Status of the HOLMES detector development

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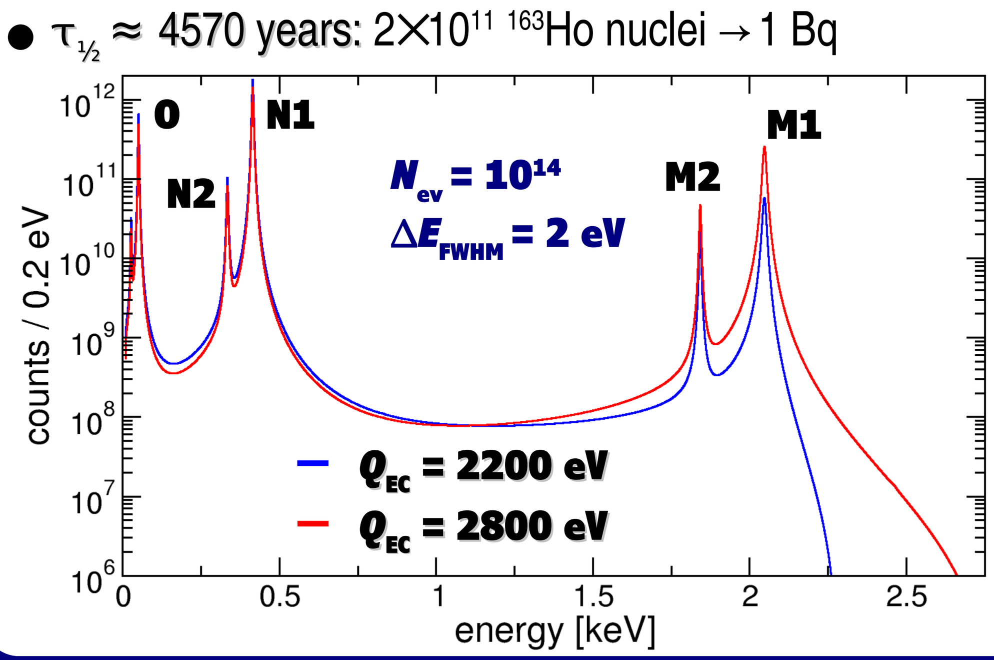
HOLMES is a new experiment to directly measure the neutrino mass with a sensitivity as low as 0.4 eV. **HOLMES** will perform a calorimetric measurement of the energy released in the electron capture decay of ^{163}Ho (A. De Rujula and M. Lusignoli, Phys. Lett. B 118 (1982) 429). The calorimetric measurement 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.

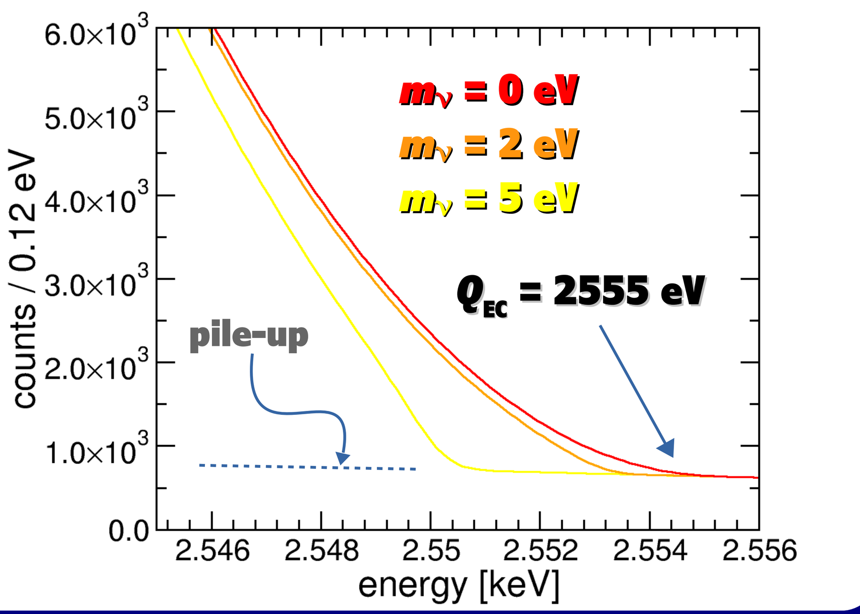
$^{163}Ho + e^- \rightarrow ^{163}Dy^* + \nu_e$

