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

Andrei Puiu on behalf of the HOLMES collaboration

The collaboration

HOLMES

European Research Council

Established by the European Commission

PI: Stefano Ragazzi

NIST

PAUL SCHERRER INSTITUT

PSI

centra

NEUTRONS FOR SCIENCE

UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

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:

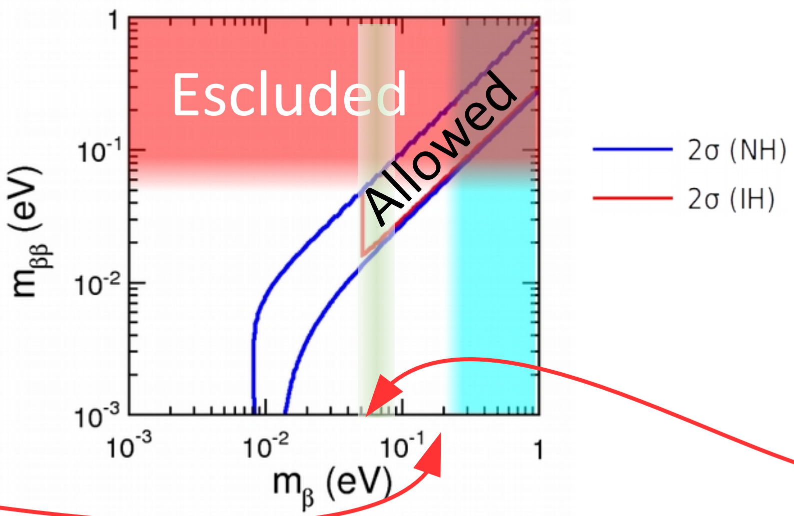
PROs:

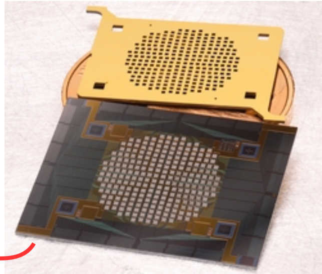
- no backscattering
- no energy losses in the source
- no solid state excitation
- no atomic/molecular final state effects

CONs:

- limiteted statistics
- systematics due to pile-up
- background

Andrei Puiu – LTD 18 Milan



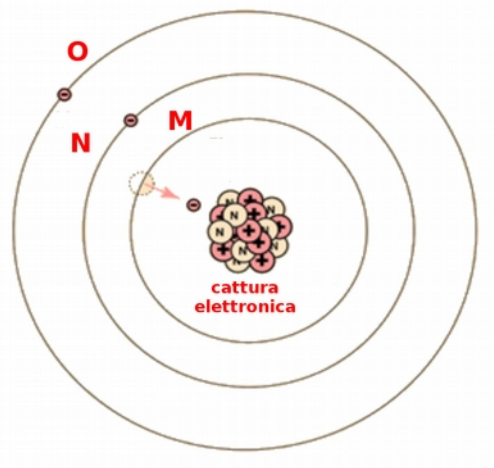


Calorimetric measurement with ^{163}Ho

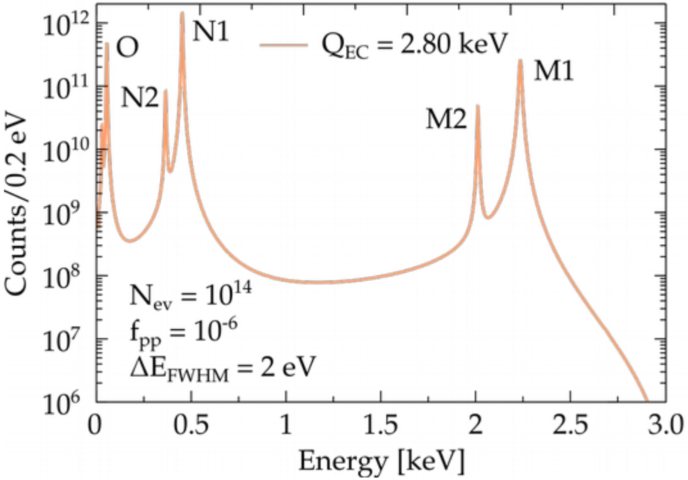
$^{163}Ho + e^- \rightarrow {}^{163}Dy^* + \nu_e$

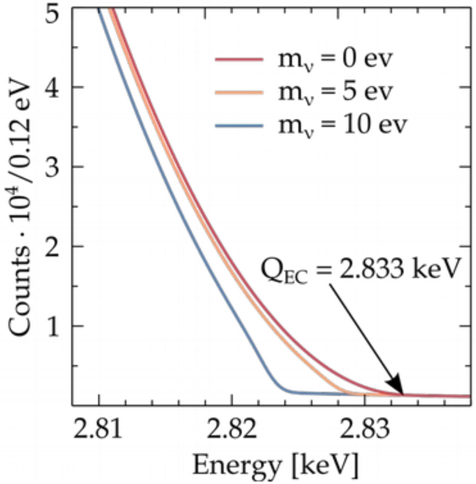
^{163}Ho decays via (EC) from shell ≥ M1, with Q_{EC} ~ 2.8keV

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



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





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

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 dector (τ_R)
- sets the limit on the maximum activity (A_{EC}) of each detector

