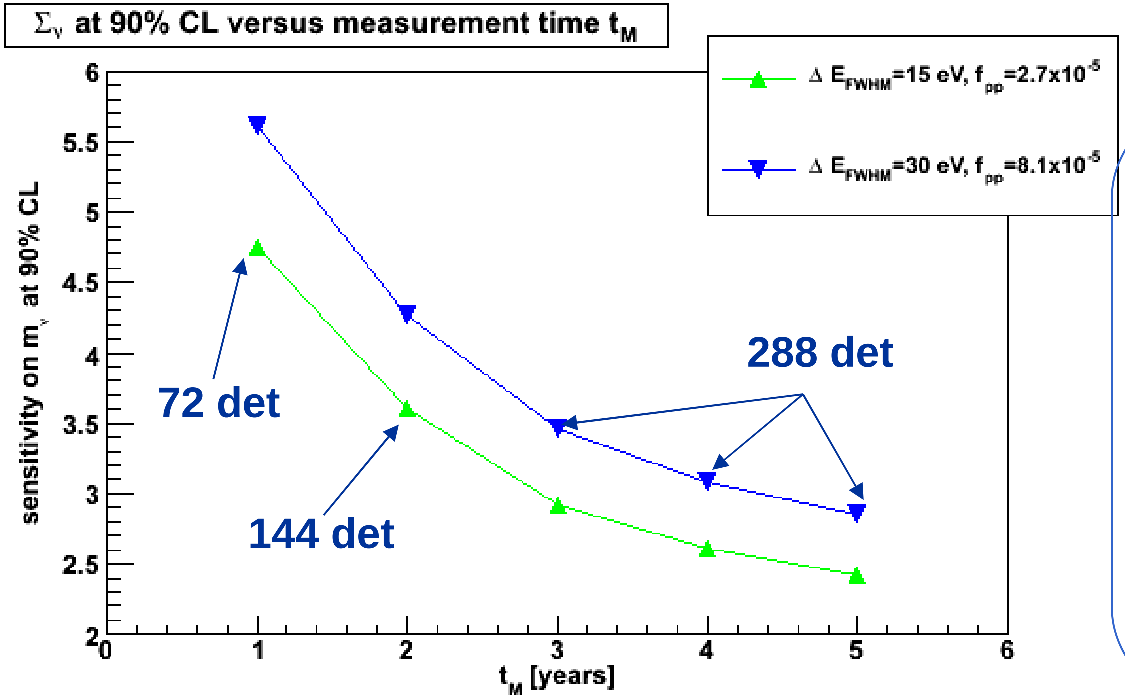
$$N_{ev} = A_\beta t_M N_{det} = A_\beta T$$

$$f_{pp} = A_\beta \tau_R$$

N_{det}=288

A_β =0.27 dec/sec

Δ E energy range of interest near E_0

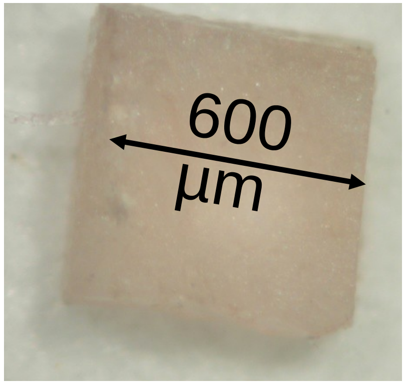


Detectors

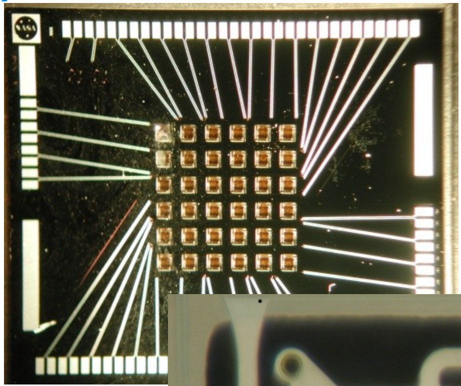
Δ E_{FWHM} ~ 15 eV e τ_R ~ 100 μ s
1 year and 72 channels → Σ (m_ν) ~5eV
3 years and 288 channels → Σ (m_ν) ~ 3eV

Δ E_{FWHM} ~ 30 eV e τ_R ~ 300 μ s
1 year and 72 channels → Σ (m_ν) ~6eV
3 years and 288 channels → Σ (m_ν) ~ 3eV