$Q_{EC} \approx$ 2.8 keV → electron capture from shell ≥ M1

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

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



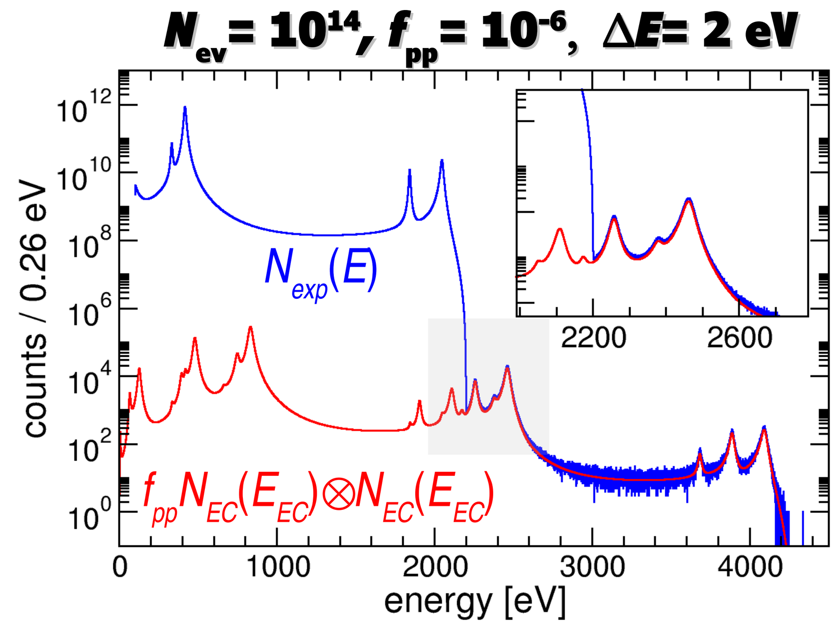


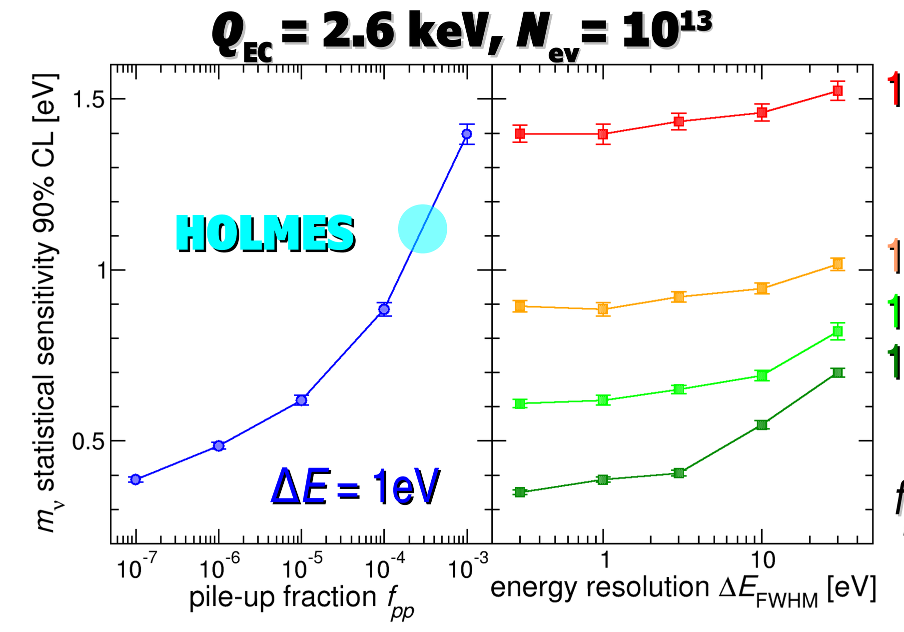
Statistical sensitivity $\Sigma(m_\nu)$ dependencies from MC simulations