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

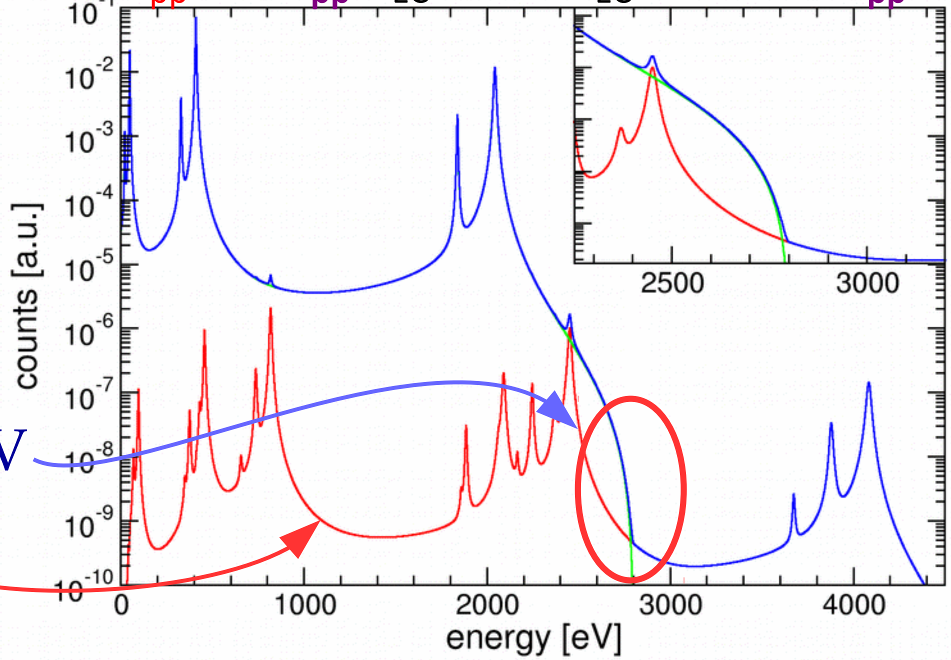
Super fast detectors with ~20 μs rise time pulses

Maximum activity ~ 300 Bq/riv

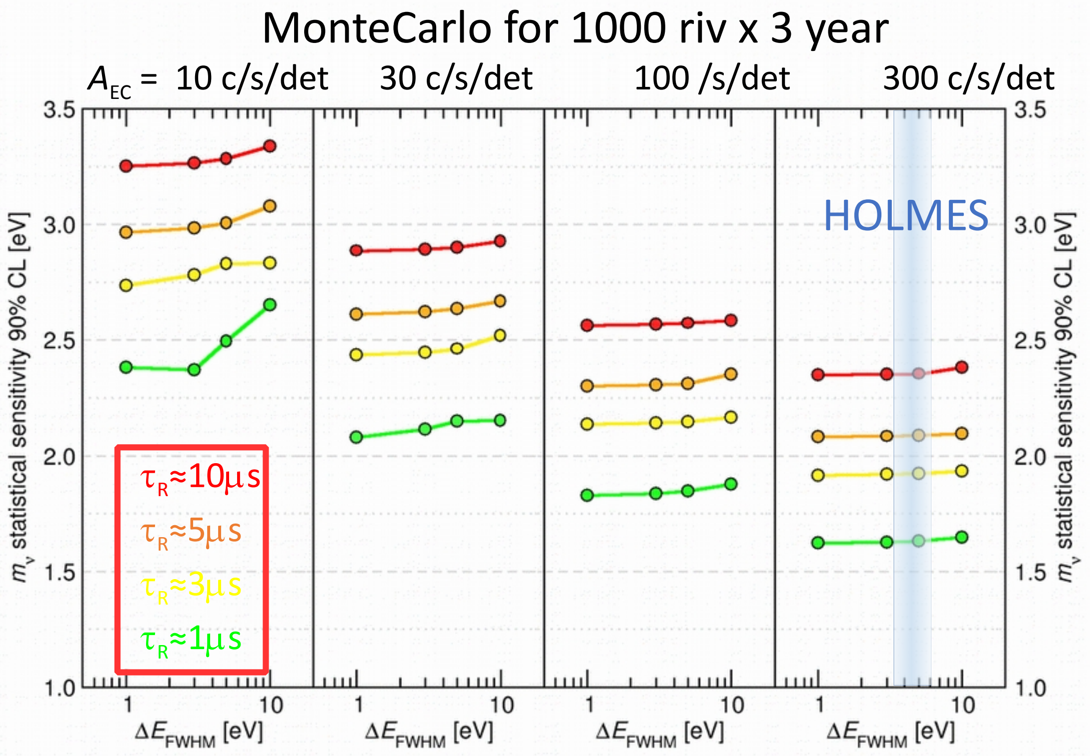
→ Very large arrays ~1000

$Q = 2800$ eV

$f_{pp} = 10^{-4}$



Number of events



(ERC-Adv. Grant 340321) PI:S.Ragazzi

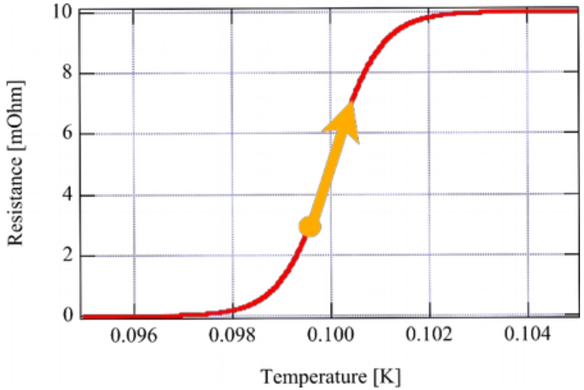
HOLMES will:

- Measure m_ν with ~ 1 eV sensitivity
- Prove that calorimeters are a valid technique
- High precision *Q-vlaue* measurement of ^{163}Ho
- Systematic errors assesment

Short and medium terms

- 64 detectors array, t_M = 1 month (m_ν < 10 eV)
- Final measurement: 1000 detectors, 3×10^{13} events in 3 y
- 6.5×10^{16} ^{163}Ho nuclei needed (≈18 μg)

