Status of the HOLMES detector development

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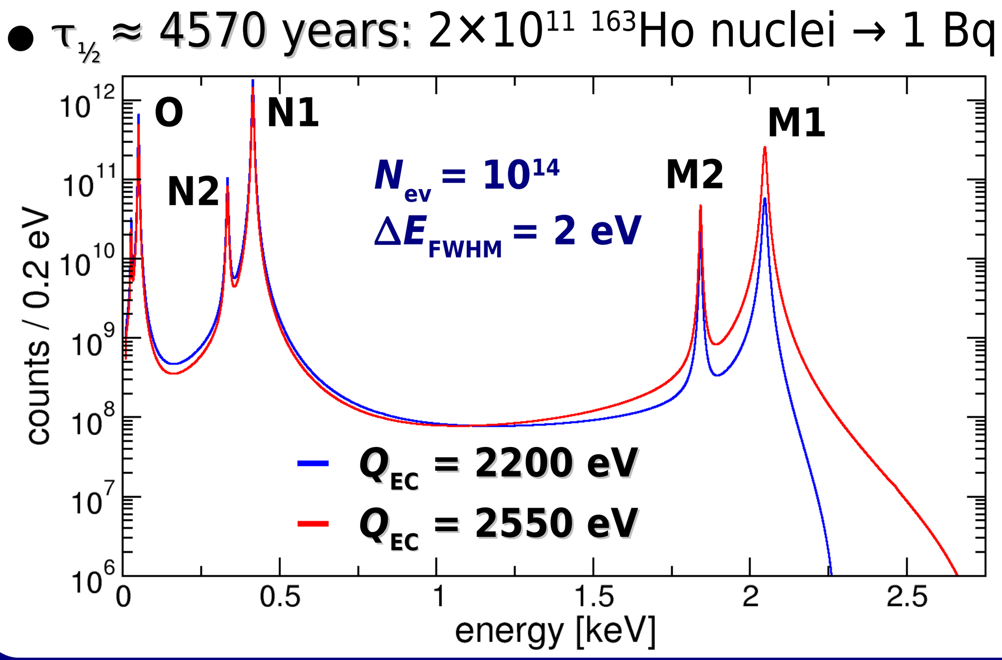
HOLMES
www
erc GA n. 340321

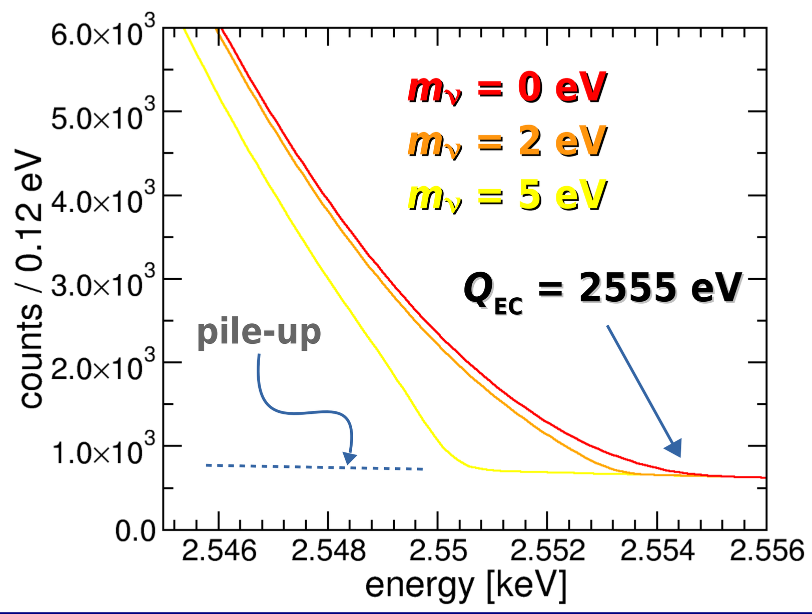
HOLMES is a new experiment to directly measure the neutrino mass with a sensitivity as low as 0.4 eV. **HOLMES** will perform a calorimetric measurement of the energy released in the electron capture decay of ^{163}Ho (A. De Rujula and M. Lusignoli, Phys. Lett. B 118 (1982) 429). The calorimetric measurement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