- 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

t_M measuring time
N_{det} number of detectors
A_{EC} EC activity per detector
τ_R time resolution (≈ rise time)

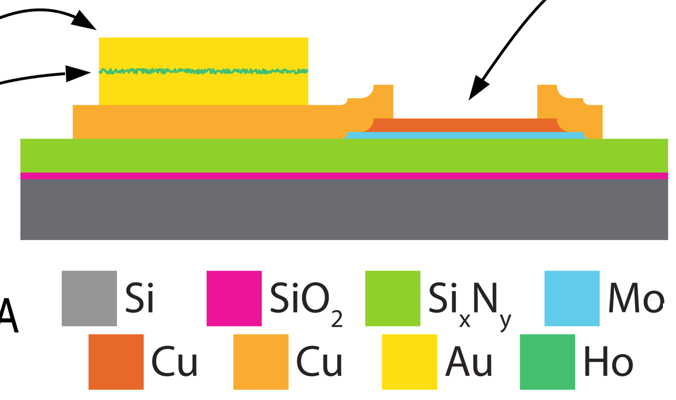
A. Nucciotti, Eur. Phys. J. C (2014) 74:3161

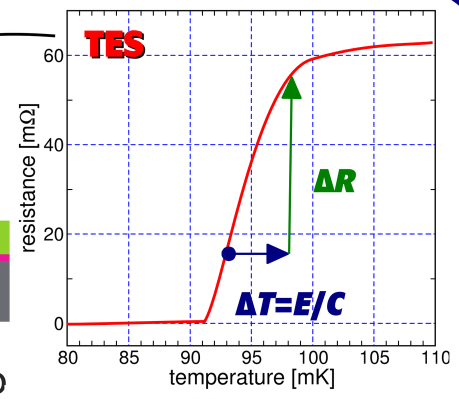


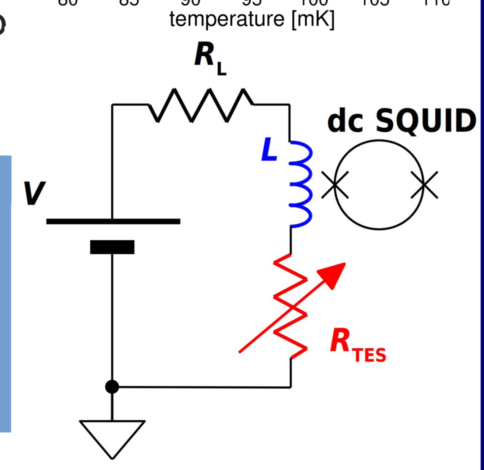


Detector R&D

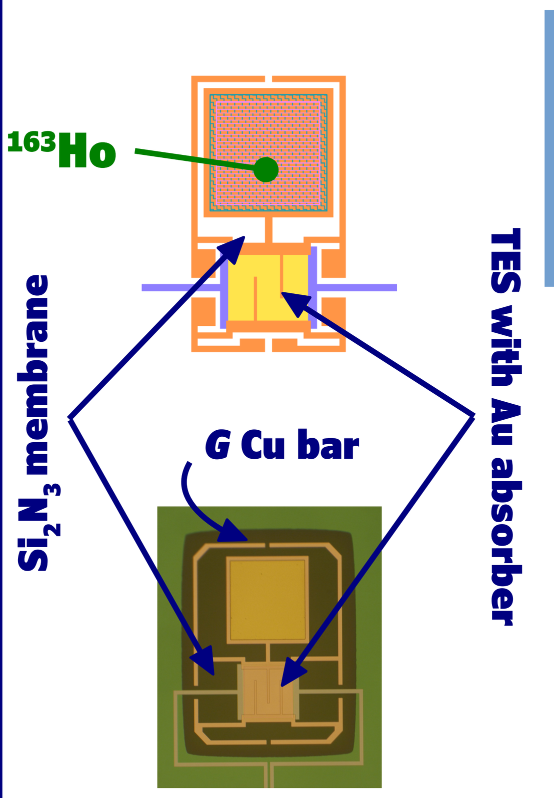
- Transition Edge Sensors (TES)
- MoCu bilayers → $T_c \approx$100mK
- 2 µm thick gold absorber
- implanted ^{163}Ho
- TES fabricated at NIST, Boulder, CO, USA
- ^{163}Ho implantation at INFN Genova