TES for HOLMES



Transition Edge Sensors Superconductive Detectors (TES)

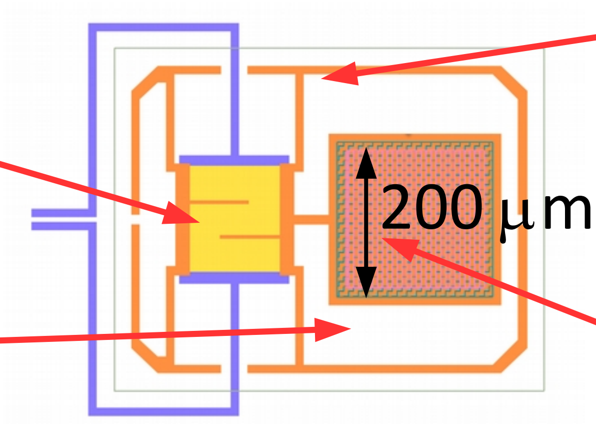
- Very steep R vs T dependency in transition region
- Gold absorber with ^{163}Ho inside coupled to TES thermometer
- Ho sandwiched between two 1 μm thick gold layers for a total electron containment
- Fast detectors to reduce pile-up
  - tunable rise time ~ L/R
  - decay time dependent on detector characteristics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

✓ Production at NIST (Boulder, CO)

