HOLMES

HOLMES

M. Faverzani

on behalf of the HOLMES collaboration

GA n. 340321

HOLMES is an experiment to directly measure the neutrino mass with a sensitivity as low as ~1 eV. HOLMES will perform a calorimetric measurement of the energy released in the electron capture decay of ^{163}Ho (A. De Rujula and M. Lusignoli, Phys. Lett. B 118 (1982) 429). The calorimetric measurement eliminates systematic uncertainties arising from the use of external beta sources, as in experiments with beta spectrometers. HOLMES will deploy a large array of low temperature microcalorimeters with implanted ^{163}Ho nuclei. We outline here the project technical challenges and the present status of the development.

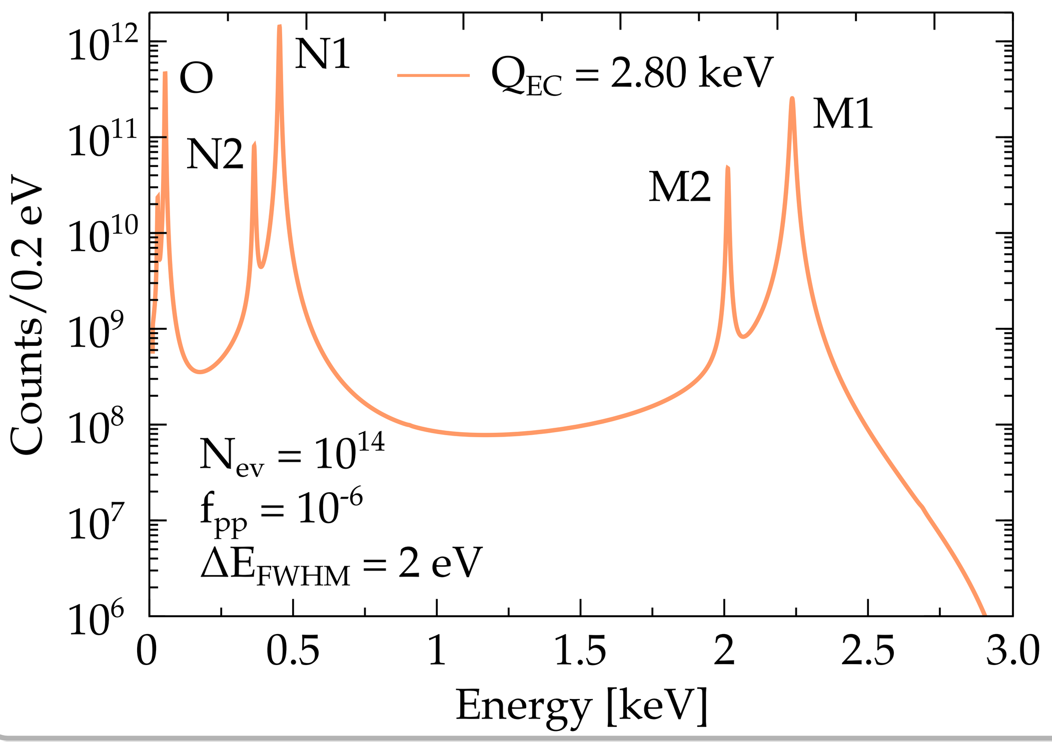
$^{163}Ho + e \longrightarrow {}^{163}Dy^* + \nu_e$ Electron capture from shell ≥ M1