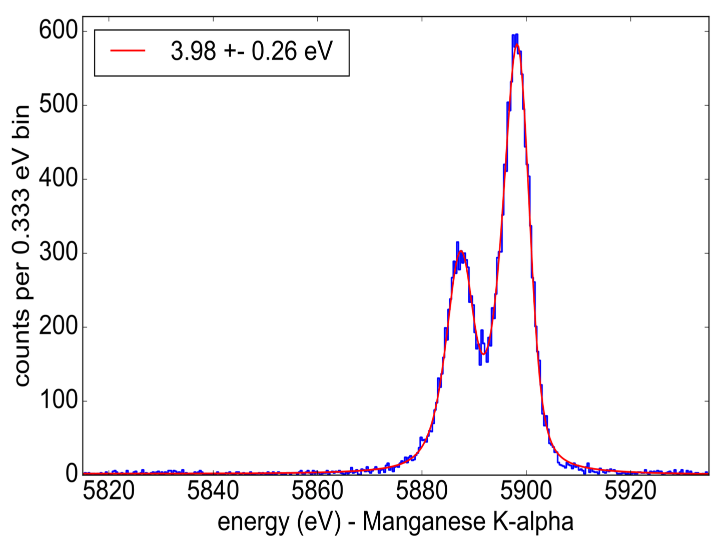




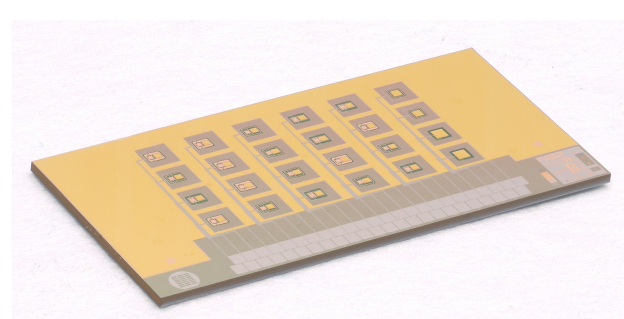


measured @ NIST*					
L	C	G	τ_{rise} (peak)	τ_{decay} (peak)	ΔE (S/N)
[nH]	[pJ/K]	[pW/K]	[µs]	[µs]	[eV]
100	0.69	600	60	60	3