$^{163}Ho + e^- \rightarrow {}^{163}Dy^* + \nu_e$ $Q_{EC} \approx 2.5$ 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} = 2200÷2800 eV. Recommended: Q_{EC} = 2555 eV
- $\tau_{1/2} \approx$ 4570 years: 2×10^{11} ^{163}Ho nuclei → 1 Bq



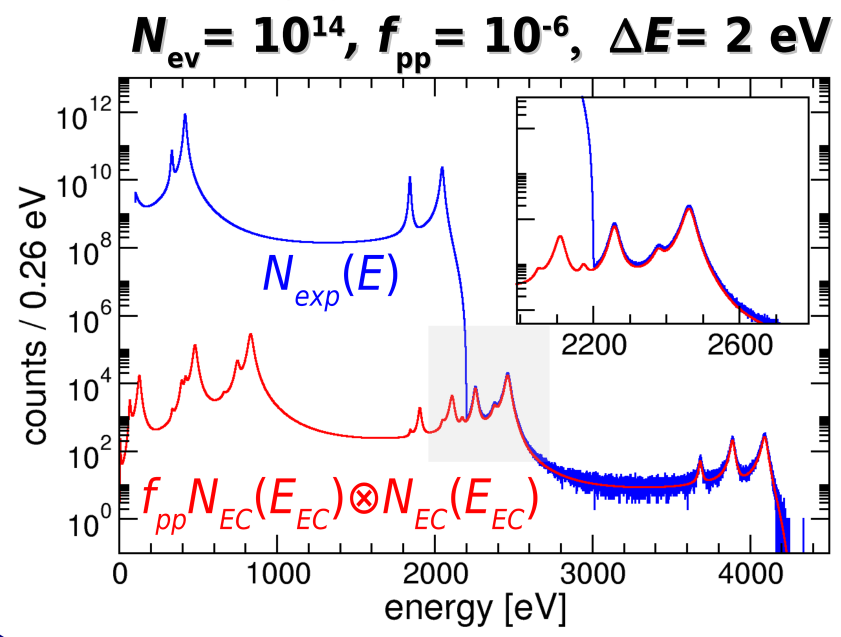


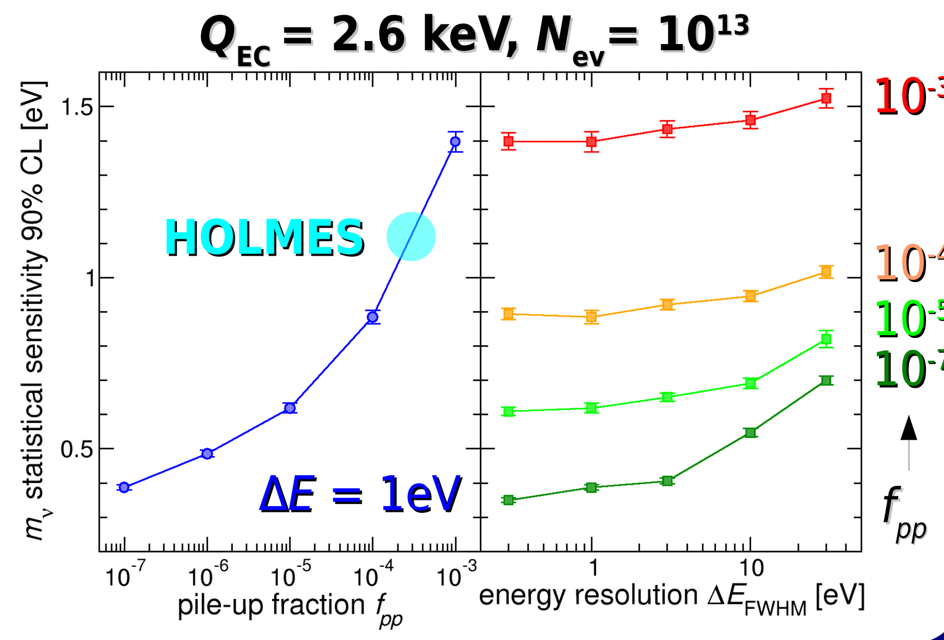
Statistical sensitivity Σ(m_ν) dependencies from MC simulations