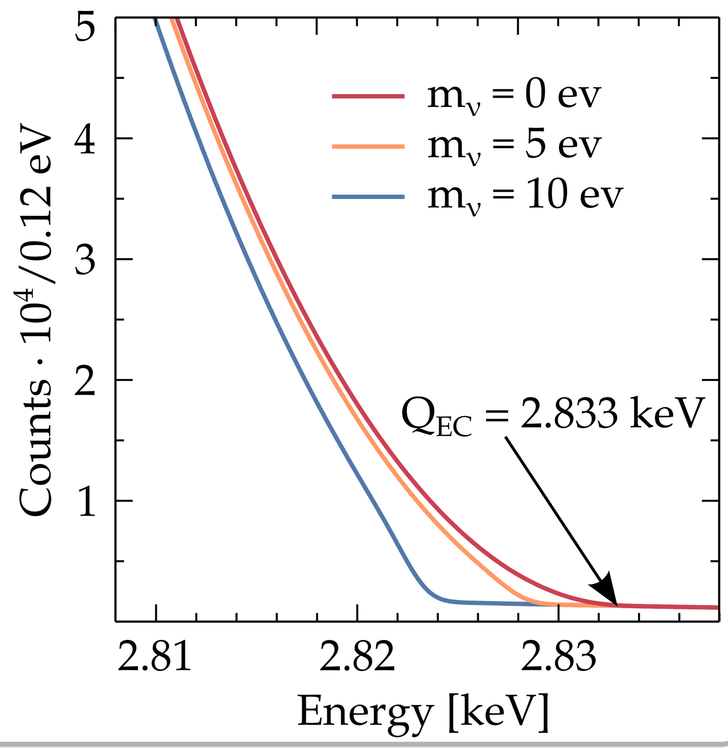
A. De Rujula and M. Lusignoli, Phys. Lett. B 118 (1982) 429

- **Calorimetric measurement of the (mostly non-radiative) de-excitation of Dy**
- Rate at the end-point depends on Q
  - Measured with Penning trap: $\boldsymbol{Q}$ **= 2.833 keV** Phys.Rev.Lett., 115:062501 (2015)