*see J. Hays-Wehle's talk



HOLMES goals*

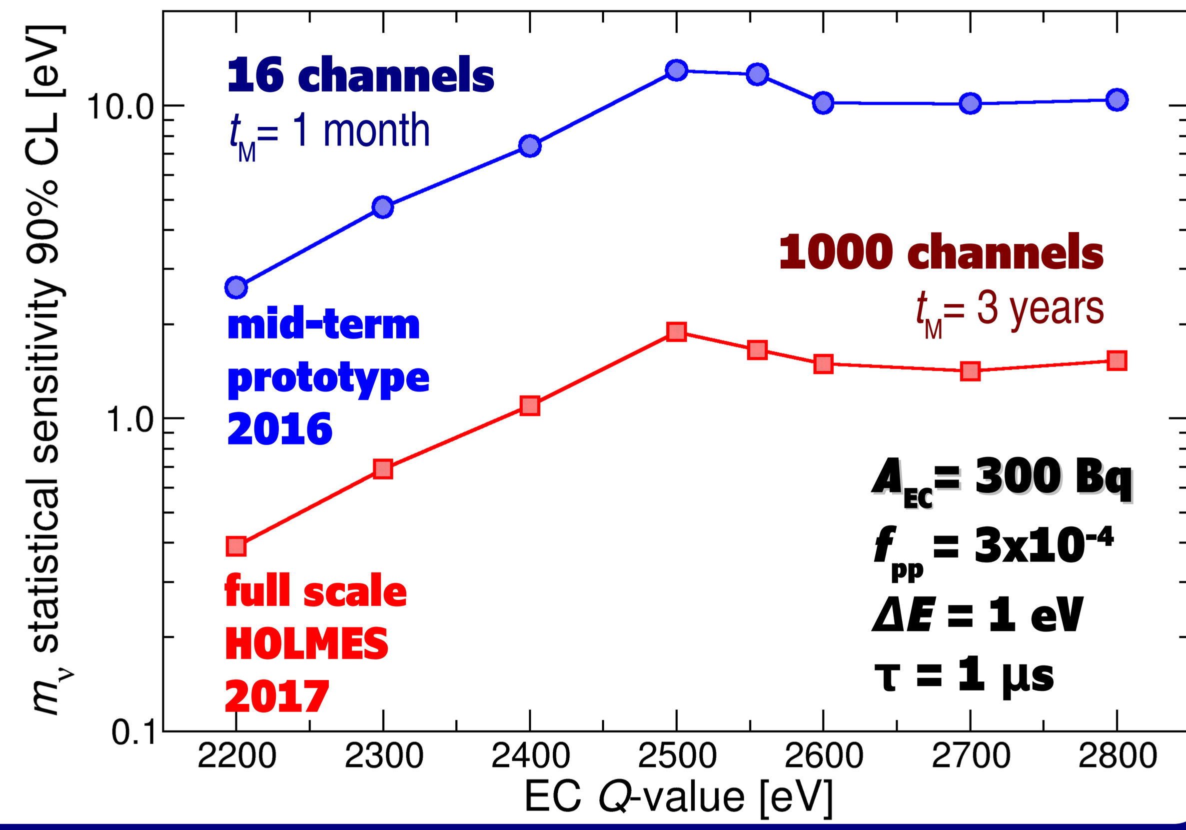
*see A. Nucciotti's talk

- neutrino mass measurement with a m_ν statistical sensitivity as low as 0.4 eV
- assess potential

HOLMES baseline

- Transition Edge Sensors with implanted ^{163}Ho
  - 6.5×10^{13} nuclei/ch → A_{EC}= 300 Bq
  - ΔE ≈ 1 eV and $\tau_R \approx$ 1 µs
- 1000 channel array
  - 6.5×10^{16} ^{163}Ho nuclei
  - 3×10^{13} events in 3 y

