the HOLMES experiment

The Electron Capture Decay of ^{163}Ho to Measure the Electron Neutrino Mass with sub-eV sensitivity

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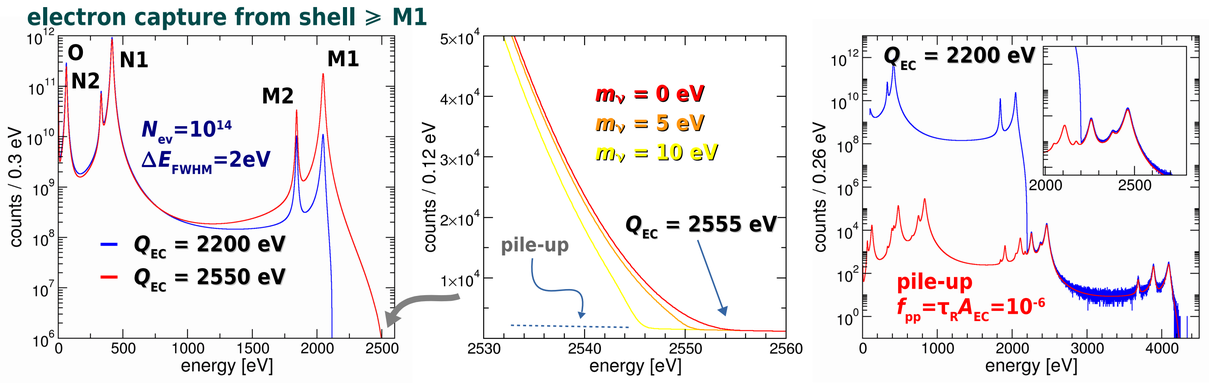
The **European Research Council** has recently funded **HOLMES**, a new experiment to directly measure the neutrino mass. **HOLMES** will perform a calorimetric measurement of the energy released in the decay of ^{163}Ho. The calorimetric measurement eliminates systematic uncertainties arising from the use of external beta sources, as in experiments with beta spectrometers. This measurement was proposed in 1982 by A. De Rujula and M. Lusignoli, but only recently the detector technological progress allowed to design a sensitive experiment. **HOLMES** will deploy a large array of low temperature microcalorimeters with implanted ^{163}Ho nuclei. The resulting mass sensitivity will be as low as 0.4eV. **HOLMES** will be an important step forward in the direct neutrino mass measurement with a calorimetric approach as an alternative to spectrometry. It will also establish the potential of this approach to extend the sensitivity down to 0.1eV. We outline here the project with its technical challenges and perspectives.

^{163}Ho + e$^-$ → ^{163}Dy* + ν_e

$$\frac{d\lambda_{EC}}{dE_c} = \frac{G_\beta^2}{4\pi^2}(Q-E_c)\sqrt{(Q-E_c)^2-m_\nu^2}\times\sum_i n_i C_i \beta_i^2 B_i \frac{\Gamma_i}{2\pi}\frac{1}{(E_c-E_i)^2+\Gamma_i^2/4}$$

- calorimetric measurement of Dy atomic de-excitations (mostly non-radiative)
- rate at end-point and ν mass sensitivity depend on Q_{EC}
  - Measured: Q_{EC} = 2200÷2800 eV. Recommended: Q_{EC} = 2555 eV
- $\tau_{1/2} \approx$ 4570 years: 2×10^{11} ^{163}Ho nuclei → 1 Bq

electron capture from shell ⩾ M1



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

M. Galeazzi et al., " The Electron Capture Decay of 163-Ho to Measure the Electron Neutrino Mass with sub-eV Accuracy", arXiv:1202.4763

HOLMES goals

- neutrino mass measurement with a m_ν statistical sensitivity as low as 0.4 eV
- demonstrate technique potential and scalability