$\tau_{1/2} \approx 4570$ years ⟶ **few nuclei are needed**

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

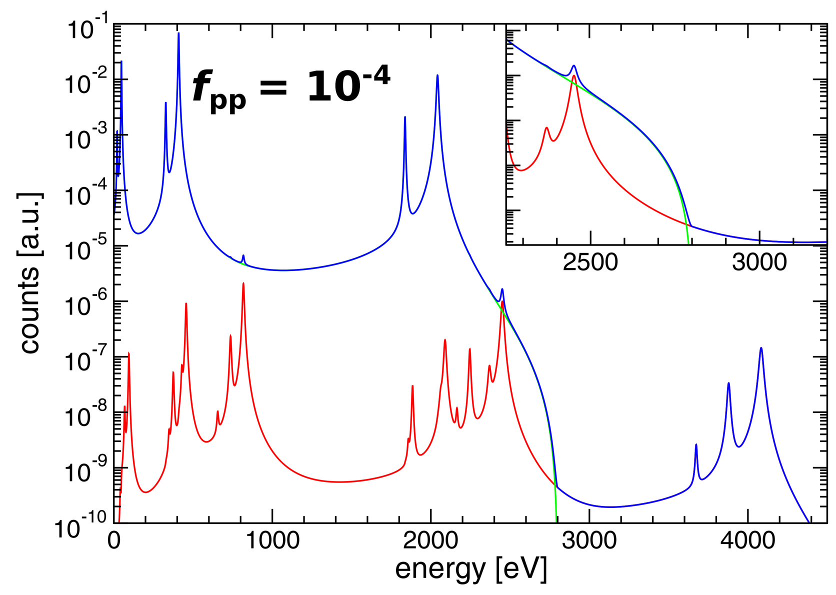


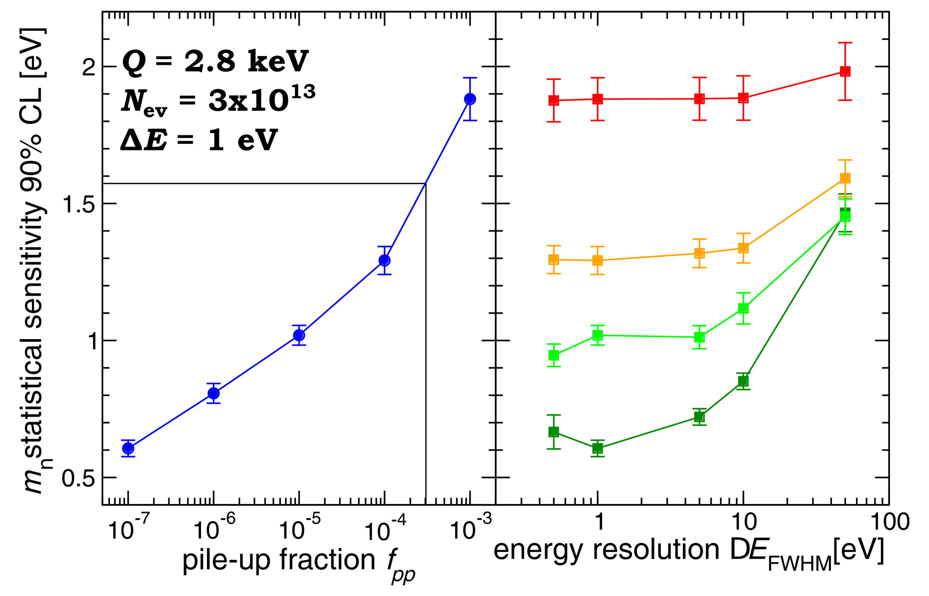


Statistical sensitivity $\Sigma(m_\nu)$ from MC simulations

- strong on statistics $N_{ev} = A_{EC} N_{det} T_M$: $\Sigma(m_\nu) \propto N_{ev}^{1/4}$
- strong on rise time pile-up (probability $f_{pp} \approx A_{EC}\tau_R$)
- weak on energy resolution ΔE