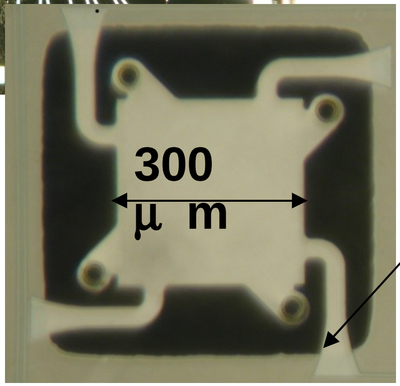
- ^{187}Re β -decay
  - ⇨ $^{187}Re \rightarrow {}^{187}Os + e^- + \bar{\nu}_e$ E_0=2.47 keV
  - ⇨ i. a. 63% and $\tau_{1/2} = 43.2$ Gy



- 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

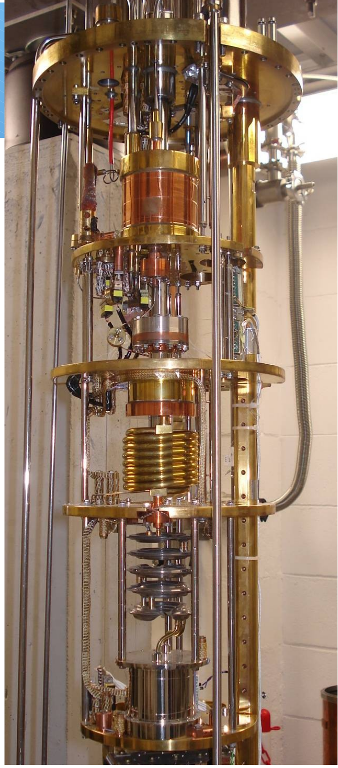


- 6x6 array of Si:P semiconductors (NASA-GSFC)
  - ⇨ pixel: 300x300x1.5 µm^3
  - ⇨ high energy resolution
  - ⇨ developed for X-ray spectroscopy

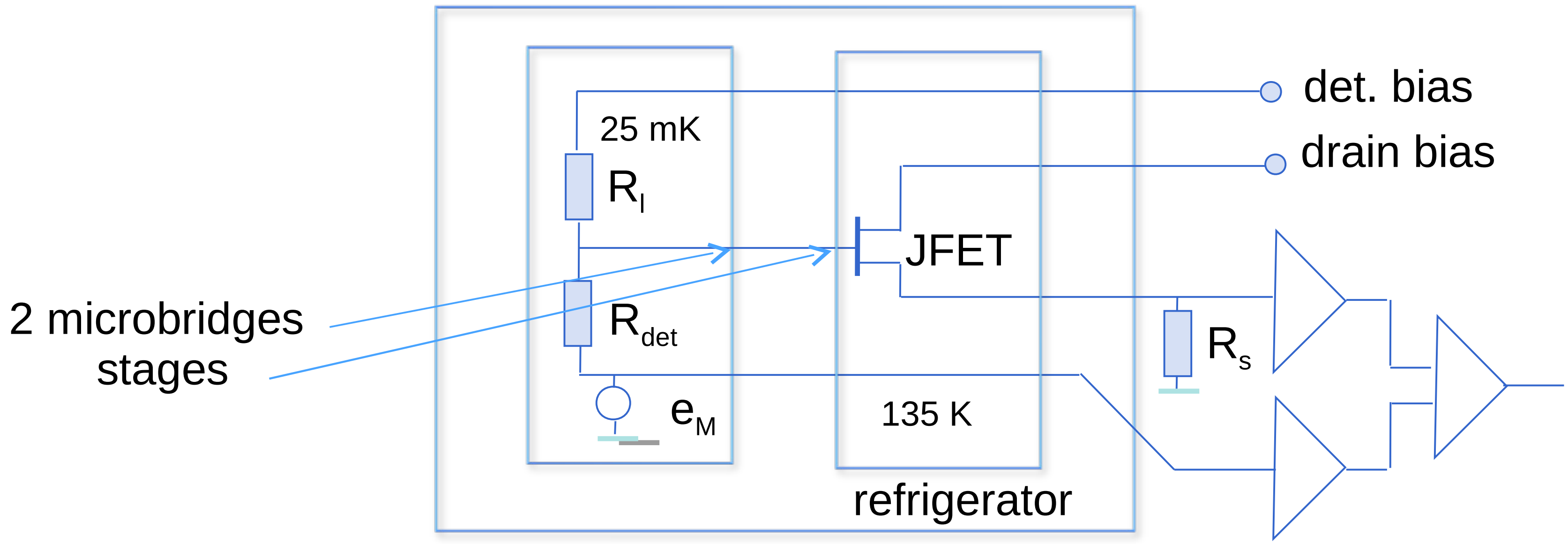


Si support

MARE 1 in Milan

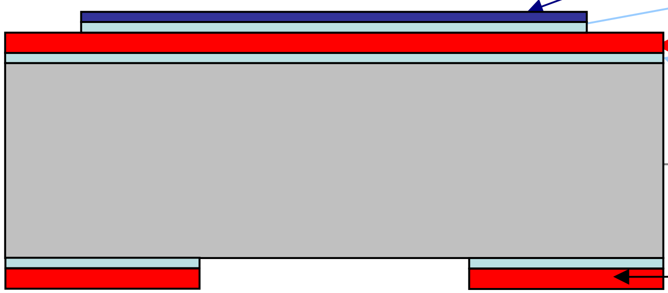


- Dilution refrigerator
- Front-end electronic
  - cold buffer stage (JFET G=1, T_{op}~ 135 K)
  - amplifier stage at room temperature



