# ISTITUTO NAZIONALE DI FISICA NUCLEARE

## Sezione di Genova

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# A CALORIMETRIC MEASUREMENT OF Ho$^{163}$ SPECTRUM BY MEANS OF A CRYOGENIC DETECTOR

# A Calorimetric measurement of Ho$^{163}$ Spectrum by Means of a Cryogenic Detector

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## Abstract

*A cryogenic micro-calorimeter to investigate the electron capture decay of Ho $^{163}$ has been developed. The interest for the Ho $^{163}$ decay is related to its possible application in experiments to determine a limit on the electron neutrino mass.*

*The advantages of the utilisation of cryogenic detector with respect to the conventional detectors are related to an higher energy resolution, and to a total absorption of the isotope emitted energy.*

*The preliminary results obtained with a prototype detector have demonstrated that a cryogenic micro-calorimeter permits to resolve the doublet NI NII, and the doublet MI MII of the Ho $^{163}$ electron capture spectrum that gas proportional counters and semiconductor diode detectors were unable to separate.*

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## 1. Introduction

It has been pointed out [1] that the study of the total energy release spectrum following the electron capture provides the simplest and most accurate way to investigate the electron capture processes.

The total energy released after an electron capture ( EC ) event corresponds approximately to the binding energy of the captured electron in the daughter atom. The energy is released through the emission of x rays and Auger electrons. For each occupied energy level from which the electron capture is energetically allowed, there is a line in the *calorimetric* energy spectrum.

The electron capture rates from a subshell $H$ in the case of an EC super-allowed transition, such as the Ho $^{163}$ decay, can be written as :

$$\lambda_H = K\beta_H^2 B_H q_H w_H \tag{1.1}$$

where $K$ contains the squares of the nuclear matrix element and Fermi coupling strength, $\beta$ is the captured electron wave function on the nucleus, $B$ is the factor which takes into account the not perfect overlap among initial and final atomic states and the indistinguishability of electrons, $W$ and $q$ are the neutrino total energy and momentum. Consequently because of the dependence on $q$, electron capture rates can, in principle, provide constraints on the electron neutrino mass; the equation 1.1 can be rewritten in the following way:

$$\lambda_H = K\beta_H^2 B_H \left[ (Q - E_H)\sqrt{(Q - E_H)^2 - m^2_\nu} \right] \tag{1.2}$$

where $E_H$ is the binding energy of the electron $H$ of the daughter nucleus (with a small correction [2]), $Q$ the decay end point and $m_\nu$ the neutrino mass.

It is clear that as more lines are identified and measured, more constraints can be imposed to find Q and $m_\nu$ by a fit procedure.

Moreover the sensitivity of the fit on neutrino mass is critically dependent by the factor $\sqrt{1 - \dfrac{m^2_\nu}{(Q - E_H)^2}}$, which must be significantly different from unity. Consequently, the closer $Q$ is to the binding energy $E_H$, the lower the $H$ line counting rate has to be in order to set a significantly limit on neutrino mass.

From literature data (see for example Tab. 1 in [3];[4],[5],[6]) the measured value of Q ranged from 2.3 to 2.8 keV.

If the correct value of Q is the highest one, the calorimetric measurement of the Ho $^{163}$ spectrum could not provide a limit on electron neutrino mass which is competitive with the actual limit on electron antineutrino mass [7].

Nevertheless the actual limit on neutrino mass is $m_\nu = 110^{+350}_{-110} eV$ [4], and therefore we believe it is meaningful to improve significantly this limit. The actual limit has been set by the measurement of the Ho $^{163}$ x ray spectrum. A cryogenic calorimetric measurement of the spectrum provides a better energy resolution with respect to conventional detectors and permits to resolve more lines. Moreover the advantage of a calorimetric spectrum with respect to the detection of the emitted x-rays only, or the Auger electrons only, is that it do not need any theoretical or experimental knowledge of Ho$^{163}$ fluorecence yield.

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In this report we want to demonstrate that a cryogenic μ–calorimeter is more suitable than conventional detectors in order to perform the measurement of Ho[163] calorimetric spectrum.

## 2. Preliminary results

A prototype of cryogenic μ–calorimeter to investigate Ho[163] EC spectrum has been developed. The schematic of the detector is illustrated in Fig. 1.
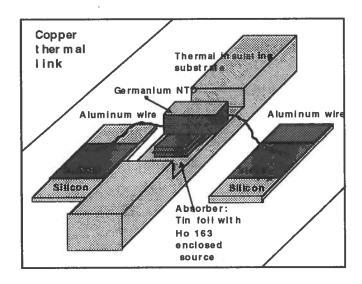


**Fig. 1** μ–calorimeter scheme.

The Holmium source has been deposited on a Tin foil (250x800x25 μm³) from a water solution in form of organic complex. In order to enclose the Ho[163] source in the superconducting Tin absorber, the deposit has been covered with a drop of epoxy, and the Tin foil has been folded and pressed. The epoxy acts as good thermal link between the organic crystals containing the Holmium isotopes and the superconducting Tin absorber. Because of the small diameter (approximately 100μm) of the deposited source in the centre of the absorber, the expected energy escape is negligible.

The micro-calorimeter thermistor is a NTD-Germanium (100x200x200 μm³) coupled to the Tin foil using epoxy. The detectors operate at a temperature of 50-60mK.

As the Ho[163] spectrum consists of a series of peaks, it is self-calibrating. However a fast check with a Fe[55] external x ray source has been made in order to control that the energy range was correct.

The technique used in the signal processing and analysis is the same one applied to the cryogenic detectors developed by the Genova group for the study of β decay processes, and is reported in details elsewhere [8] [9],[10].