A. Nucciotti, Eur. Phys. J. C (2014) 74:3161

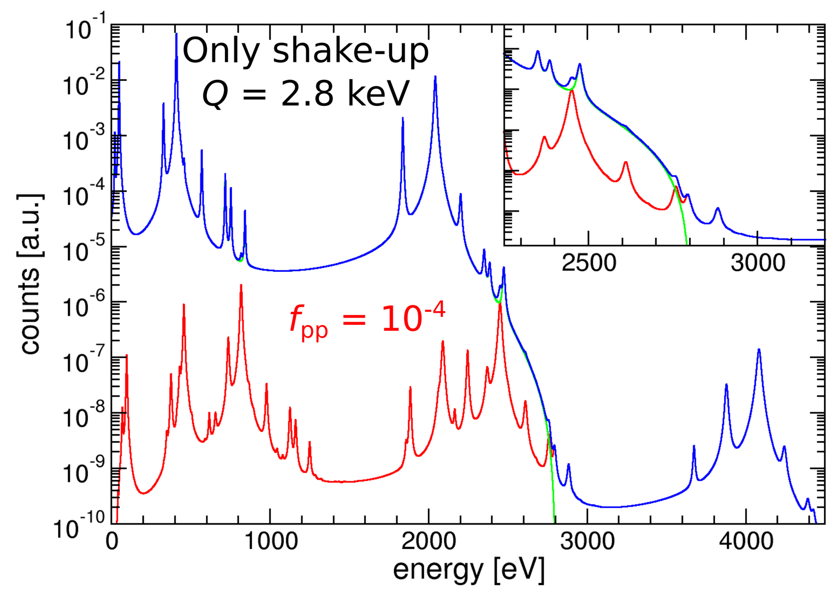


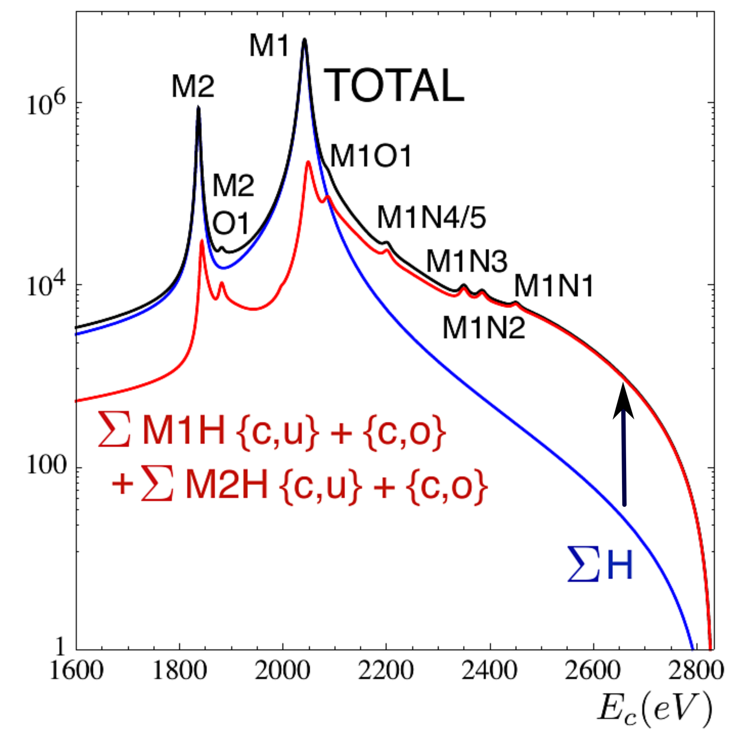


Shake up/shake off ⟶ double hole excitations

- Even more complex pile-up spectrum
- Statistics enhanced (shake-off)
  - Best predictions: factor 40

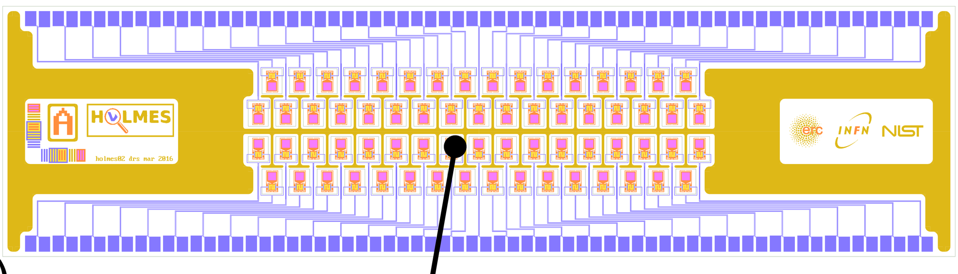
A. De Rújula and M. Lusignoli arXiv:1601:04990