Microbridges fabrications

fabrication of Ti/Al film



Ti or Al **200 nm**

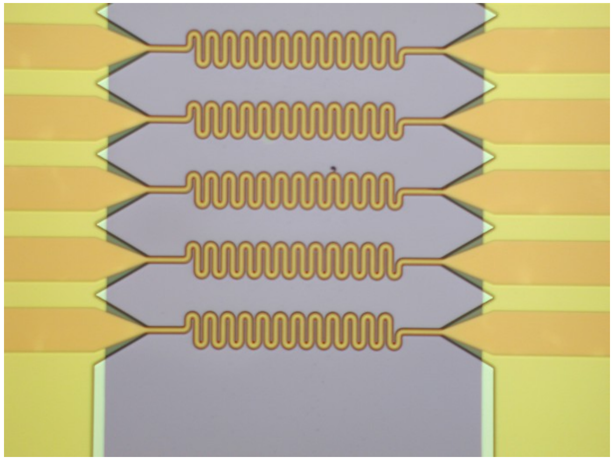
SiO_2 800 nm

Si_3N_4 150 nm

SiO_2 500 nm

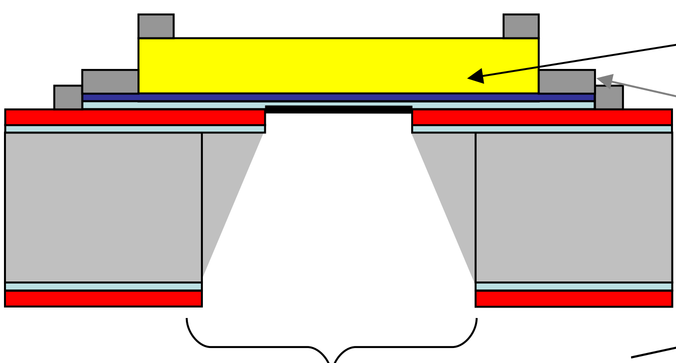
Si 330 µm

SiO_2 and Si_3N_4 (protective layers)