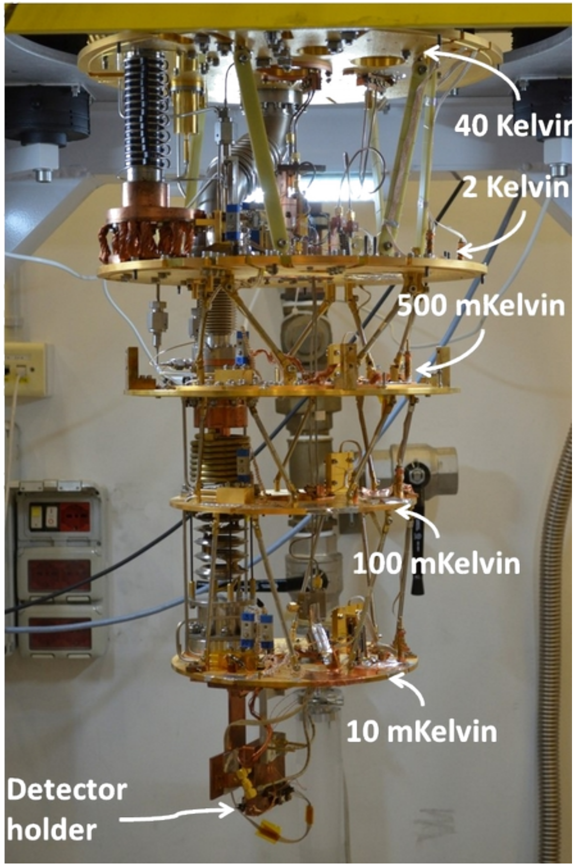
✓ tested at NIST and in Milano

➢ ^{163}Ho implating facility at Genova

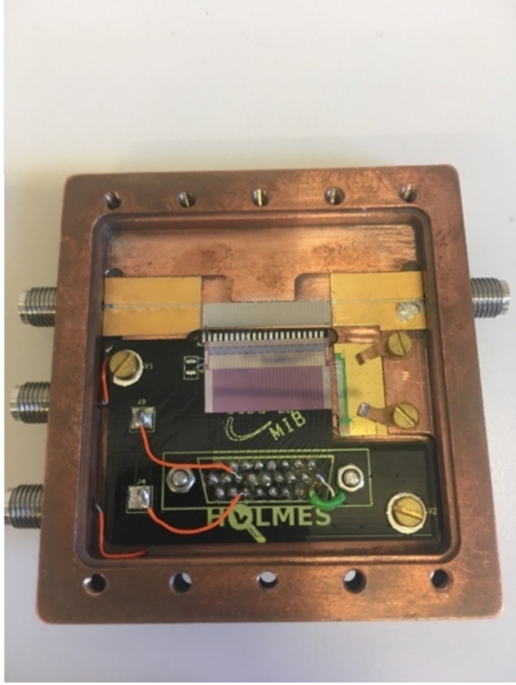
➢ Final Au coverage at Mi-Ge

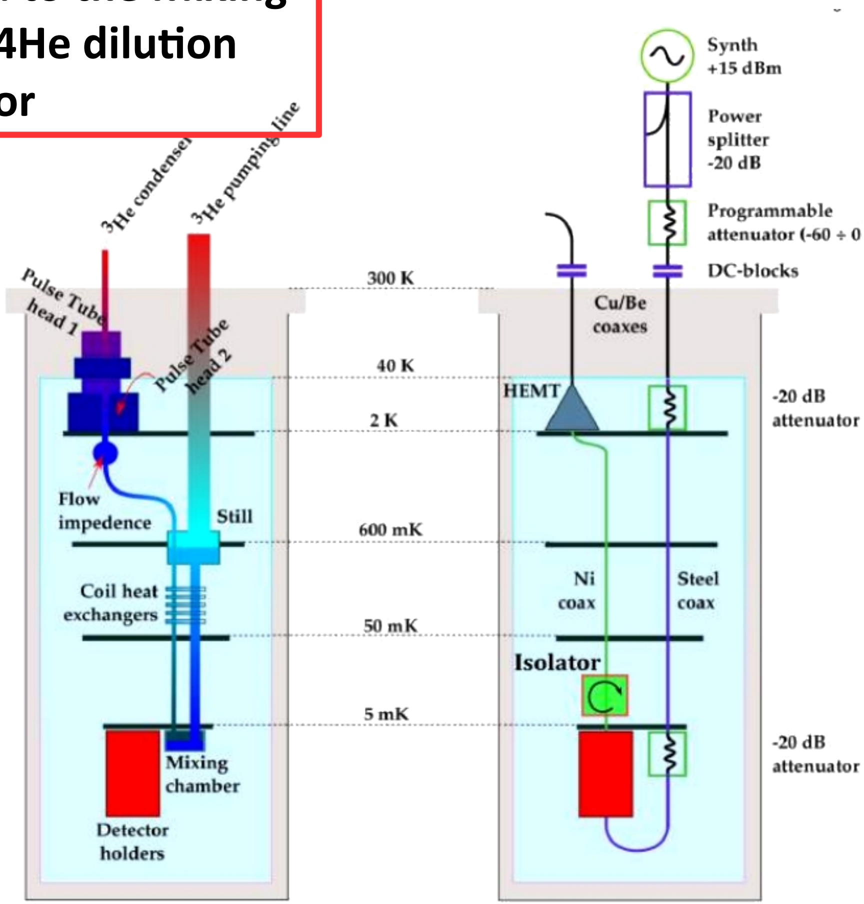


The cryogenics - Milan



Detctor box is coupled to the Mixing Chamber of a 3He/4He dilution refrigerator

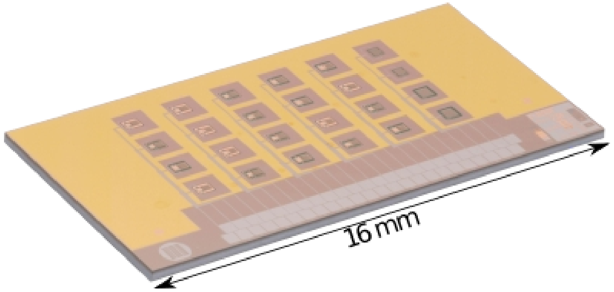


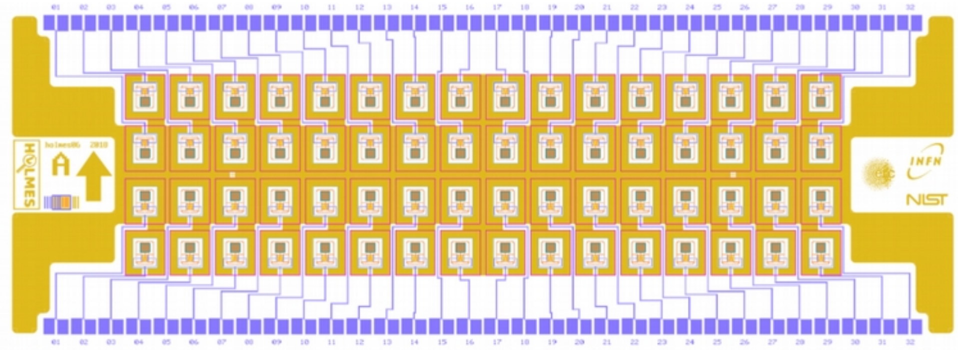


TES array

First Transition Edge Sensors array

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

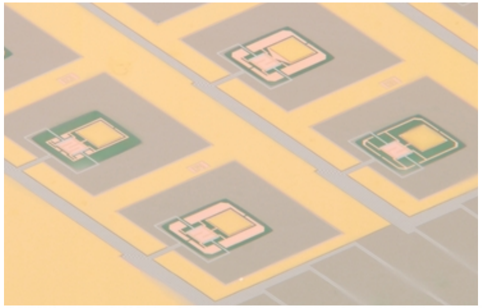