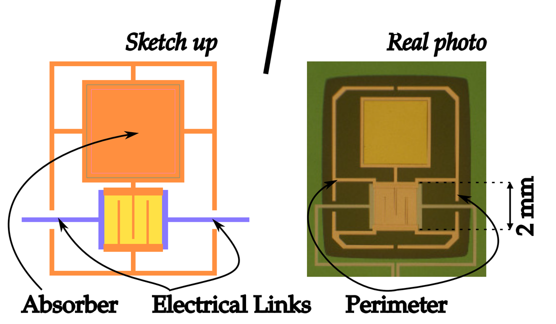


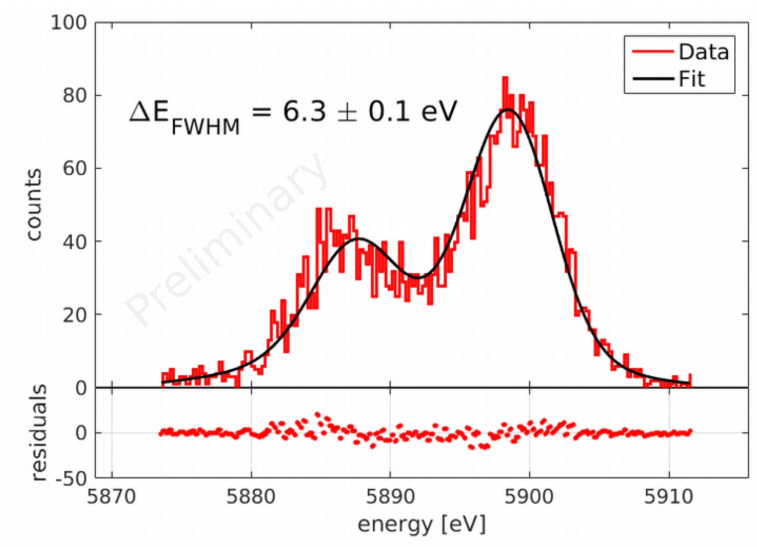


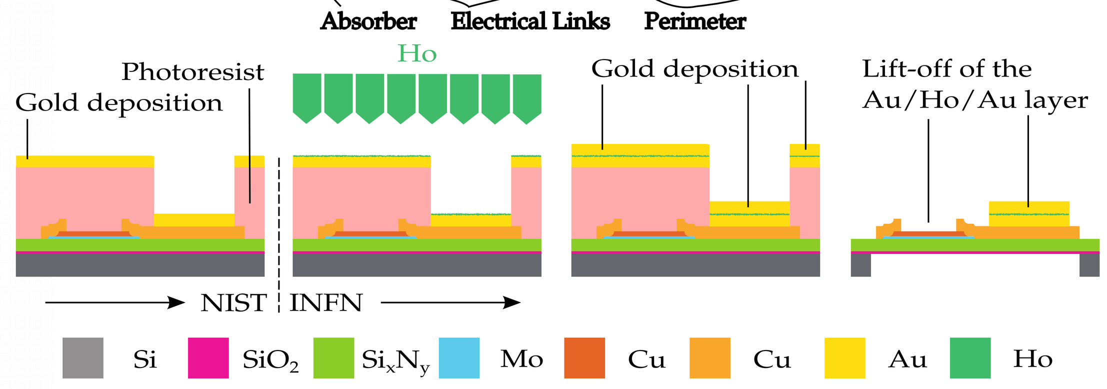
Transition edge sensors (TES)

- Thermal microcalorimeters
- Mo/Cu bilayers: $T_c \approx 100$ mK
- 2 µm thick gold absorbers
- produced @ NIST (Boulder, CO, USA)
- Implanted ^{163}**Ho** (INFN)