- 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





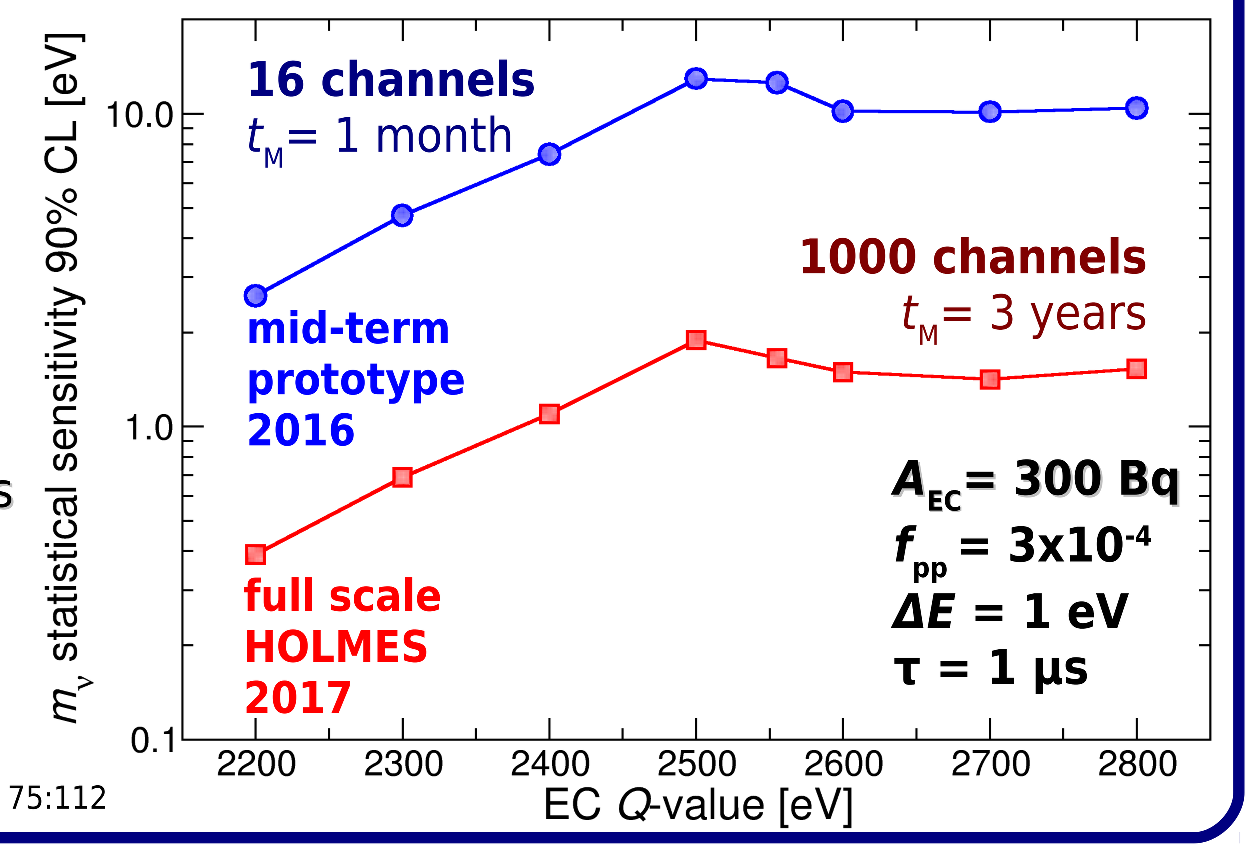
HOLMES goals

- 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

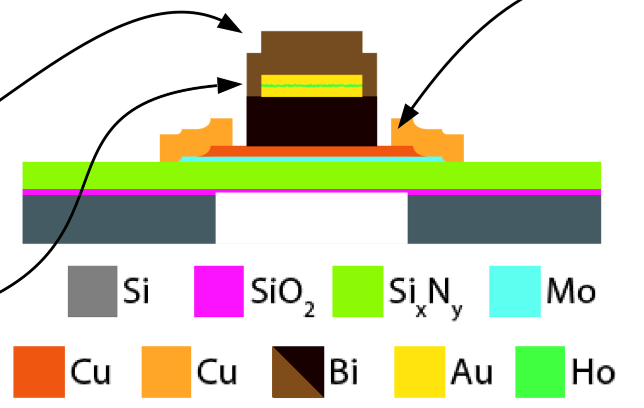
B. Alpert et al., Eur. Phys. J. C, (2015) 75:112