Before etching of Si wafer

Silicon etching



Polyimide 3µm

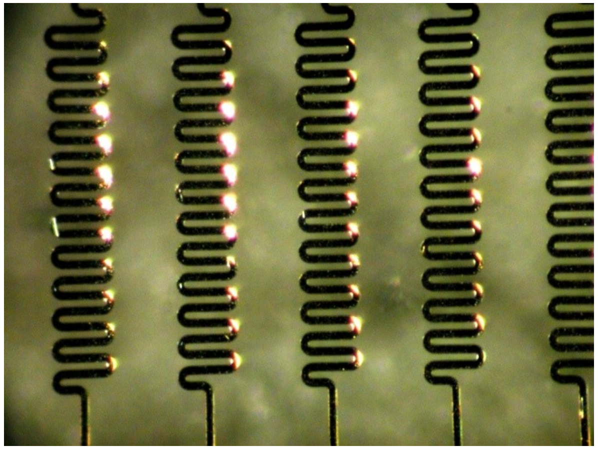
Al bond pads

“microbridge”: Ti or Al with polyimide

wire suspended

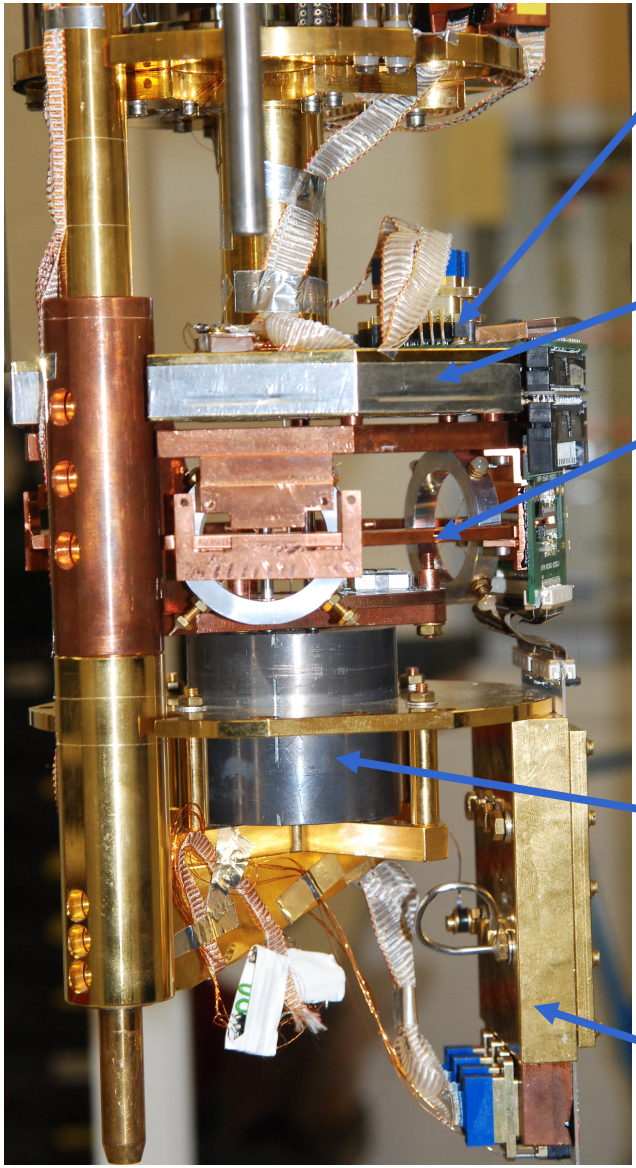
length: 6.5 mm

wire width: 20 µm



After etching of Si wafer