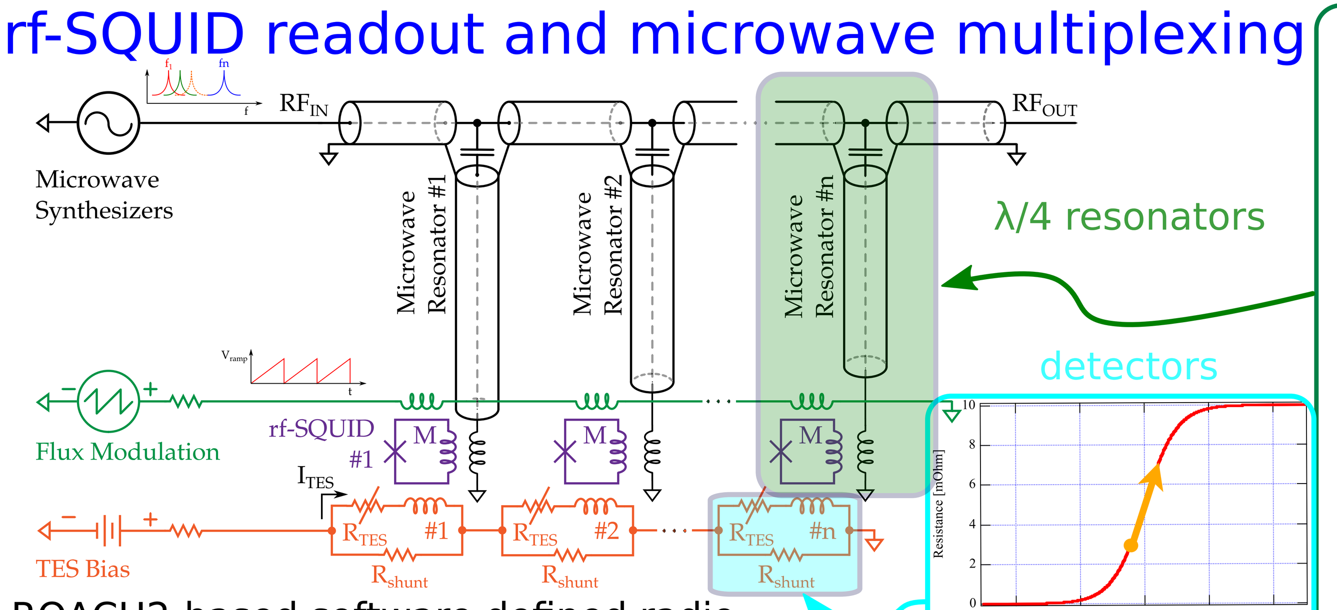


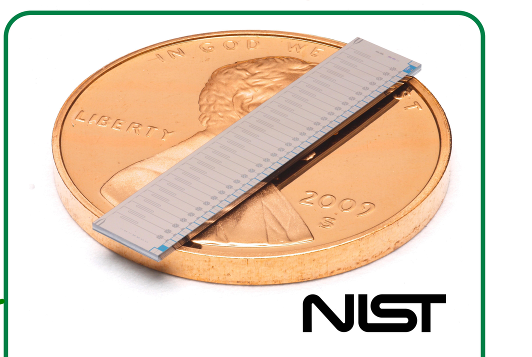




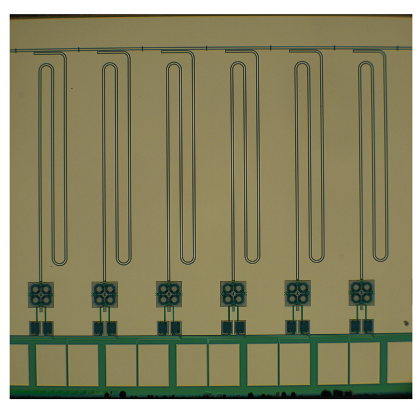


rf-SQUID readout and microwave multiplexing





NIST



ROACH2-based software defined radio

- f_{TES} bandwidth required/detector
- $f_{TES} \geq 2\, n_{\Phi_0} f_{sampl}$; $f_{sampl} \geq 5/\tau_R$
- $N_{mux} \leq f_{ADC}/10 f_{TES}$; $f_{sampl} = 0.5$ MHz, $n_{\Phi_0} = 2$

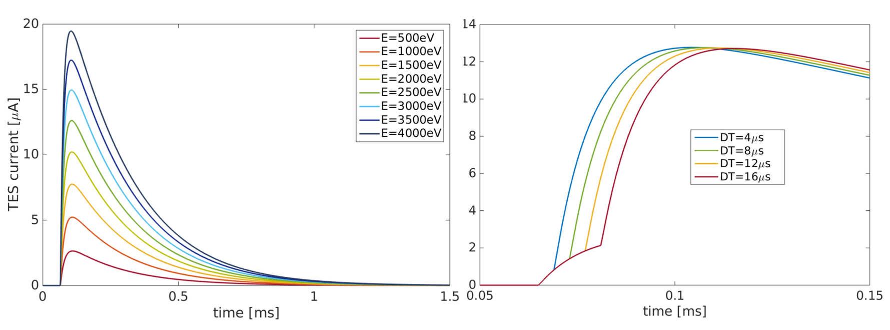
$N_{mux} \approx 30$

MC simulations for effective time resolution

- generate realistic TES signals from differential equations
- $E_1 + E_2 \in Q \pm 0.1$ keV
- sampled records with realistic noise (ΔE)
- signal $S(\omega)$, noise $N(\omega)$

$$H_{OF}(\omega) \propto \frac{S^*(\omega)}{N(\omega)} \qquad H_{WF}(\omega) \propto \frac{S^*(\omega)}{|S(\omega)|^2 + |N(\omega)|^2}$$

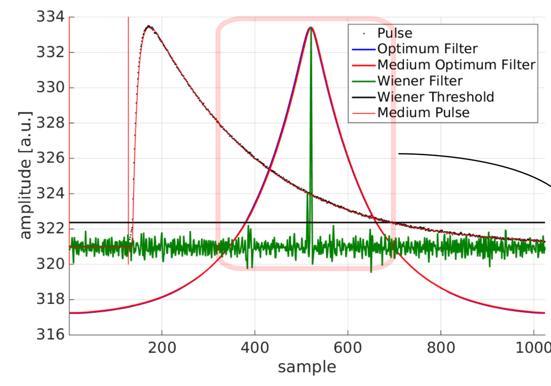
$$f_{pp} = A_{EC}\Delta t_{max}\left[1 - \int_0^{\Delta t_{max}} \frac{\eta(x)}{\Delta t_{max}} dx\right] = A_{EC}\tau_{eff}$$



