MARE: Status and Perspectives

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for the Collaboration MARE

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MARE: Microcalorimeter Arrays for a Rhenium Experiment

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Goddard Space Flight Center, NASA, Maryland, USA
Kirkhoff-Institute Physik, Universität Heidelberg, Germany
Università dell’Insubria, Università di Milano-Bicocca e INFN Sez. di Milano-Bicocca
NIST, Boulder, Colorado, USA
ITC-irst, Trento e INFN Sez. di Padova
PTB, Berlin, Germany
University of Miami, Florida, USA
Università di Roma ‘La Sapienza’ e INFN Sez. di Roma1
SISSA, Trieste
Wisconsin University, Madison, Wisconsin, USA
...

[Logos of various institutions]
Rhenium (63% $^{187}$Re)

15 crystals of this type are needed for 0.2 eV sensitivity experiment
Calorimetric spectroscopy

Thermistor
Ir-Au TES on Si

Electrical & Heat link
Al -1% Si wires
15 μm diam., 1mm length

RISE TIME
(Depends on internal Parameter Absorber-TES)

FALL TIME
(Depends on C, G, Bias Power)

Re Crystal
surfaces cleaned to optical level
annealed at 1300°C in UHV

Thermal contact
High purity epoxy

ΔT
TIME

Counts: 1 k

Energy [eV]

11 eV FWHM

5.500
5.502
5.504

5.560
5.562
5.564

5.600
5.620
5.640

100
80
60
40
20
0
MARE measurement challenges

- Statistics $\rightarrow 10^{14}$
- Unresolved pileup $\rightarrow 10^{-7}$
- Energy Resolution $\rightarrow 1$ eV
- Energy calibration $\rightarrow 10^{-4}$
- Background $\rightarrow$ negligible!
- BEFS $\rightarrow$ know at very precise level
- Possible unknown systematics $\rightarrow$ under continuous investigation (we are at the frontiers...)

\[
\text{signal} = \left| N_{\beta}(E,m_{\nu}=0) - N_{\beta}(E,m_{\nu}=15 \text{ eV}) \right|
\]
Sensitivity and uncertainties of array based experiment

\[ N_{\text{ev}} = 10^{14} \]

- Error on energy resolution $\Delta E$: $\sigma_{\text{err}}(\Delta E)/\Delta E$ (maximum uncertainty for $\Delta m_{\nu}^2 < 0.01 \text{ eV}^2$)
- Error on single pixel energy calibration $K$: $\sigma(K)/K$ (0.0004)
- Spread in energy resolution $\Delta E$ in the array: $\sigma_{\text{spread}}(\Delta E)/\Delta E$ (0.1)
- Underlying constant background: $N_{\text{bg}}/N_{\text{ev}}$ (10$^{-8}$)

A.Nucciotti
MARE-I: assessment of methods and technology

- The full MARE experiment is still in the R&D phase and multiple options are being evaluated.
- Mainly: 2 options for $\beta$–isotopes, 2 option for the detector technology
Current Developments

- Re-TES array: Genoa, Miami
- AgReO –Si array: Milan-Wisconsin-Goddard
- MUX Readout: PTB-Genoa
- Kinetic Inductance Sensors: Como-IRST-Trento
- Magnetic Calorimeter: Heidelberg
- GEANT simulation and data Analysis: U.Florida-Miami
- MC modeling for experiment design: Milan
- Ho-163: Genoa-Lisboa/ISOLDE CERN-Goddard
- Production and study of E.C. isotopes: GSI
Re-TES detector prototypes (Genoa)

• Improve detector pulse rise-time to usec;
• Improve energy resolution from 10 eV (presently) to few eV;
• Large arrays (K-pixels) in order to achieve $10^4$ - $10^5$ detectors in small volume;
• Provide an array design fully compatible with the requirements of a high precision experiment (high reproducibility, stability, fully energy calibrated, ...);
• Multiplexed read-out with large bandwidth (> 300 KHz) per channel;
Pilot experiment of 72 detector array (Milan)

Single crystal of silver perrhenate (AgReO4) as absorber
- mass ~ 500 mg per pixel (Ab~0.3 decay/sec)
- regular shape (600x600x250 mm3)
- low heat capacity due to Debye law

6x6 array of Si thermistors (NASA/GSFC)
- pixel: 300x300x1.5 mm3
- high energy resolution
- developed for X-ray spectroscopy
Metallic Magnetic Calorimeters

- Operation at low temperatures ($T<100\text{mK}$)
  - Small heat capacity
  - Large temperature change
  - Small thermal noise

- Main differences to resistive calorimeters
  - No dissipation in the sensor
  - No galvanic contact to the sensor

Temperature rise upon absorption:

$$\delta T = \frac{E}{C_{\text{tot}}}$$

Recovery time:

$$\tau = \frac{C_{\text{tot}}}{G}$$

Paramagnetic sensor: Au:Er

Signal size:

$$\delta M = \frac{\partial M}{\partial T} \delta T = \frac{\partial M}{\partial T} \frac{E_{\gamma}}{C_{\text{tot}}}$$
Planar sensors on meander shaped pickup coils