B. Alpert et al., Eur. Phys. J. C, (2015) 75:112



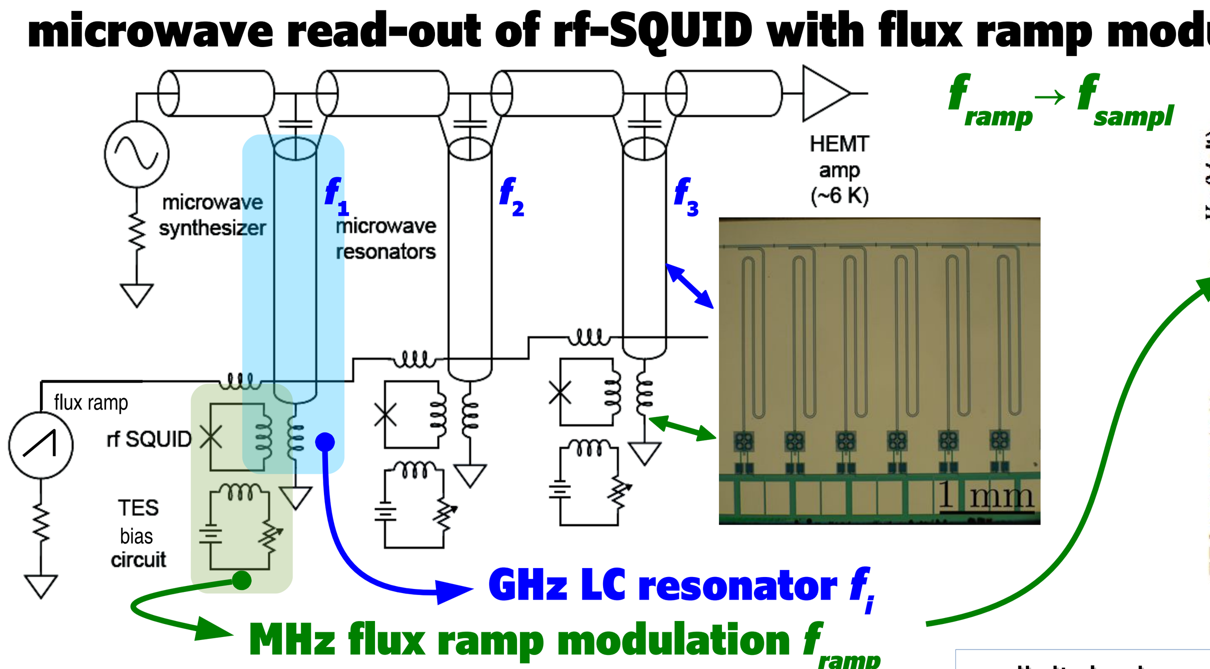
TES read-out and signal multiplexing

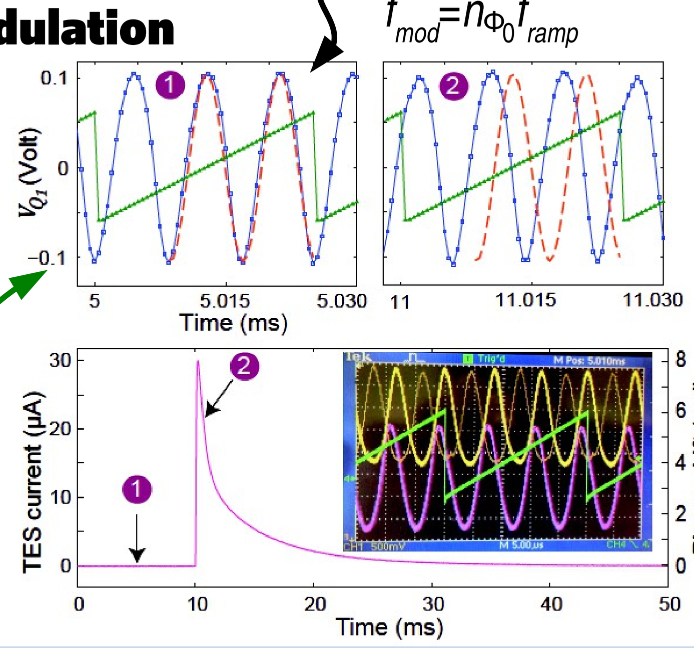
microwave read-out of rf-SQUID with flux ramp modulation

n_{Φ_0}=3 ($n_{\Phi_0} \geq 2$)