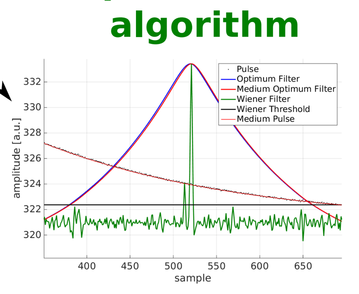
E. Ferri et al. J.Low Temp. Phys 184:405 (2016)

f_{sam}	reclen	L	$\tau_{rise (10-90)}$	τ_{decay}	false +	τ_{eff}	ΔE
[MHz]	[sample]	[nH]	[us]	[us]	%	[us]	[eV]
1	1024	45	18	262	3	3.4	2.4
1	1024	84	31	225	4.5	3.7	2.4

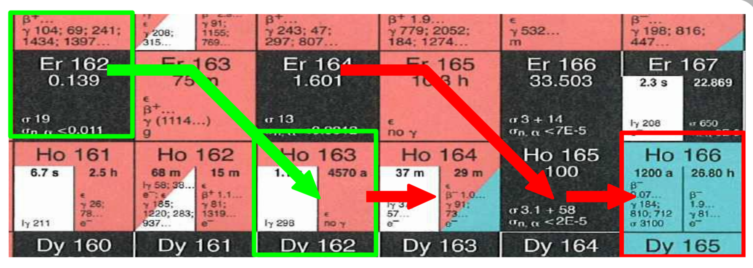
Single value decomposition also under study B.Alpert et al. J.Low Temp. Phys 184:263 (2016)



Wiener filter based pile-up discrimination algorithm



^{163}Ho production and embedding



≈**200 MBq** of ^{163}Ho required

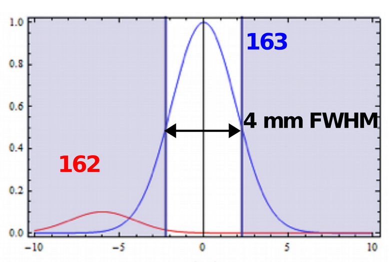
- ^{162}**Er (n,γ)** ^{163}**Er** $\sigma_{thermal} \approx 20$b
- ^{163}**Er** ⟶ ^{163}**Ho** $\tau^{1/2}_{EC} \approx 75$ min
- ILL reactor (Grenoble, France) thermal neutron flux = 1.3x10^{15} n/cm^2/s