The Ho[163] spectrum has been reported in Fig. 2 ( a ), in comparison with Si(Li) [5] and gas proportional counter [6] Ho[163] full energy absorption spectra. Although the statistic of this preliminary spectrum is not high, it has been possible to resolve four lines of the EC decay, NI, NII MI and MII.
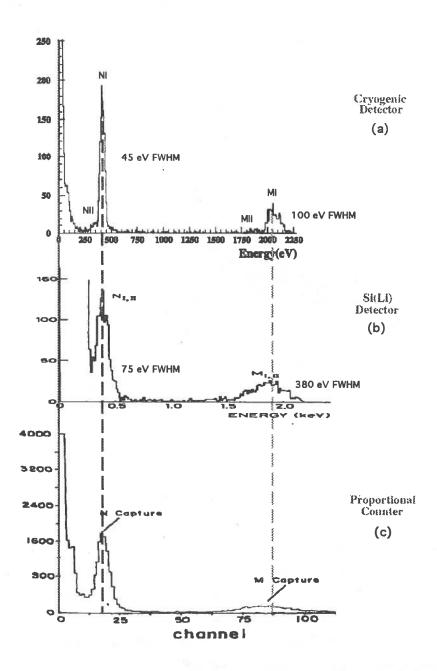
**Fig. 2** Ho$^{163}$ spectrum obtained with total absorption of the emitted energy.

( a ) Preliminary spectrum measured with a cryogenic detector; although the statistic is not high in this first test, it has been possible to resolve four lines of the spectrum, NI, NII,MI and MII.

( b ) Ho$^{163}$ spectrum measured with a semiconductor detector doped with radioactive Holmium [5].

( c ) Spectrum obtained with a gaseous proportional counter [6].

The theoretical energy lines are reported in Tab. 1.

| Spectrum energy lines ( including energy shift from ref [2] ) | | | |
|---|---|---|---|
| NII (eV) | NI (eV) | MII (eV) | MI (eV) |
| 339 | 406 | 1824 | 2050 |

**Tab. 1**    Spectrum energy lines.

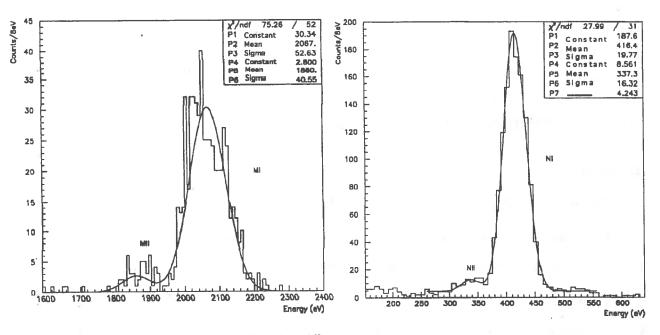In Fig. 3 details of N lines and M lines have been reported.



**Fig. 3**  $Ho^{163}$ M and N lines.

It has to be noted that the width of the M-lines is larger than the resolution of the N-lines (50 eV FWHM for the N lines and 100 eV FWHM for the M lines ). In order to investigate a possible instrumental effect, we measured the $Ho^{163}$ spectrum again adding an external $Fe^{55}$ X rays source. We detected the $K\alpha$ and the $K\beta$ lines (5898 and 6490 eV) with an energy resolution of 50 eV FWHM, and we detected also the Al fluorescence line (1480 eV) with the same resolution. We concluded that the worsening of the energy resolution with the energy line would be a consequence of a not homogeneous absorber. Better methods to enclose the source in a superconductive absorber are under investigation.

This preliminary result demonstrates that cryogenic micro-calorimeter permits a higher energy resolution and a lower energy threshold with respect to traditional detectors.

## 3. Conclusion

The detection of the $Ho^{163}$ M and N spectral lines has been successfully made with an improvement in the energy resolution ( 50 FWHM N lines, 100 eV FWHM M lines ) by a factor of 2 from previous measurements. For the first time it has been possible to resolve the NI, NII, MI and MII lines.

Further improvements in the detector realisation with a more homogeneous absorber could permit a better energy resolution and a lower energy threshold, therefore also the OI line could be detected.

Because of these positive preliminary results, there is the prospect of measuring an higher statistic calorimetric spectrum of $Ho^{163}$ in order to determine the end point Q of the transition and to improve the actual limit on electron neutrino mass [4].

The measurement of four or five lines of the spectrum would reduce the dependence on theoretical uncertainty, nevertheless new atomic physics calculation in support of electron capture theory are in progress [11].

## References

1. W. Bambynek et al., Rev. Mod Phys. **49** (1977) 77.

2. P. T. Springer et al., Phys Rev. **A 31** (Rapid. Commun.) (1985) 1965.

3. H. Axelsson et al., Phys. Lett. B **210** (1988) 249

4. S. Yasumi et al., Phys Lett. B **334** (1994) 229.

5. E. Laegsgaard et al. Proceeding of 7th International Conference on Atomic Masses and Fundamental Constants (AMCO-7), 1984.

6. F.X. Hartmann and R.A. Naumann, Nucl. Instr. And Meth. **A 313** (1992) 237.

7. Ch. Weinheimer et al., Phys Lett. B **300** (1993) 210.

8. F.Fontanelli et al., Nucl. Instr. and Meth., **A 370** (1996) 273.

9. E.Cosulich et al., Nucl. Phys., **A 592** (1995) 59.

10. F.Gatti and A.Nostro, Nucl. Instr. and Meth., **A 368**, 765.

11. P. Cortona, Private Communication.

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