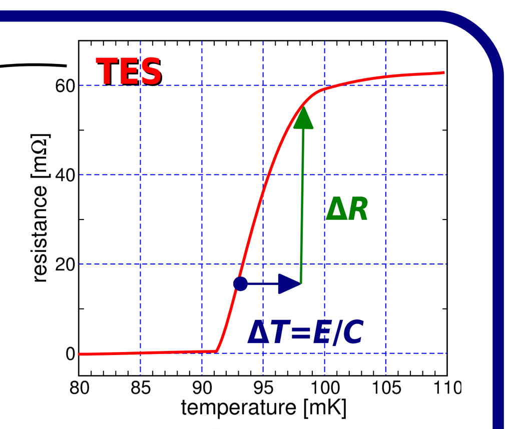


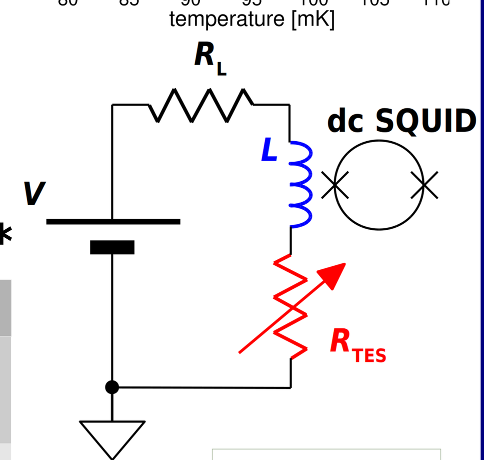
Detector R&D

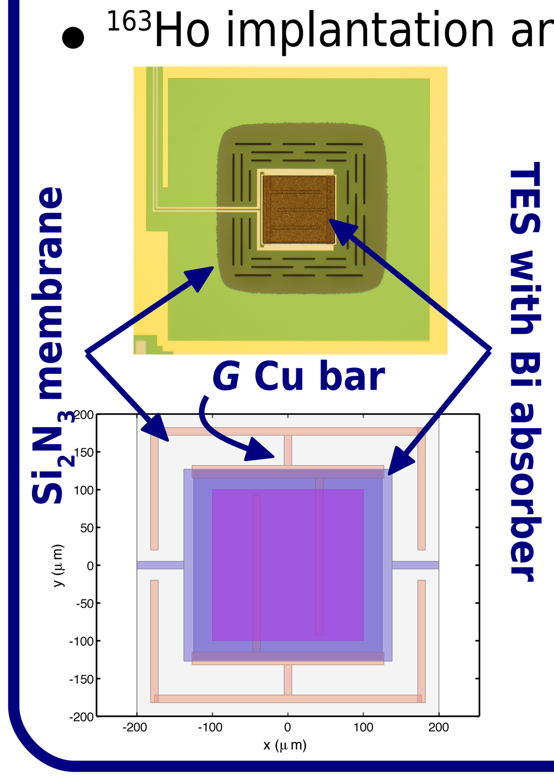
*see G. Pizzigoni poster

- Transition Edge Sensors (TES)
- MoCu bilayers → $T_c \approx$100mK
- 3 μm thick Bi absorber with ^{163}Ho/Au source for full absorbtion
- thin electrodeposited Au encapsulating implanted ^{163}Ho
- TES fabricated at NIST, Boulder, CO, USA