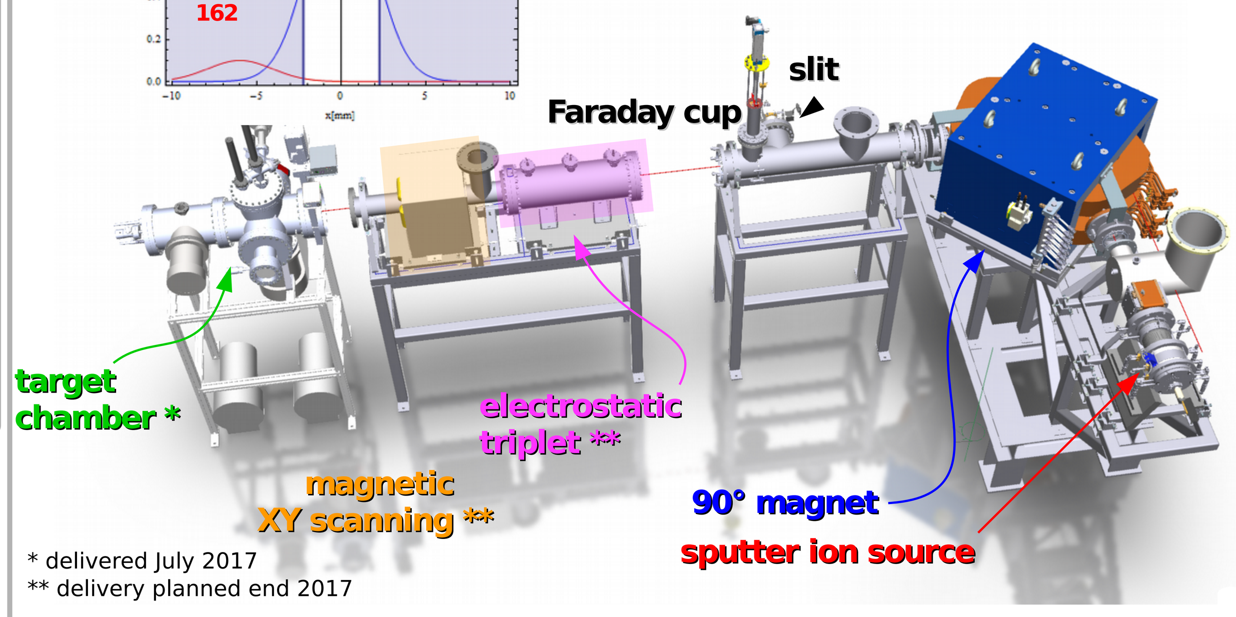
≈ 270 kBq(^{163}Ho)/mg(^{162}Er)/week

- **burnup** ^{163}Ho(n,γ)^{164}Ho reduces yield, σ ≈ 220b
- ^{165}Ho(n,γ)^{166m}Ho (from contaminations of ^{164}Er), $\tau_{1/2}$ = 1200 y

100 mg (^{162}Er) for 7 weeks ⟶ ~ 100 kBq of ^{166m}Ho (∝^{164}Er abundance)

- **500 mg** of 30% enriched Er_2O_3 are required for HOLMES





* delivered July 2017
** delivery planned end 2017

- Extraction voltage 30-50 kV
- 10-100 nm implantat depth
- ^{163}Ho/^{166m}Ho separation better than 10^5
- Ion source, magnet and slit delivered end 2016

Evaporation of gold simultaneous to the implantation to reduce sputtering effects of the ions on gold and to prevent excess of heat capacities

- **Enriched Er_2O_3 samples* pre/post processed at PSI**

25mg irradiatied for 55 days ⟶ $A(^{163}\text{Ho}) \approx 5$ MBq, $A(^{166m}\text{Ho})_{meas} \approx 10$ kBq

150mg irradiated for 50 days ⟶ $A(^{163}\text{Ho}) \approx 38$ MBq, $A(^{166m}\text{Ho})_{meas} \approx 37$ kBq

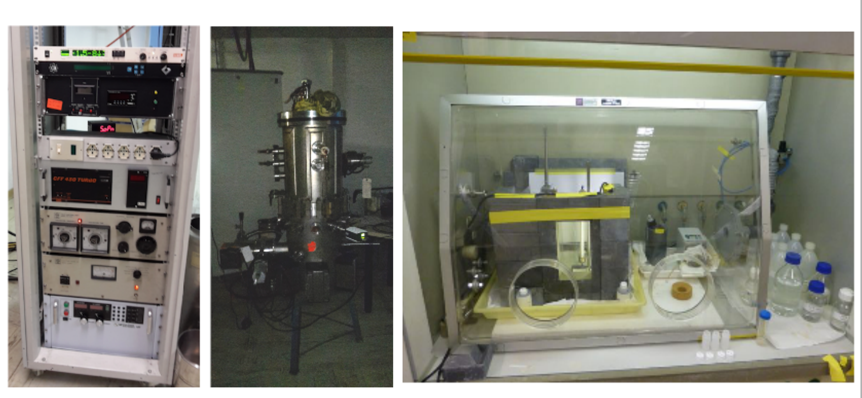
- **Holmium chemical separation**

efficiency ≈ 79%

- **Metallic holmium sputter target**

thermoreduction/distillation in furnace @ INFN Genoa

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



* from CENTRA, Lisbon