$f_{mod} = n_{\Phi_0} f_{ramp}$

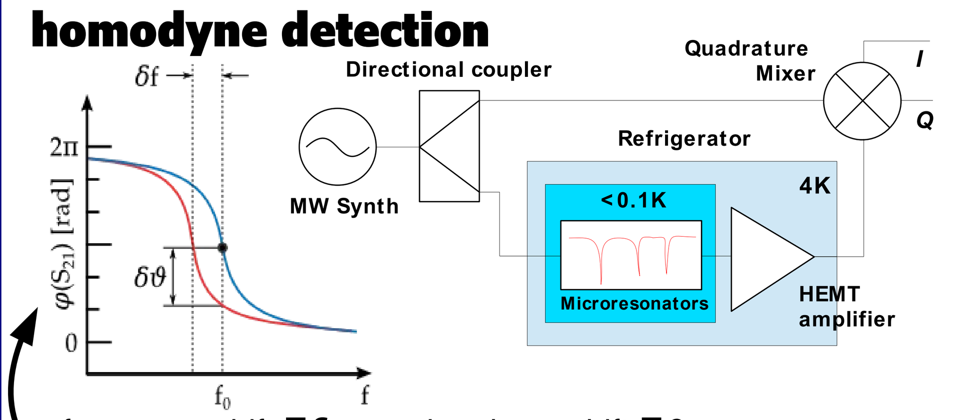
$f_{ramp} \rightarrow f_{sampl}$





O. Noroozian et al., Applied Phys.Lett. 103, (2013) 202602

homodyne detection



frequency shift **δf** ↔ carrier phase shift **δϑ**

$\varphi(S_{21}) = \arctan(Q/I)$

- digital microwave multiplexing
- comb from up-conversion → $f_1 \oplus f_2 \oplus f_3 \oplus \ldots \oplus f_{N_{mux}}$
- down-conversion → digitization: f_{ADC}= 0.5 GHz
- required bandwidth per channel: f_{TES}
  - $f_{TES} = g_f 2 n_{\Phi_0} f_{sampl} = 2 g_f n_{\Phi_0}(R_d/\tau_{rise})$
  - → g_f guard factor (crosstalk), R_d distortion factor

$N_{mux} = \frac{f_{ADC}}{f_{TES}}$ τ_{rise}=10 µs, n_{Φ_0}= 2, R_d=0.5 g_f=5 → $N_{mux} \approx$30

Effective time resolution from MC simulations*

*see E. Ferri's talk

- for subsequent (Δt) events with energy E_1 and E_2: time resolution $\tau_R = \tau_R(E_1, E_2)$

$$N_{pp}(E) = A_{EC}\int_0^\infty \tau_R(E,\epsilon) N_{EC}(\epsilon) N_{EC}(E-\epsilon)\, d\epsilon$$

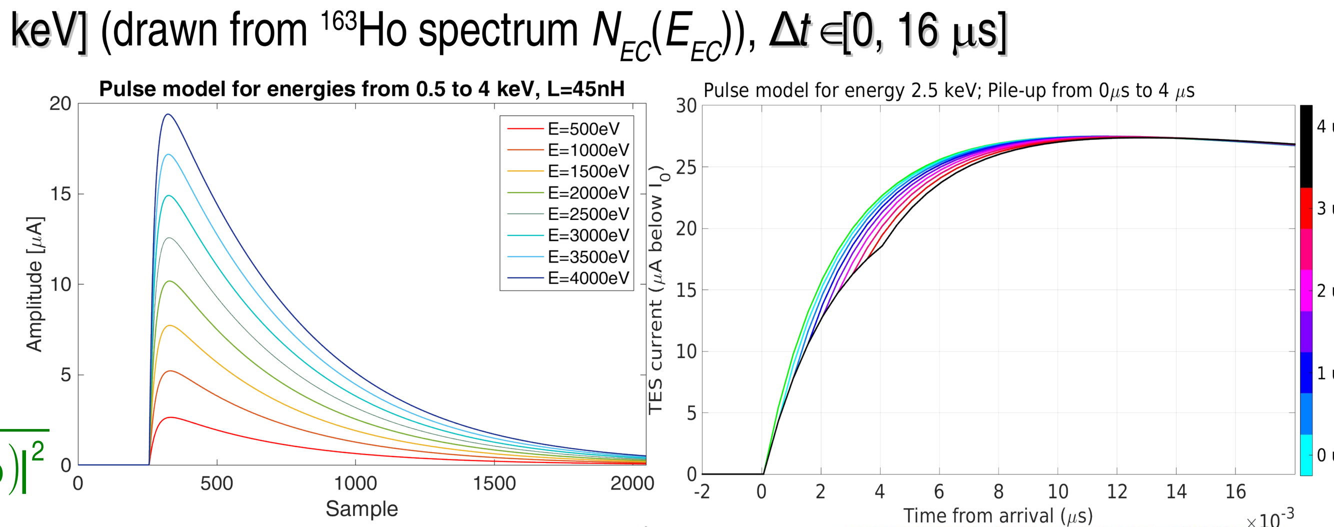
- generate realistic TES signals (→ E, τ_{rise}, τ_{decay}) solving differential equations
  - sampled records (reclen, n_{bit}, f_{sampl}) with signal pairs in realistic noise (→ ΔE)
    - $E_1+E_2 \in$[2.4 keV, 2.6 keV] (drawn from ^{163}Ho spectrum $N_{EC}(E_{EC})$), $\Delta t \in$[0, 16 µs]