- ^{163}Ho implantation and Si_2N_3 membrane release at INFN Genova*



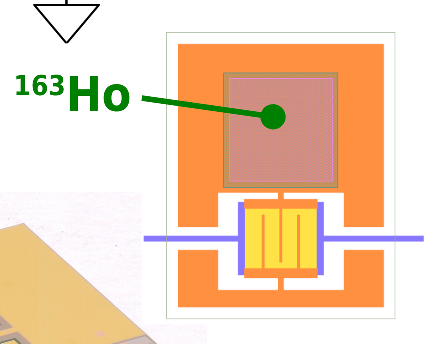


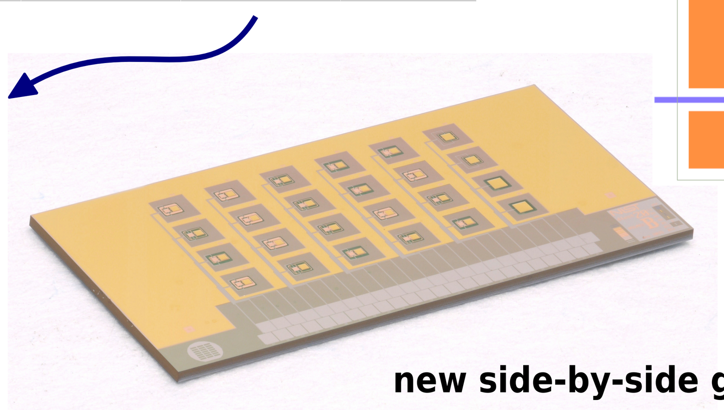




measured @ NIST					
L	C	G	τ_{rise} (peak)	τ_{decay} (peak)	ΔE (S/N)
[nH]	[pJ/K]	[pW/K]	[μs]	[μs]	[eV]
80	0.5	400	35	133	1.8

from model		
L	τ_{rise}	τ_{decay} (10-90%)
[nH]	[μs]	[μs]
40	3.6	154
60	6.4	142
80	9.5	127