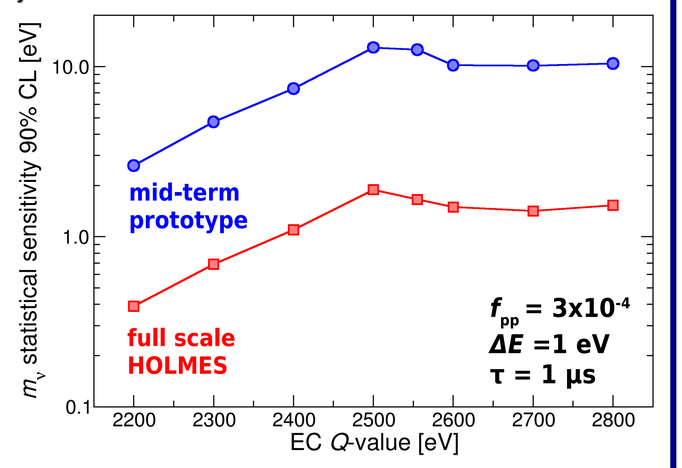
16 channels
t_M=1 month
A=300Hz/ch
→ 10^{10} decays

1000 channels
t_M=3 years
A=300Hz/ch
→ 3x10^{13} decays

HOLMES baseline

- Transition Edge Sensors (TES) with ^{163}Ho implanted Au absorbers
  - 6.5×10^{13} nuclei per detector → A_{EC}=300 Bq
  - $\Delta E \approx$1eV and $\tau_R \approx$1μs
- 1000 channel array
  - 6.5×10^{16} ^{163}Ho nuclei → ≈18μg
  - 3×10^{13} events in 3 years

→ Project Start: February 1st, 2014



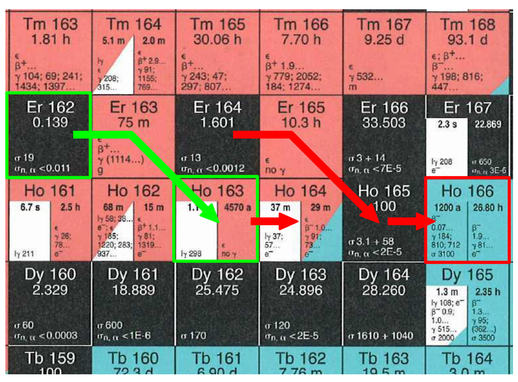
A. Nucciotti, *Statistical sensitivity of 163-Ho electron capture neutrino mass*, submitted to EPJC. arXiv:1405.5060

^{162}Er (n,γ) ^{163}Er $\sigma_{thermal} \approx$ 20b

^{163}Er → ^{163}Ho + ν_e $\tau_{1/2}^{EC} \approx$ 75min

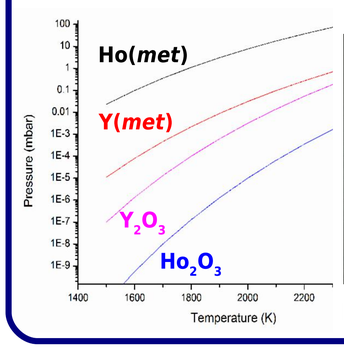
^{163}Ho production at nuclear reactor

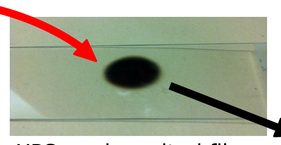
- high yield (not all cross sections are measured)
  - ≈3×10^{12} ^{163}Ho nuclei/mg(^{162}Er)/h for a thermal neutron flux of 10^{13} n/cm^2/s
- ^{163}Ho(n,γ)^{164}Ho (burn-up)?
- ^{165}Ho(n,γ)^{166m}Ho (β, τ½=1200y)
- from Ho contaminations or ^{164}Er(n,γ)
- requires ^{162}Er enrichment and oxide chemical form (Er_2O_3)



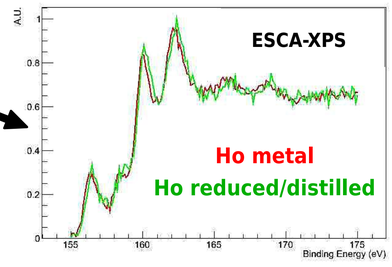
Er_2O_3/Ho_2O_3 thermoreduction → metallic Ho target for implantation