Energy resolution

$$\Delta E_{\text{FWHM}} = 2.8 \text{ eV} \ @ \ 6 \text{ keV}$$

$$\Delta E_{\text{FWHM}} = 2.65 \text{ eV} \ @ \ 0 \text{ keV}$$

→ Expected energy resolution for next produced detectors <2 eV
Micro-fabricated x-ray detectors

- Planar sensors on meander shaped pickup coils
- Energy resolution
- Rise time

**rise time**: 90 ns @ 30 mK

as expected from Korringa-constant for Er in Au
 Optimization of MMCs with superconducting rhenium absorber

- minimization of the rise-time
- investigation of energy down-conversion in superconducting absorbers
- investigating the energy resolution achievable with superconducting absorber

Improvements in the rise-time:
A. manually assembled detector ~1ms
B. sensor deposited directly on the Re absorber ~20μs

Achievable rise-time ≤ 1μs
Optimization of MMCs with superconducting rhenium absorber

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Calorimetric investigation of new candidates for the neutrino mass direct measurements by electron capture decay

- $^{163}$Ho, $^{157}$Tb, $^{194}$Hg, $^{202}$Hg
- Development of micro-structured MMCs for ion implantation at ISOLDE
- First detector with implanted $^{163}$Ho ready to run
Genoa-PTB development on MUX readout

Enhanced Bandwidth requirement respect to X-ray det. readout

FDM readout scheme under study at Genoa

PTB SQUID under test at Genoa
A second isotope for neutrino mass calorimetric measurements: $^{163}$Ho

- We have already (10 year ago) performed some test experiment with Ho-163 (F. Gatti, et al. 1997)
- $^{163}$Ho $\rightarrow ^{163}$Dy* + $\nu_e$
- $^{163}$Dy* decays via Coster-Kronig transition nS, nP$_{1/2}$
- Breit Wigner M, N, O lines have an end-point at the Q value $\rightarrow$ finite neutrino mass causes a kink at the end-point similarly to beta spectra of 187-Re.
- The major issue has been the preparation of the absorbers and the overall detector performance that was unsatisfactory due to the not uniform absorber.
In the past we made a tentative experiment to verify the feasibility of a measurements
Ho-163 Cl solution from ISOLDE (E Laesgaard) after a tentative made by INR-Moscow (purification failed)
Many effort for production of electroplated tin foils from organic solution at high voltage
Final result was an admixture of fine salt grain onto tin matrix
→ not satisfactory E resolution
But $^{163}$Ho is very attractive

- **Advantages:**
  - Tunable source activity independent from the absorber masses
  - Minimization of the absorber mass to the minimum required by the full absorption of the energy cascade → resolution less dependent from the activity
  - Rise-time much less of 10 us for SiN suspended detector
  - Higher Counting rate per detector → $10^2$ c/s
  - Self-calibrating experiment
  - Easiest way to reach higher count rate with presently better performing detectors

- Implantation tests have been done at ISOLDE (CERN) as product of spallation of Ta target by energetic proton and magnetic selection

- First sample contains high level of radioactive impurities

- Defined an alternative solution: neutron activation of enriched $^{162}$Er, chemical processing form achieve metal state, implantation at ISOLDE or LISBOA facility
163Ho sensitivity

- With 2eV detectors (X-ray type) a great step forward in overall sensitivity and detector integration for neutrino mass should be achieved
- 187-Re and 163-Ho should provide very low systematic measurement
Ho-163 in Goddard Array

TES development at NASA/GSFC
Study of the B.-W. shape far from the maximum and intrinsic line-width, other possible systematics.

Simulation under way for simulating sensitivity in realistic condition including the pile-up and the uncertainties on Q value.

A high spectral resolution measurement is needed to fix the Q value and other decay parameters.
GEANT simulation of whole experiment (Miami-Florida)

1. Unidentified pileup
2. Effect of the decay position in the absorber
3. Efficiency and systematics of the analysis tools
4. Background events originating from radioactive decays in the surrounding cryostat material (cosmics activated)
Summary

- MARE-I developments are going to the end
  - An array of 72 channel is starting taking data taking for testing multiple detector experiment
  - Study for detector-absorber coupling for Re or Ho are under way and have define the strategy
  - Detectors with **1-2 eV energy resolution** and **0.1 us time resolution** are becoming available
  - Electronics, Simulation, Data Analysis have defined the roadmap

- Technology almost ready and but need to be fully exploited and scaled to high detector multiplicity.

- In the next 1-2 years a decision on the isotope and detector technology should be made and a prototype for MARE II detector built.

- MARE-II is a challenging experiment, but feasible.

- Full development could start immediately after that (if funding is available both in the US and Europe)

- We are more confident that MARE will provide fully complementary results to KATRIN