Cryogenic Set-up 1



Load Resistence 50 MΩ

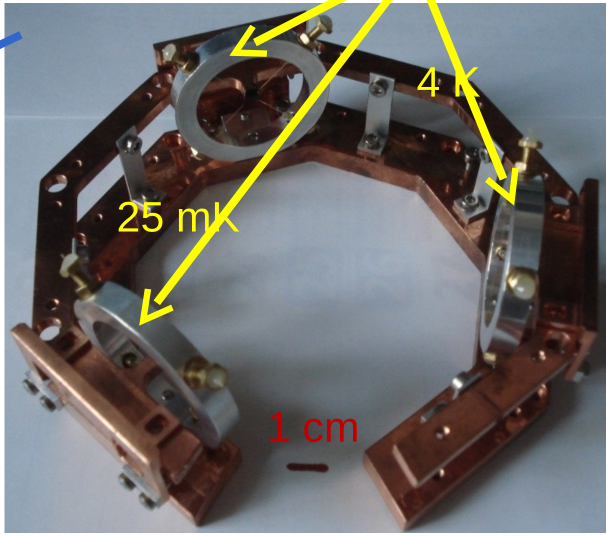
Detector holder

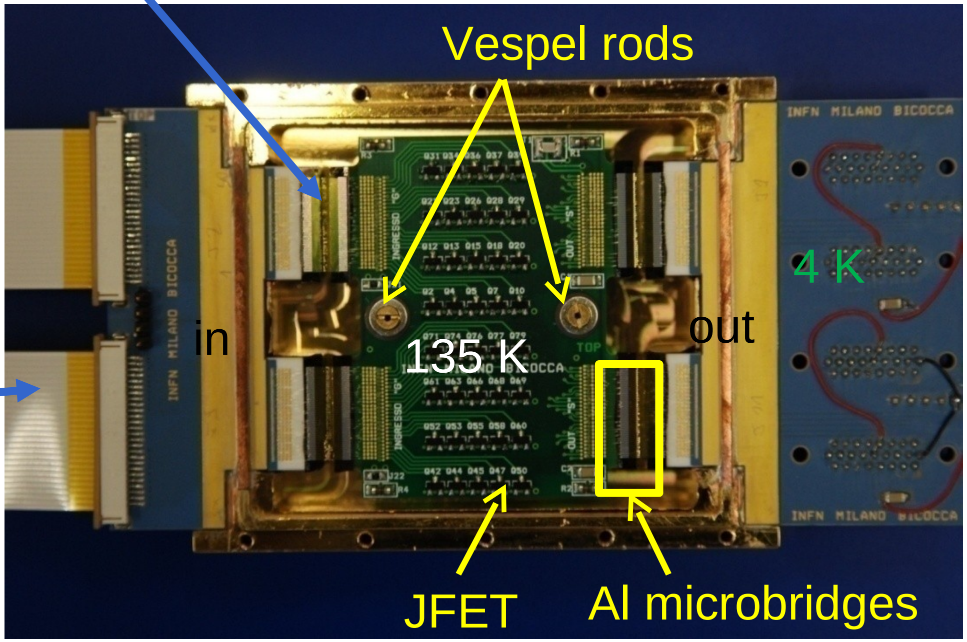
Pb shield for calibration source

JFET box

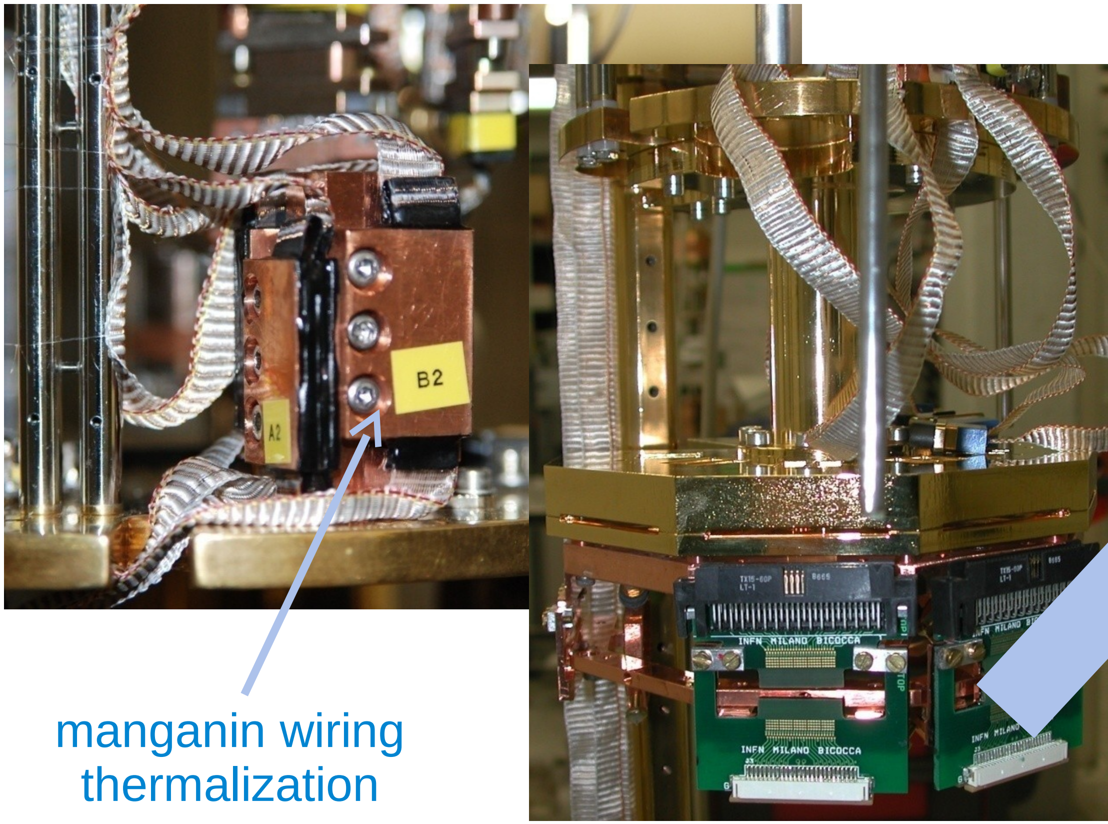
Replace Al microbridges with Al/Si wires
Ø 17.5 μm
L = 1.3 cm