- Ho_2O_3+2Y(*met*) → 2Ho(*met*)+Y_2O_3 at 2000°C





XPS on deposited film:
- 80% metallic Ho
- 20% re-oxidized Ho



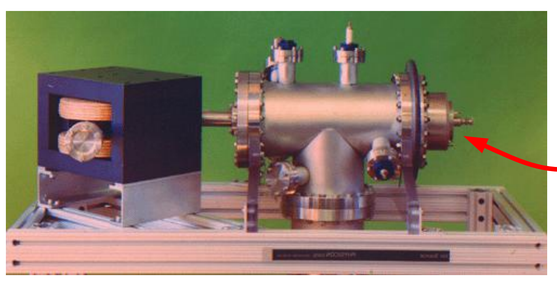
Ho(*met*) distillation around 2000K

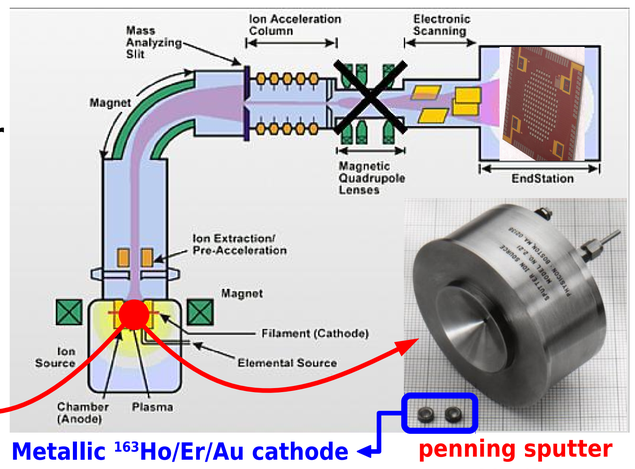
^{163}Ho separation from Dy, Er, ...

- radiochemistry (before and/or after irradiation)
- magnetic mass separation

^{163}Ho embedding in detector absorber

- implantation +magnetic separation
- Au film deposition for full containment

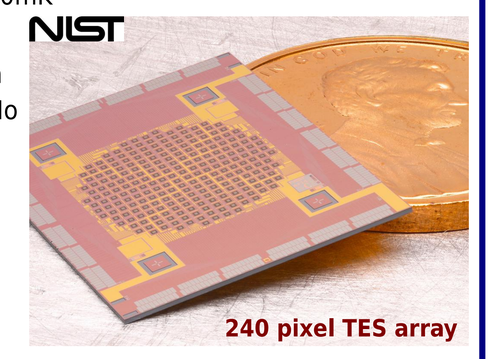


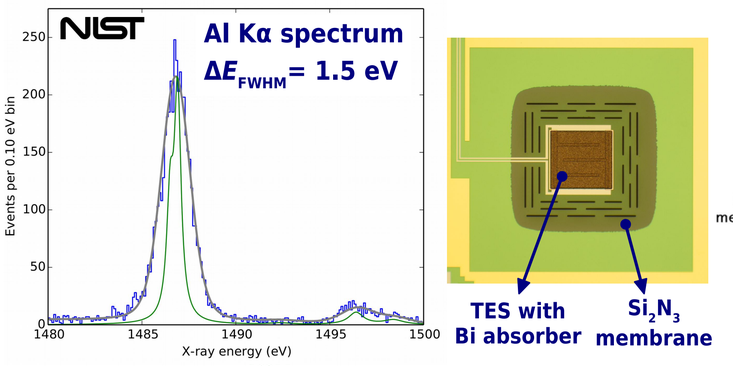


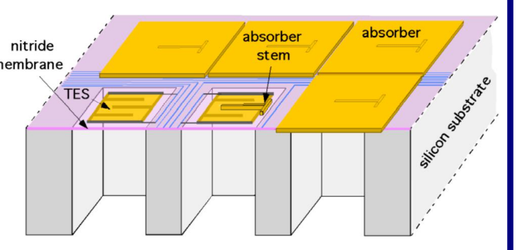
Z. Nouri et al., Nuclear Instruments and Methods in Physics Research A614 (2010) 174

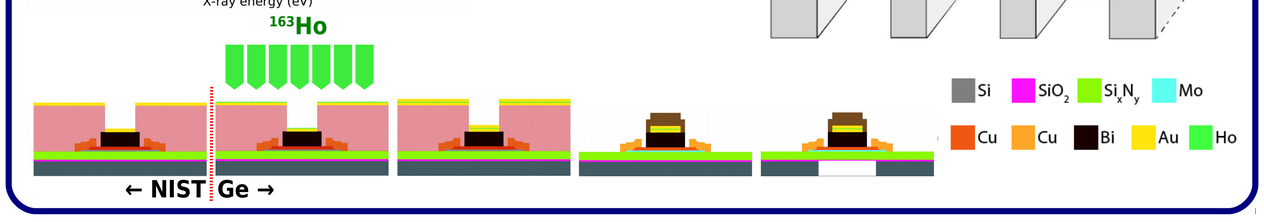
Transition Edge Sensors (TES): MoCu bilayers → T_c≈100mK

