HOLMES is an experiment with the aim to directly measure the neutrino mass. HOLMES will perform a calorimetric measurement of the energy released in the Electron Capture decay of the artificial isotope $^{163}\text{Ho}$. The most suitable detectors for this type of low temperature thermal detectors. HOLMES will deploy 1000 detectors of low temperature microcalorimeters with implanted $^{163}\text{Ho}$ nuclei with the aim to extract information on neutrino mass with a sensitivity below 2 eV. As soon as the embedding technique will be optimized the first sub-arrays will provide useful data about the EC decay of $^{163}\text{Ho}$ together with a first limit on neutrino mass.

### Overview

- **Electron capture from shell**
  - Sensor: TES Mo/Au bilayers, critical temperature
  - $4 \times 16$ linear sub-array designed for high implant efficiency
  - Absorber: Gold, 2 µm thick for full $e^{-}$ absorption (sidecar design)

- **Gold deposition**
  - $4 \times 16$ sub-array Single pixel

- **Gold production and embedding**
  - $^{163}\text{Ho}$ production and embedding

- **Electron capture spectroscopy**
  - $^{163}\text{Ho}$ EC = 2.833 keV; $^{163}\text{Ho}$ absorption (sidecar design)

- **HOLMES target**
  - Microcalorimeters based on Transition Edge Sensors with $^{163}\text{Ho}$ implanted Au absorber
  - Pixel activity of $A_{\text{EC}}$ = 300 Bq/det
  - Energy resolution: $\sigma(E) = 2\text{eV}$
  - 1000 channels for $3 \times 10^9$ events collected in $t_f = 3$ years

### Production by neutron activation of enriched $^{163}\text{Er}$

$^{163}\text{Er}^{(n, \gamma)^{164}\text{Er}} \rightarrow ^{164}\text{Ho} + n, T_{\text{fission}} = 20\text{d}$

- Irradiation at the ILL reactor in Grenoble with a high thermal flux $\Phi_h = 1.3 \times 10^{15}$ n/cm$^2$/s
- Cross section burn up $^{163}\text{Ho}^{(n, \gamma)^{164}\text{Ho}}$ not negligible ($\sim 200$ b)
- Unavoidable $^{163}\text{Ho}^{(n, \gamma)^{163}\text{Ho}}$ (most from $^{163}\text{Er}^{(n, \gamma)^{164}\text{Er}}$)

### Mass separation based on ion implanter

- From MC simulations $\sim 300$ Bq/det, the $^{163}\text{Ho}$ concentration in absorbers saturate because $^{163}\text{Ho}$ sputters off Au from absorber
- Effect compensated by Au co-evaporation during the implantation procedure
- Absorbers finalization with 1 µm Au layer deposited in situ to avoid oxidation
- Au deposition rate = 100 nm/hour (tunable with RF power or Ar energy)

### Deposition and target chamber

- To obtain $A_{\text{EC}} = 300$ Bq/det, the $^{163}\text{Ho}$ concentration in absorbers saturate because $^{163}\text{Ho}$ sputters off Au from absorber
- Effect compensated by Au co-evaporation during the implantation procedure
- Absorbers finalization with 1 µm Au layer deposited in situ to avoid oxidation

### Detectors and read-out

- **Low Temperature microcalorimeters**
  - Sensor: TES Mo/Au bilayers, critical temperature $T_c = 100$ mK
  - Absorber: Gold, 2 µm thick for full $e^{-}$ absorption (sidecar design)
  - Produced @ NIST (Boulder, CO, USA)
  - $^{163}\text{Ho}$ implanting and absorber finalization @ INFN-GE (Italy)
  - $4 \times 16$ linear sub-array designed for high implant efficiency

### Microwave rf-SQUID multiplexing read-out

- SQUID coupled with DC biased TES and a 4/3-wave resonant circuit
- Readout with flux ramp demodulation to linearize the SQUID response
- $N_{\text{det}} = 33$
- Multiplexer designed by NIST
  - 33 resonances packed in 500 kHz
  - 2 kHz BW per resonance (for a time resolution ~1 µs)
  - Resonators spacing ~14 MHz (to avoid crosstalk)

### Single pixel characterization with calibration source

- ROAC2-based read-out system: demodulation and triggering in real time performed by FPGA Virtex-6
- A rise time of 15 µs and a sampling frequency of $f_{\text{sample}} = 500$ kHz allow an effective time resolution of 3 µs by Wiener filtering and Singular Value Decomposition-based algorithms
- The development of a 64-channel read-out and multiplexing system is currently in progress
- This setup will be fundamental to acquire the data from the first two microcalorimeter $4 \times 16$ sub-arrays with $^{163}\text{Ho}$ nuclei implanted starting from 2019

#### Neutrino 2018 - XXVIII International Conference on Neutrino Physics and Astrophysics

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