signal $S(\omega)$

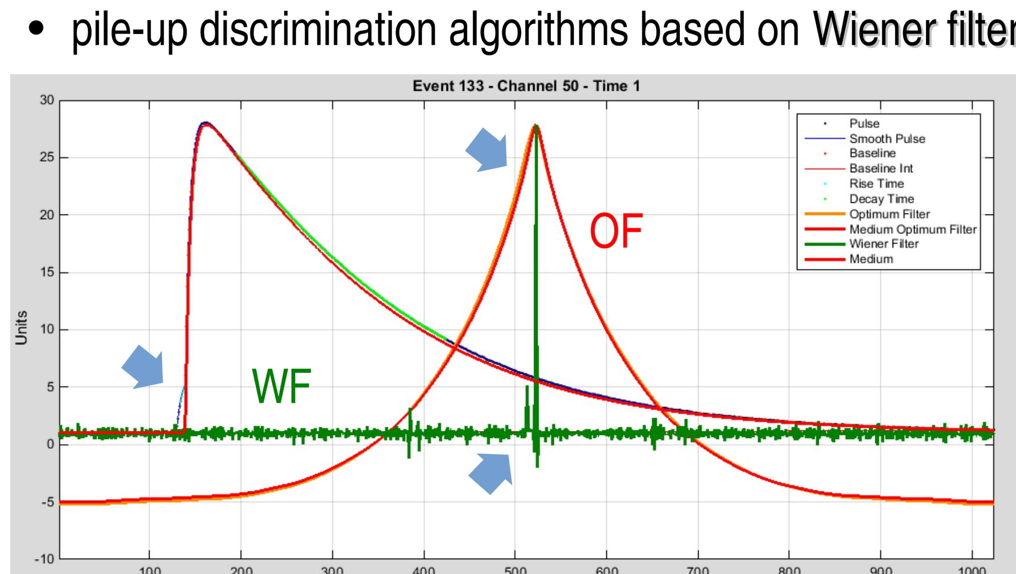
noise $N(\omega)$

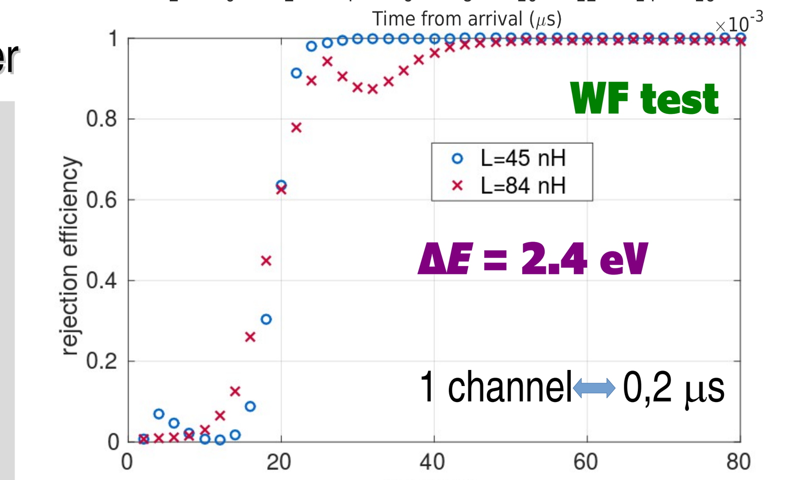
$$H_{OF}(\omega) \propto \frac{S^*(\omega)}{N(\omega)}$$

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



- pile-up discrimination algorithms based on Wiener filter





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

n_{bit}=12

C = 0.86 pJ/K

G = 0.44 nW/K

$\tau_{dec} \approx$ 240 µs

L	τ_{rise}	f_{sampl}	reclen	False pos.	τ_{eff}	ΔE @ 2500 eV
[nH]	[µs]	[MHz]	[sample]	%	[µs]	[eV]
45	18	1	2048	3	3.4	2.4
84	31	1	1024	4.5	3.2	2.4