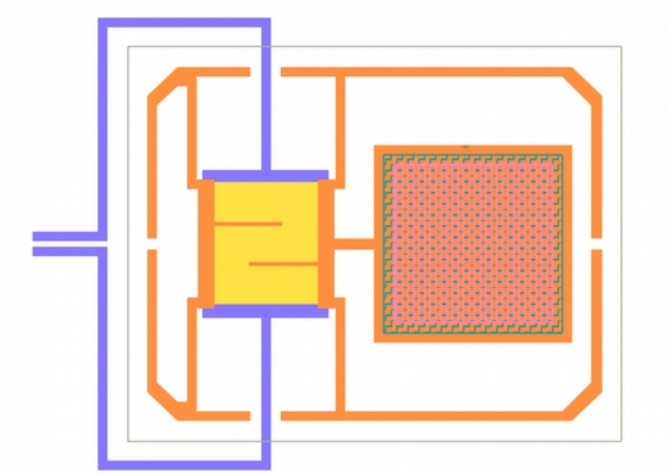


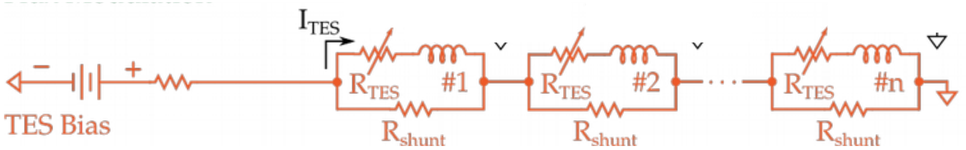
Readout

- Each TES is coupled to a RF-SQUID

$$E \rightarrow \delta T_{TES} \rightarrow \delta I_{TES}$$



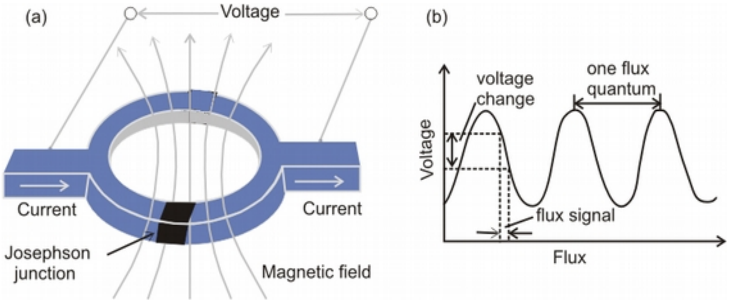


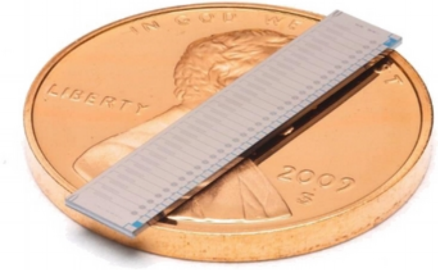


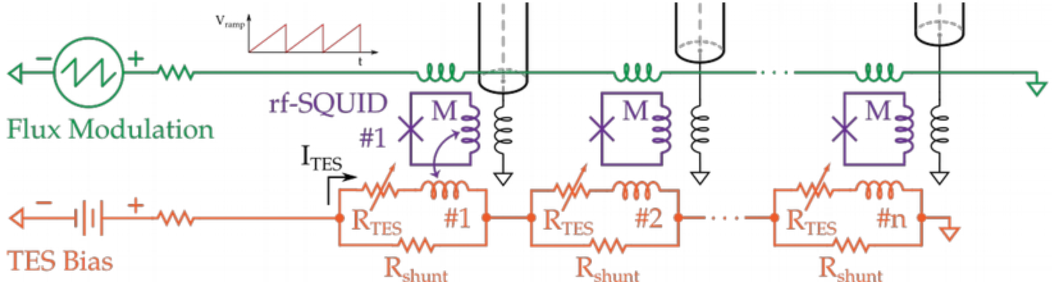
Readout

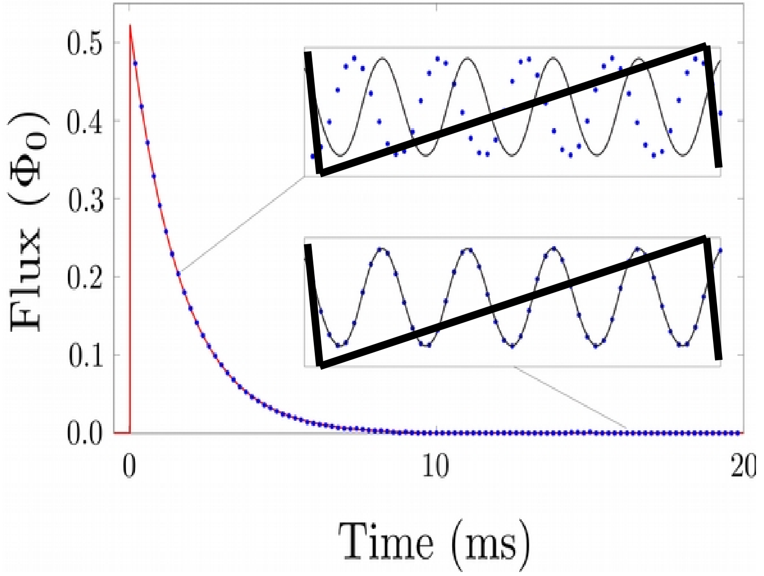
- Each TES is coupled to a RF-SQUID
- Every RF-SQUID is coupled to a common ramp

$$E \rightarrow \delta T_{TES} \rightarrow \delta I_{TES} \rightarrow \delta\phi_{squid}$$