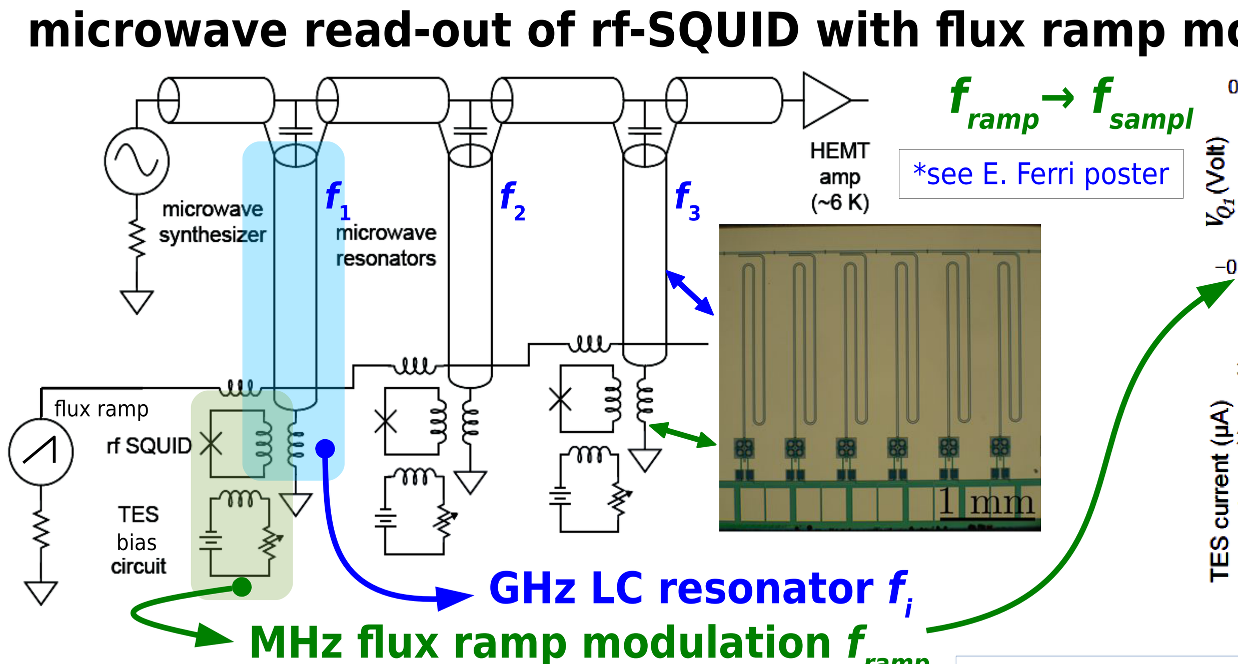


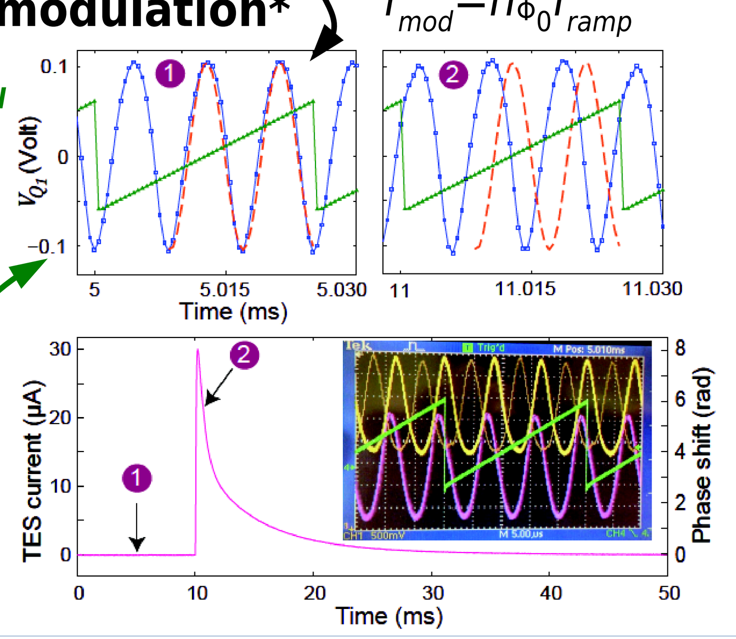
new side-by-side geometry

TES read-out and signal multiplexing

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

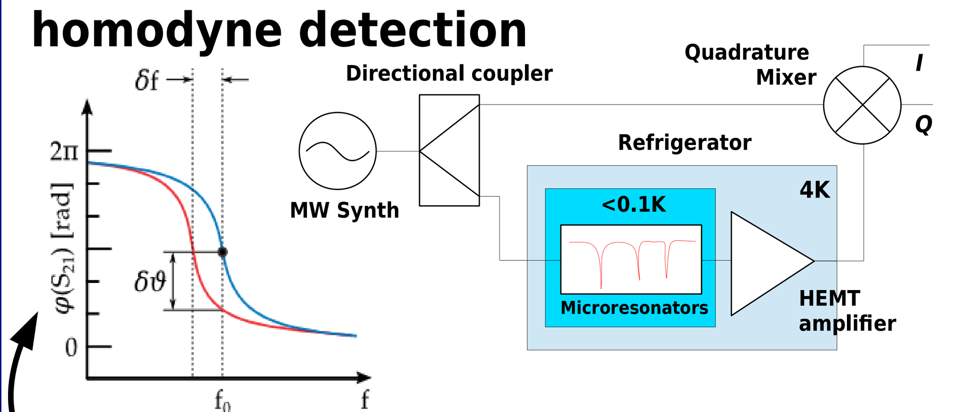
n_{Φ_0}=3 (n_{Φ_0}≥2)
$f_{mod}=n_{\Phi_0}f_{ramp}$





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 → $f_1 \oplus f_2 \oplus f_3 \oplus ... f_{N_{mux}}$
- down-conversion → digitization: f_{ADC} = 0.5 GHz
- required bandwidth per channel: f_{TES}
  - $f_{TES} = 2n_{\Phi_0}f_{sampl} \gtrsim 2n_{\Phi_0}(1/\tau_{rise})$