Kevlar crosses



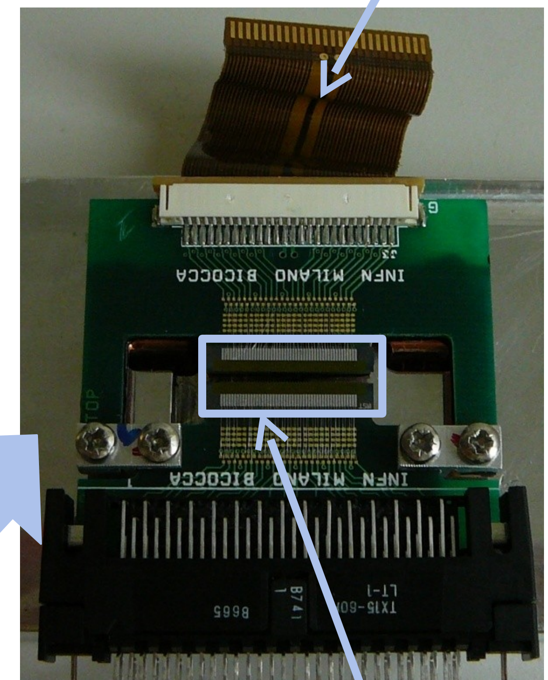


Cryogenic Set-up 2



manganin wiring
thermalization

Capton band



Ti microbridges

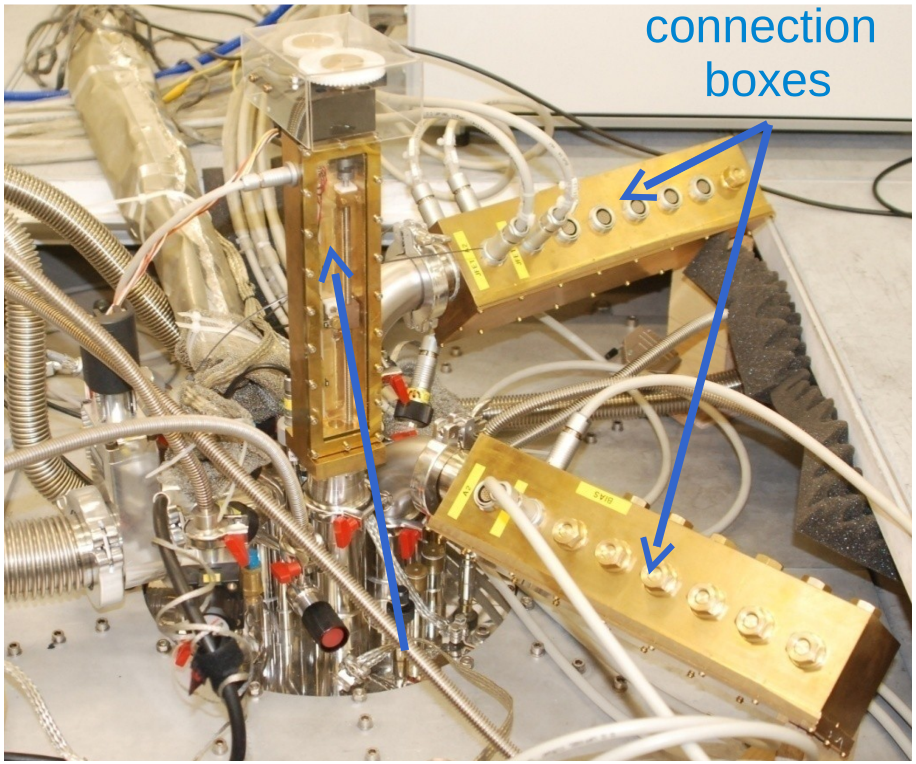
unexpected failure of Al microbridges & Kevlar crosses

Cryogenic Set-up 3

front-end electronic

cryostat top

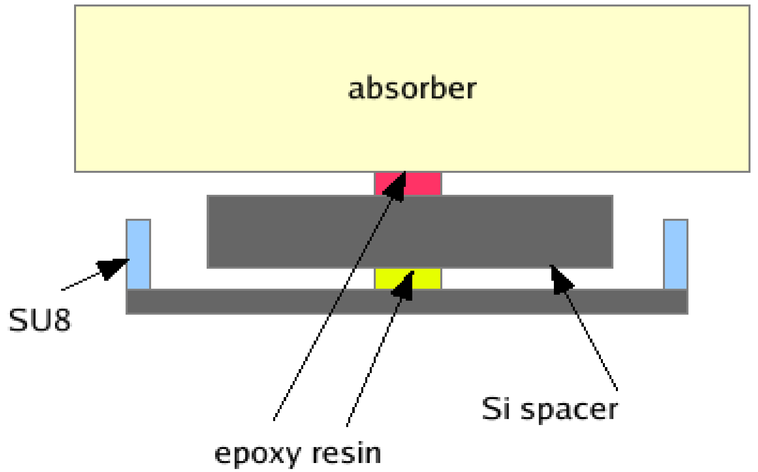
connection
boxes



calibration
source lift

DAQ

Detector



- ⇨ Δ E = 33 eV@ 2.6 keV
- ⇨ τ_R ~ 500 μs
- ⇨ Araldit / ST2850

MIBETA & Test

Calibration source: ^{55}Fe

targets: NaCl, Ti, CaF_2, Al

⇩

Al, Cl, Ti,Ca, Mn (Kα e Kβ)

