Transition Edge Sensors for HOLMES
LTD 18: 22-26 July 2019 Milan

Andrei Puiu on behalf of the HOLMES collaboration
**Spectrometers and calorimeters**

**Spectrometers**

**PROs:**
- High statistics
- Very good energy resolution

**CONs:**
- Systematics due to source effects
- Systematics due to decay to excited states
- Background

**Calorimeters**

**PROs:**
- No backscattering
- No energy losses in the source
- No solid state excitation
- No atomic/molecular final state effects

**CONs:**
- Limited statistics
- Systematics due to pile-up
- Background

![Graph showing excluded and allowed regions for 
\( m_{\beta\beta} \) vs. \( m_\beta \) with lines for 2\( \sigma \) (NH) and 2\( \sigma \) (IH)]

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Calorimetric measurement with $^{163}$Ho

$^{163}$Ho decays via (EC) from shell $\geq$ M1, with $Q_{EC} \sim 2.8$keV


- calorimetric measurement of $e^-$ from Dy de-excitation
- end point close to M1 resonance enhances rate at the end point where $m_\nu$ is measured
- $\tau_{1/2} \sim 4570$ y: $2 \times 10^{11}$ nuclei $^{163}$Ho = 1 Bq

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Sentivity on neutrino mass and pile-up

Since all the events occurring within one detector are recorded without previous selection, pile-up becomes a crucial limiting factor:
- events occurring closer in time than the timing resolution of the detector ($\tau_R$)
- sets the limit on the maximum activity ($A_{EC}$) of each detector

$$N_{pp}(E) = f_{pp} N_{EC}(E) \otimes N_{EC}(E) \text{ with } f_{pp} \approx A_{EC} \tau_R$$

Super fast detectors with $\sim 20 \mu s$ rise time pulses
Maximum activity $\sim 300$ Bq/riv
→ Very large arrays $\sim 1000$

$Q = 2800$ eV
$f_{pp} = 10^{-4}$
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Number of events

Monte Carlo for 1000 riv x 3 year

- $A_{PC} = 10$ c/s/det
- $30$ c/s/det
- $100$ c/s/det
- $300$ c/s/det

$\text{HOLMES will:}$

- Measure $m_\nu$ with $\sim 1$ eV sensitivity
- Prove that calorimeters are a valid technique
- High precision $Q$-value measurement of $^{163}\text{Ho}$
- Systematic errors assessment

Short and medium terms

- 64 detectors array, $t_M = 1$ month ($m_\nu < 10$ eV)
- Final measurement: 1000 detectors, $3 \times 10^{13}$ events in 3 y
- $6.5 \times 10^{16}$ $^{163}\text{Ho}$ nuclei needed ($\approx 18 \mu$g)

(ERC-Adv. Grant 340321) PI: S. Ragazzi
Transition Edge Sensors Superconductive Detectors (TES)

- Very steep $R$ vs $T$ dependency in transition region
- Gold absorber with $^{163}$Ho inside coupled to TES thermometer
- Ho sandwiched between two 1 $\mu$m thick gold layers for a total electron containment
- Fast detectors to reduce pile-up
  - tunable rise time $\sim L/R$
  - decay time dependent on detector characteristics $C/G$

- Production at NIST (Boulder, CO)
- tested at NIST and in Milano
- $^{163}$Ho implating facility at Genova
- Final Au coverage at Mi-Ge
The cryogenics - Milan

Detector box is coupled to the Mixing Chamber of a 3He/4He dilution refrigerator.
TES array

First Transition Edge Sensors array

- 6 different designs to be tested
- Different thermal conductances G
- Different TES intrinsic parameters
Readout

- Each TES is coupled to a RF-SQUID

\[ E \rightarrow \delta T_{\text{TES}} \rightarrow \delta I_{\text{TES}} \]
Readout

- Each TES is coupled to a RF-SQUID
- Every RF-SQUID is coupled to a common ramp

\[ E \rightarrow \delta T_{\text{TES}} \rightarrow \delta I_{\text{TES}} \rightarrow \delta \phi_{\text{squad}} \]
Readout

- Each TES is coupled to a RF-SQUID
- Every RF-SQUID is coupled to a common ramp
- Every RF-SQUID is coupled to a resonant circuit

\[ E \rightarrow \delta T_{\text{TES}} \rightarrow \delta I_{\text{TES}} \rightarrow \delta \phi_{\text{squid}} \rightarrow \delta f_{\text{resonator}} \]
We tested four different designs to define:
- heat capacity
- thermal link geometry
- TES design

Calibration run performed with

$^{55}\text{Fe}$ (5.9 keV) + fluorescence from
Ca – 3.7 keV
Cl – 2.6 keV
Al – 1.5 keV
TES performance

HOLMES tested non implanted detectors → final design established
Stray iductance tuned to achieve pulse edge of $\tau_R \approx 10 \mu s$

$\Delta E = 4.7 \pm 0.2$ eV

<table>
<thead>
<tr>
<th>$E$ [keV]</th>
<th>$\Delta E$ [eV]</th>
</tr>
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<tbody>
<tr>
<td>1.49</td>
<td>4.5</td>
</tr>
<tr>
<td>2.62</td>
<td>5</td>
</tr>
<tr>
<td>3.69</td>
<td>5</td>
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</table>

$\tau_D \approx 190 \mu s$

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Linearity

Calibration function:
\[ E [\text{keV}] = 0.11927\phi_0^2 + 2.7345\phi_0 + 0.041166 \]

Detectors have good linearity over a wide (0 keV to 6 keV) energy range.

\(^{163}\text{Ho}\) end point: 2.8 keV


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**ROACH-2 readout**

- **FPGA (Virtex6 Xilinx)** for data processing
- **550 MHz ADC**

  - ROACH2 (real time)
    - Pulse reconstruction
    - Trigger

  - **Server** (almost real time)
    - Optimum Filter and Pile-up rejection

- **HOLMES** final specifications
  - 32 Channels / ROACH-2 board
  - 500 kHz sampling
  - 20 ms RT pulses

See Andrea Giachero's poster #150-397

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Next steps

→ The determination of the electron neutrino mass with $^{163}$Ho is complementary to the determination of the neutrino mass with Tritium.

→ Spectral shape measurement is needed for theoreticians to refine the EC model of $^{163}$Ho.

→ HOLMES has already demonstrated:
  • Production and purification of large amount of $^{163}$Ho sample.
  • Operation of large arrays of high resolution low temperature detector.
  • First low energy background studies.

→ HOLMES detector modules will be soon tested for $^{163}$Ho enclosure aiming at 300 Bq.
Thank you for your patience and attention ;}