- microcalorimeters with electro-thermal feedback
- 3 μm thick Bi absorber with ^{163}Ho/Au source for full absorbtion
- source: thin electrodeposited Au encapsulating implanted ^{163}Ho
- TES fabricated by subcontractor (NIST, Boulder, CO, USA)
- ^{163}Ho implantation and Si_2N_3 membrane release at Genova







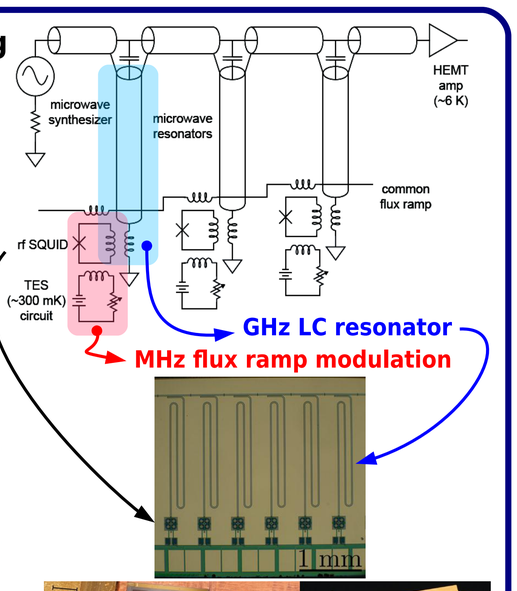


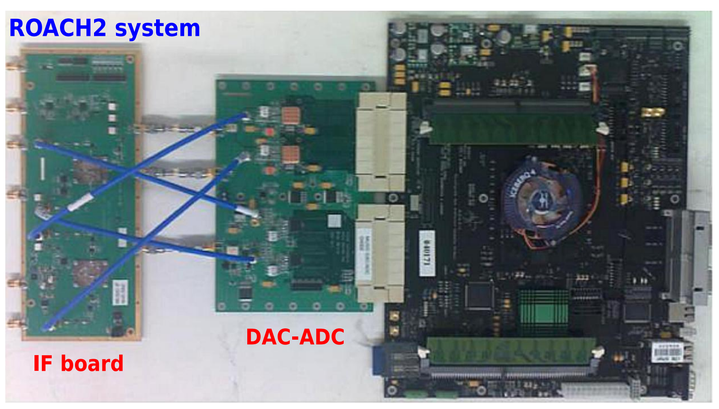
rf-SQUID read-out with microwave multiplexing

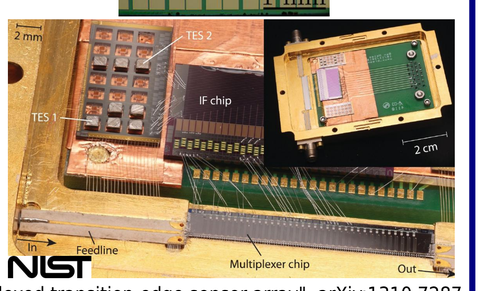
- DC biased TES
- microwave rf-SQUID read out with flux ramp modulation

ROACH2-based Software Defined Radio

- Xilinx FPGA based digital data processing
- frequency comb generation (up to ≈60 in 0 – 550 MHz)
- GHz band up/down conversion (5 – 5.5 GHz)
- I-Q signals (homodyne detection) de-multiplexing
- signal channelizing and rf-SQUID signal de-modulation
- real time signal processing → 140TB in 3 years







O. Noroozian et al., "High-resolution gamma-ray spectroscopy with a microwave-multiplexed transition-edge sensor array". arXiv:1310.7287

Project year	2014		2015		2016		2017		2018	
Tasks	6	12	18	24	30	36	42	48	54	60
Isotope production										
TES pixel optimazion / absorber implantation										
Array design and production										
Multiplexed read-out										
Room Temperature electronics and data processing										
Single pixel high resolution ^{163}Ho spectrum measurement										
4×4 array measurement										
HOLMES measurement										

1. HOLMES web site http://artico.mib.infn.it
2. pdf file of this poster
3. seminar on HOLMES, May 14th, 2014, LNGS, Italy

NEUTRINO2014
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