  - → $f_{TES} = 4n_{\Phi_0}(1/\tau_{rise})$

$N_{mux} = \frac{f_{ADC}}{5 f_{TES}}$ τ_{rise} = 5 μs, n_{Φ_0}= 2 → N_{mux} ≈ 50

Effective time resolution from MC simulations

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

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

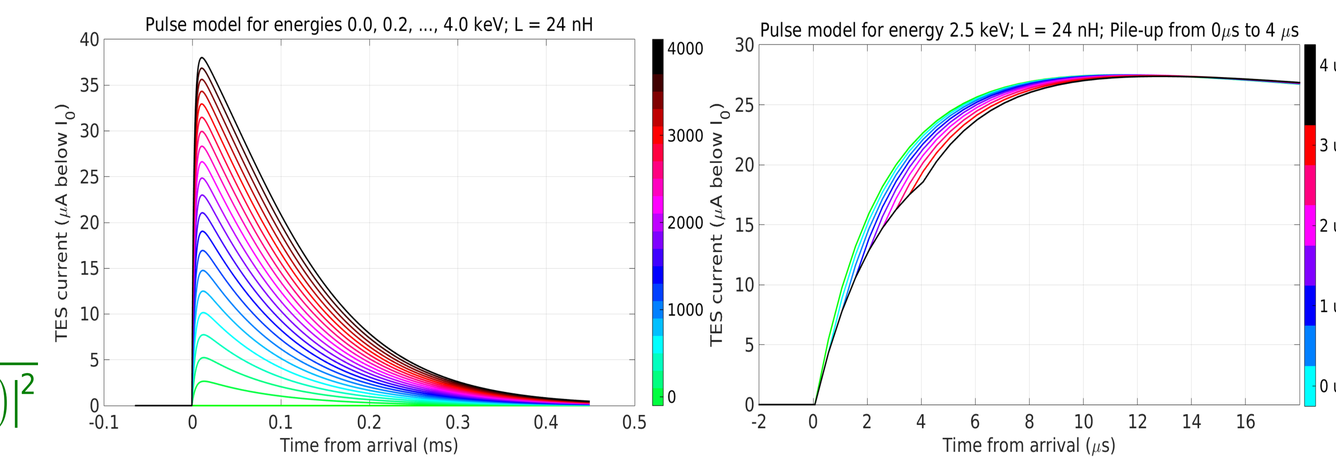
- generate realistic TES signals (→ E, τ_{rise}, τ_{decay}) solving differential equations
  - sampled records ($reclen$, n_{bit}, f_{sampl}) with signal pairs in realistic noise (→ ΔE)
    - $E_1+E_2 \in$[2.4 keV, 2.6 keV] (drawn from ^{163}Ho spectrum $N_{EC}(E_{EC})$), Δt ∈[0, 8τ_{rise}]