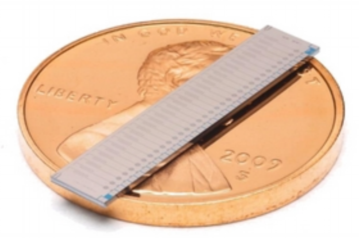


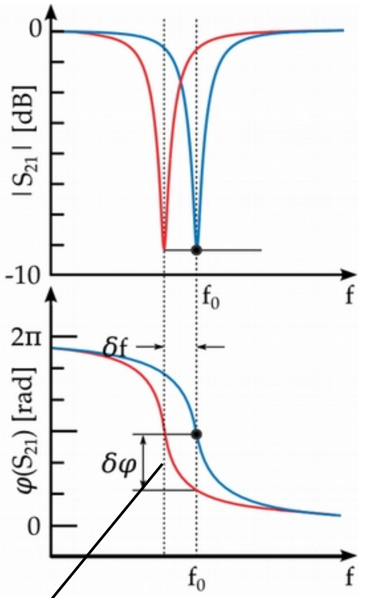




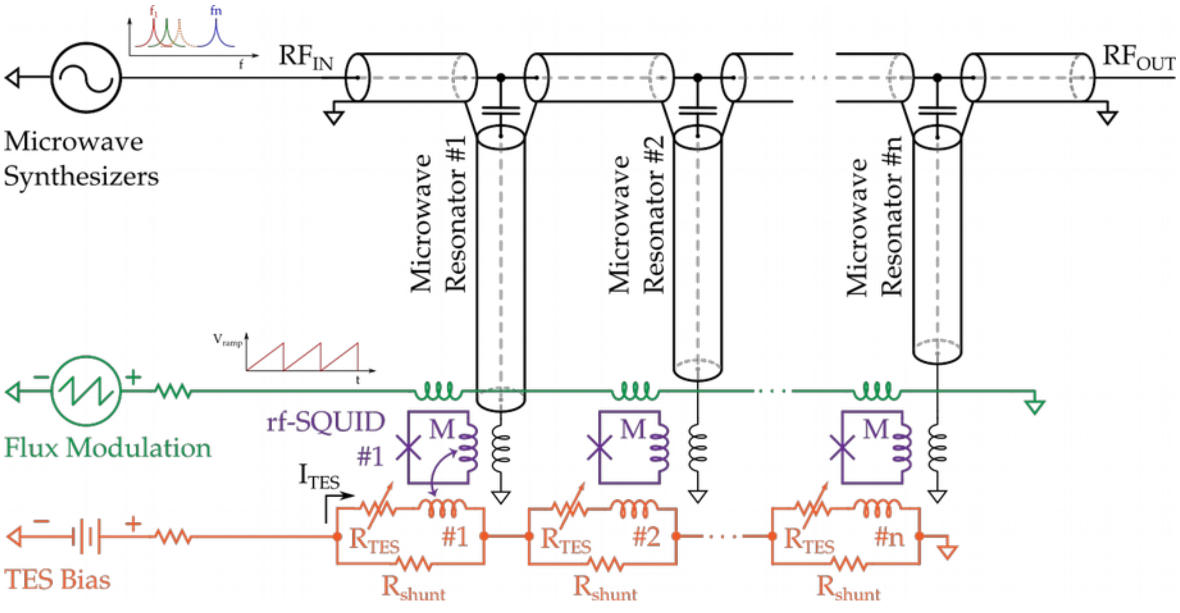
Readout

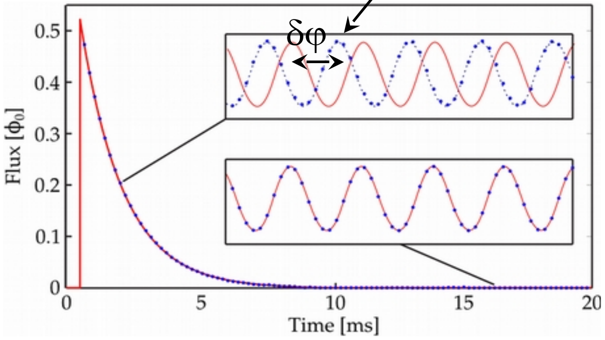
- Each TES is coupled to a RF-SQUID
- Every RF-SQUID is coupled to a common ramp
- Every RF-SQUID is coupled to a resonant circuit



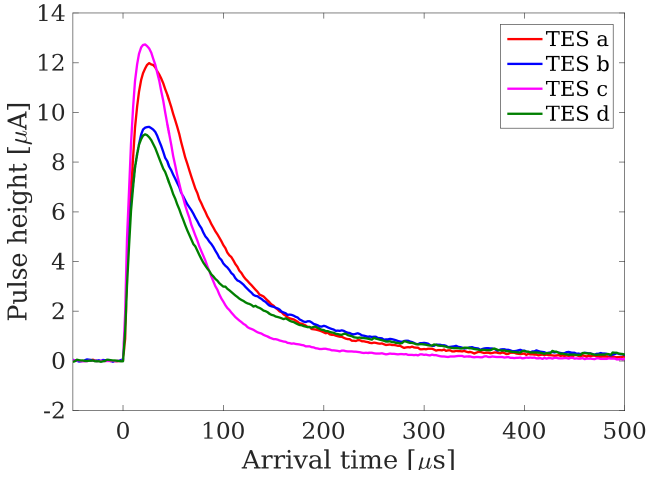


$$E \rightarrow \delta T_{TES} \rightarrow \delta I_{TES} \rightarrow \delta\phi_{squid} \rightarrow \delta f_{resonator}$$

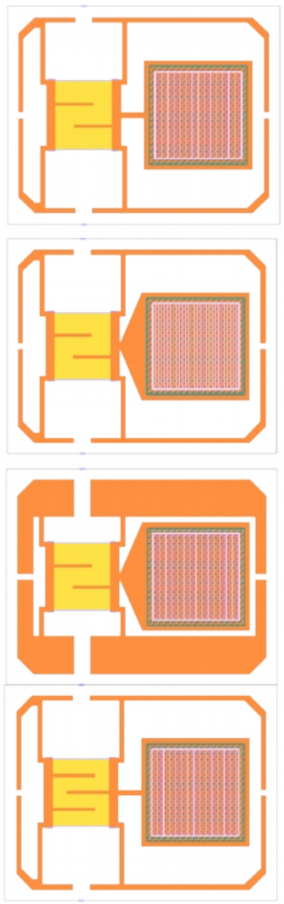




TES response

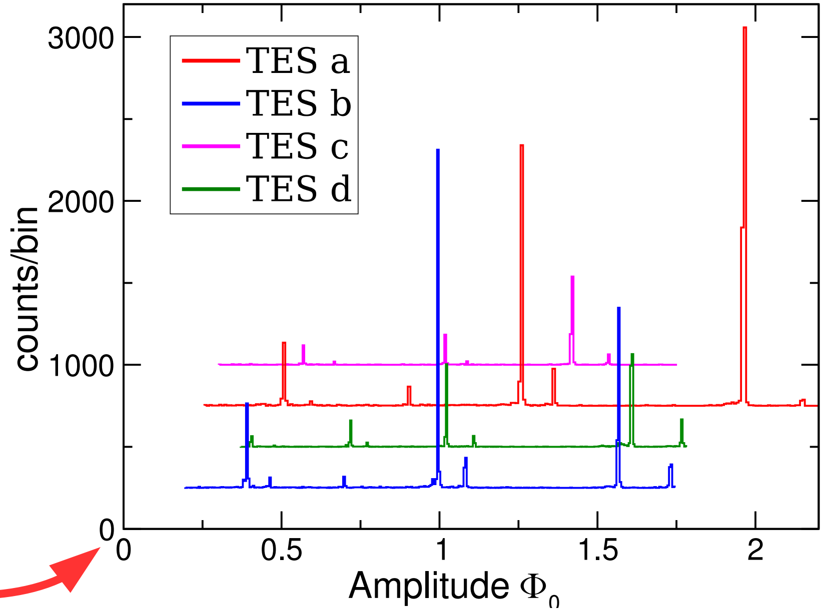


We tested four different designs to define:
- heat capacity
- thermal link geometry
- TES design