MARE

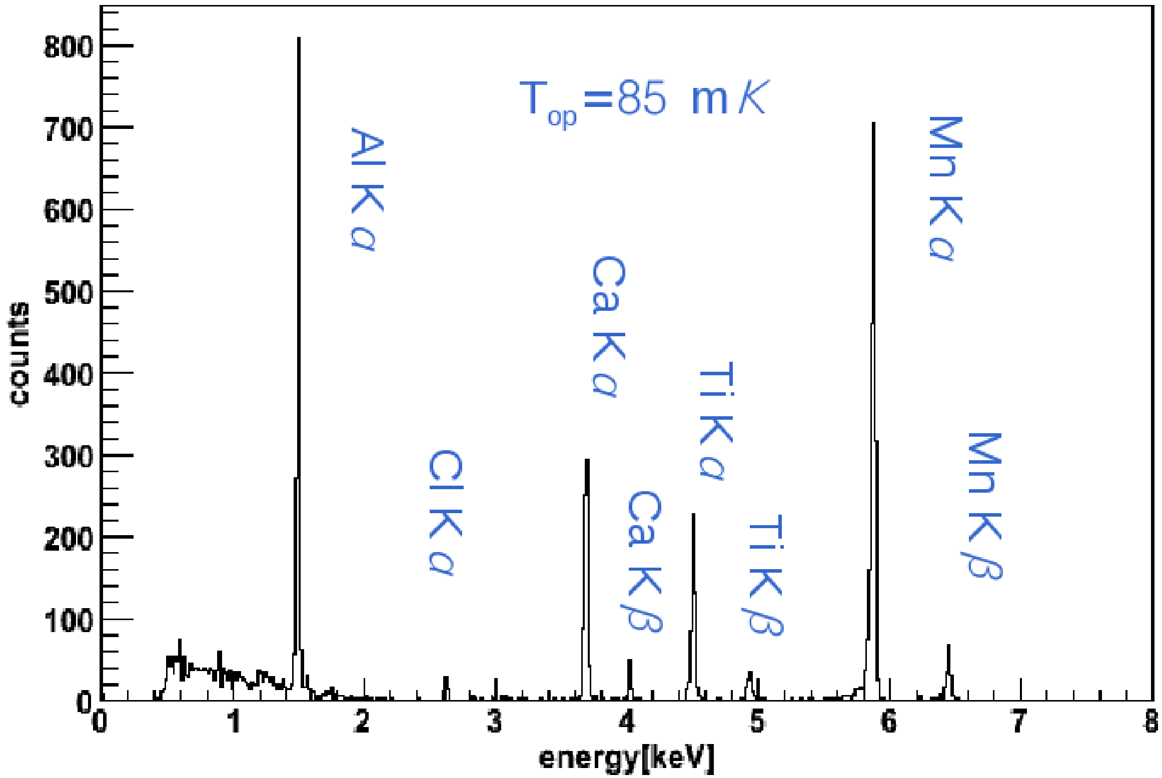
Calibration source: ^{55}Fe (10 mCi)

targets: NaCl, Ti, $CaCO_3$, Al, Si

⇩

Al, Si, Cl, Ti, Ca, Mn (Kα e Kβ)

Calibration Spectrum

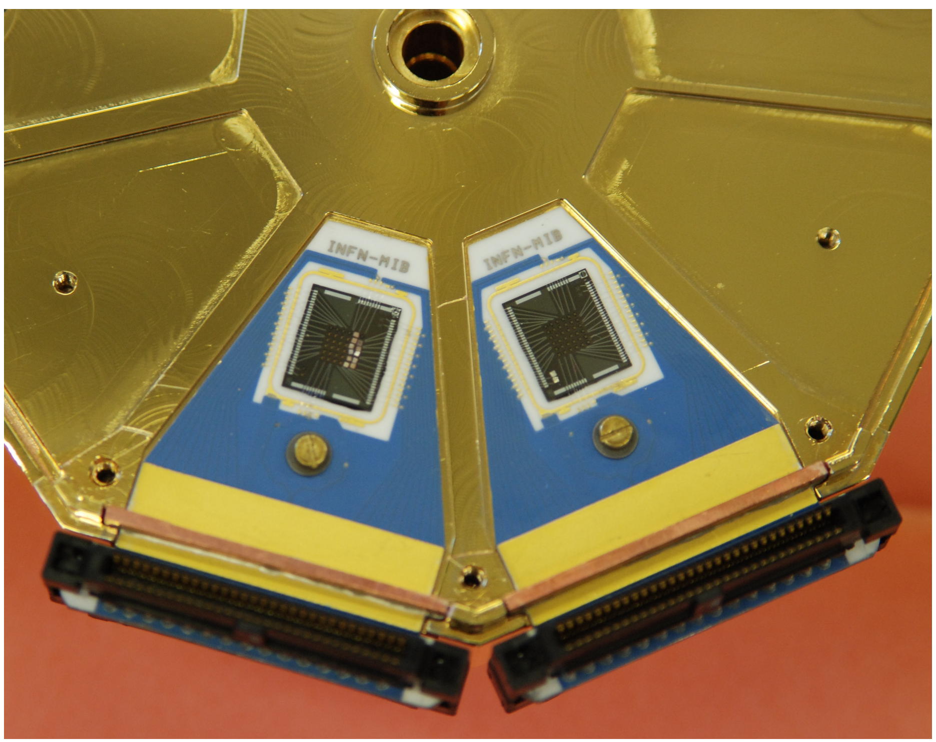


Detector 2

2 arrays :