signal $S(\omega)$

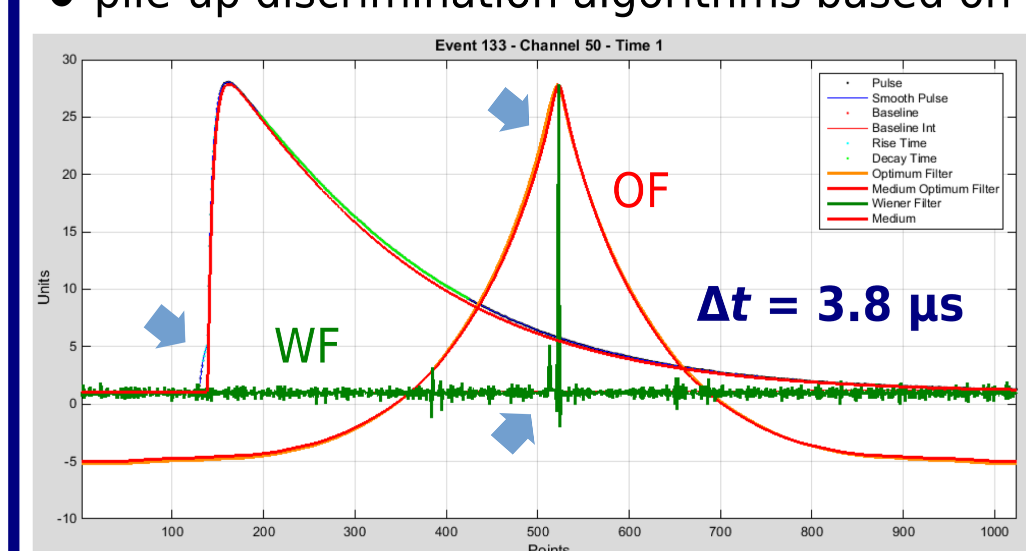
noise $N(\omega)$

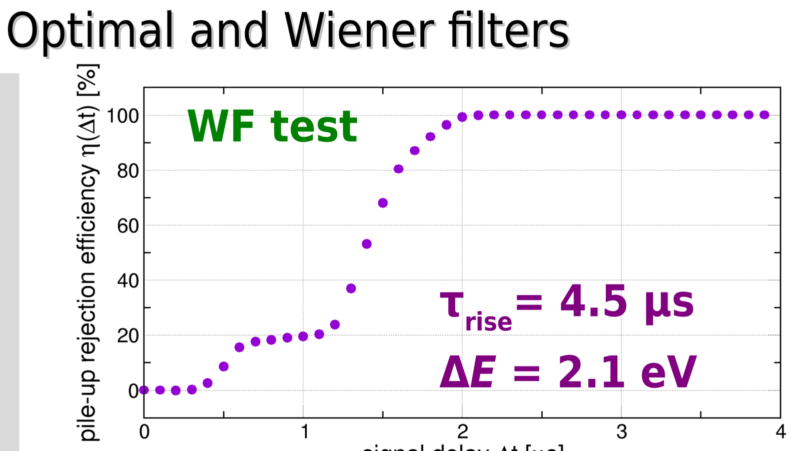
$$H_{OF}(\omega) \propto \frac{S^*(\omega)}{N(\omega)}$$

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



- pile-up discrimination algorithms based on Optimal and Wiener filters





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

n_{bit}=12
C = 0.5 pJ/K
G = 0.4 nW/K
τ_{dec}≈ 150 μs

L	τ_{rise}	f_{sampl}	reclen	OF test: τ_{eff}	WF test: τ_{eff}	ΔE @ 2047 eV
[nH]	[μs]	[MHz]	[sample]	[μs]	[μs]	[eV]
24	2.3	1	512	1.8	1.0	3.0
48	4.5	1	512	4.2	1.3	2.1