Calibration run performed with

^{55}Fe (5.9 keV) + fluorescence from
Ca – 3.7 keV
Cl – 2.6 keV
Al – 1.5 keV

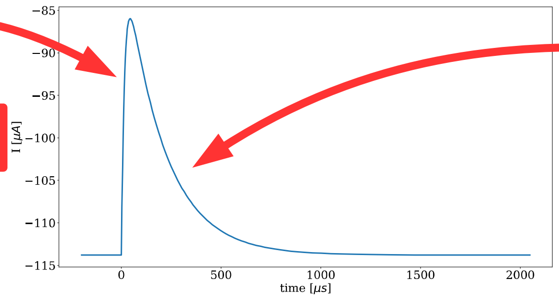


TES performance

HOLMES tested non implanted detectors → final design established

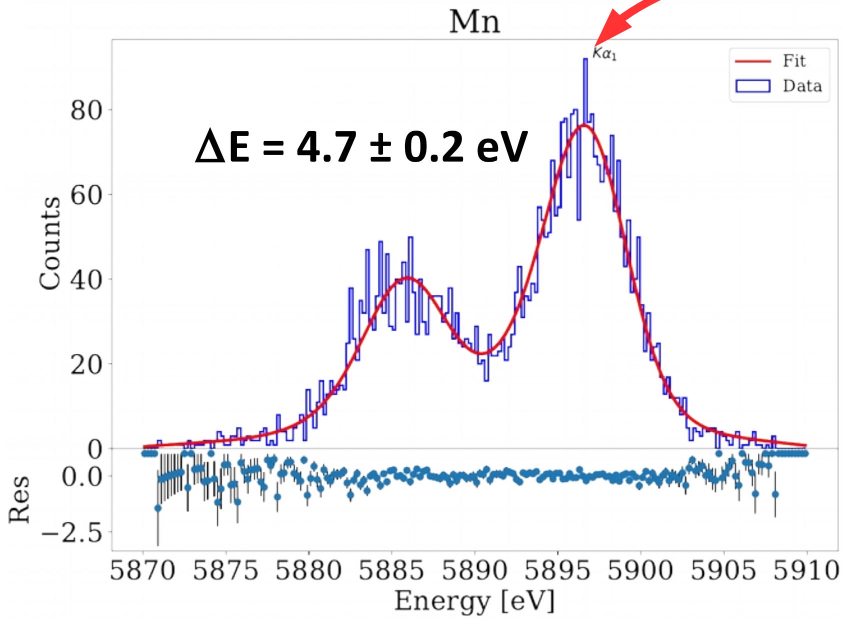
Stray iductance tuned to achieve pulse edge of $\tau_R \approx 10\ \mu s$