- 11 $AgReO_4$ crystals
- 2 Sn absorbers ↝ bkg study

ST2850: spacer/$AgReO_4$

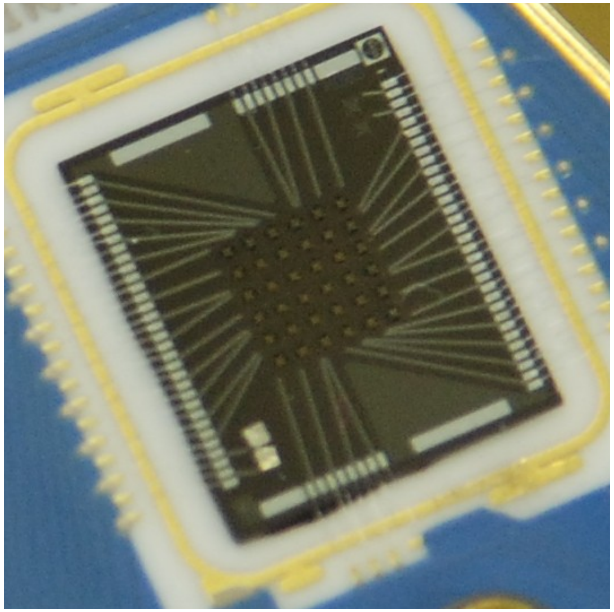


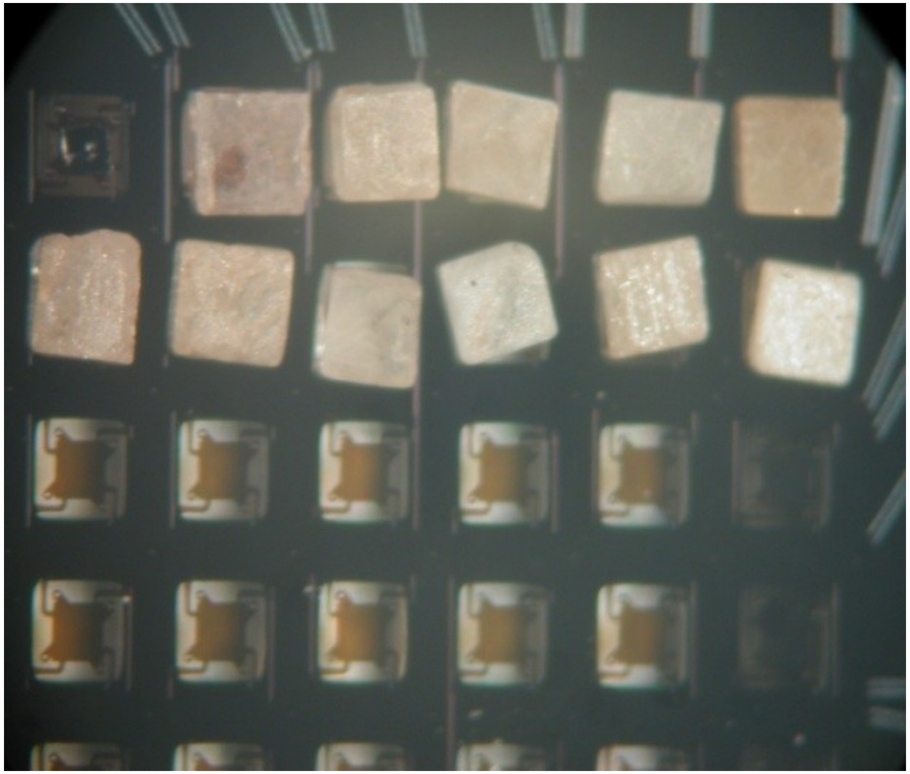
ARRAY I - $AgReO_4$	
mass µg	**Thermistor/Spacer**
517	Araldit Normal
521	Araldit Normal
397	Araldit Normal
535	Araldit Normal
459	Araldit Normal
499	ST1266
457	ST1266
410	ST1266
443	ST1266
453	ST1266
428	ST1266

ARRAY II - Sn	
Mass µg	**coupling**
81.3	ST1266 & SU8
67.8	ST1266 & SU8

Detector 3

Study the enviromental background





Check all the channels

Test the thermal coupling between thermistors and spacer

Conclusion

➔The first phase of MARE-1 in Milan is getting ready to start with 72 channels

➔ With 72 channels a sensitivity on neutrino mass of about 5 eV can be achieved in two years

➔ Based on these results, a decision concerning funding of the deployment of the remaining 6 arrays can be made