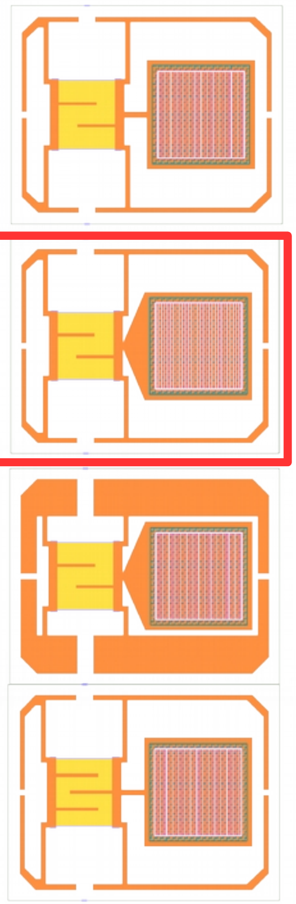
$\tau_R \approx 10\ \mu s$



$\tau_D \approx 190\ \mu s$

E [keV]	ΔE [eV]
1.49	4.5
2.62	5
3.69	5

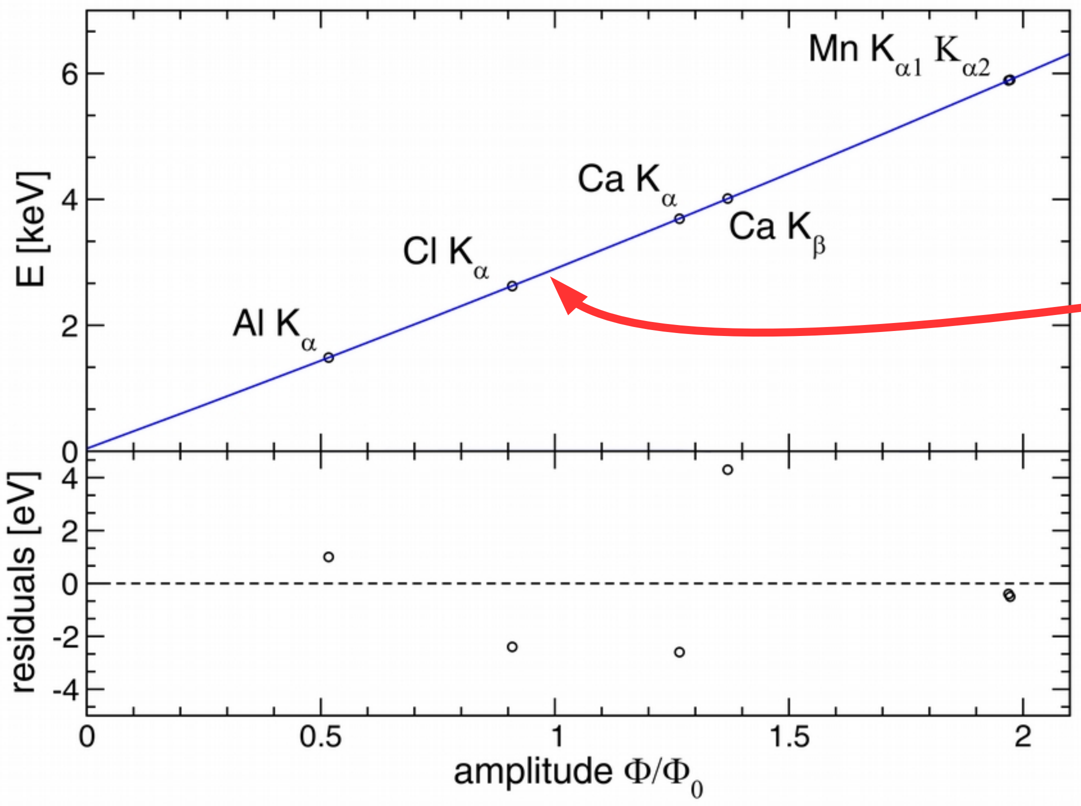




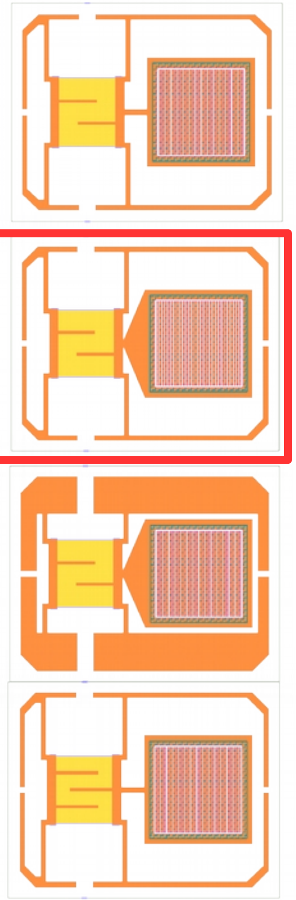
Linearity

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}Ho end point:
2.8 keV

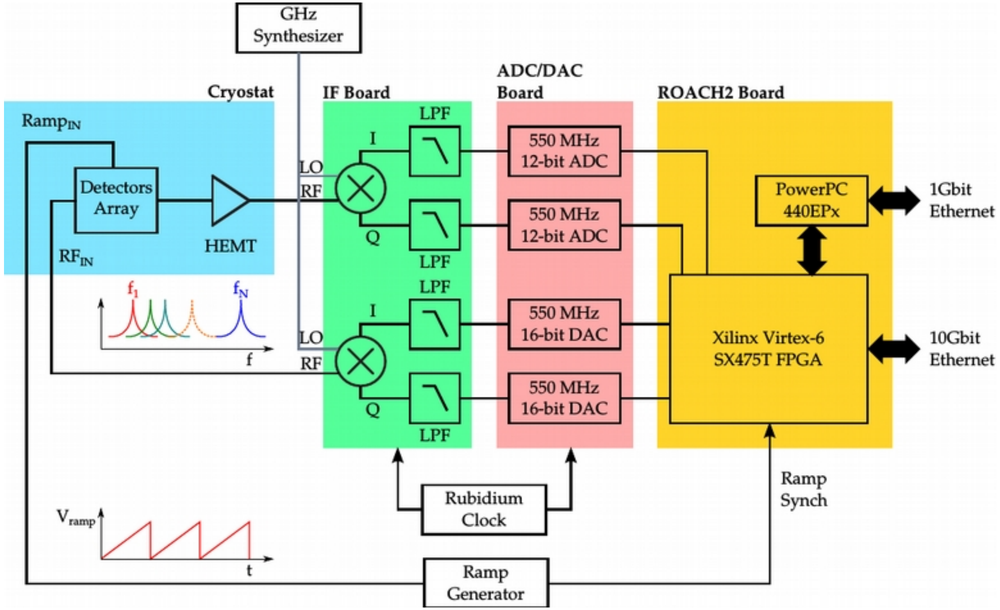
Published in Eur. Phys. J. C (2019) 79: 304

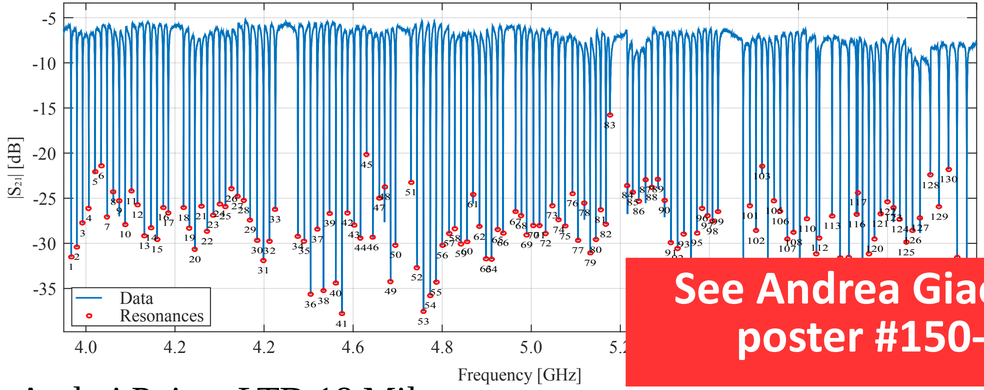
ROACH-2 readout

- *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





See Andrea Giachero's poster #150-397

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

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 you patience and attention ;)