Microresonator Detectors for Neutrino Physics in Milano

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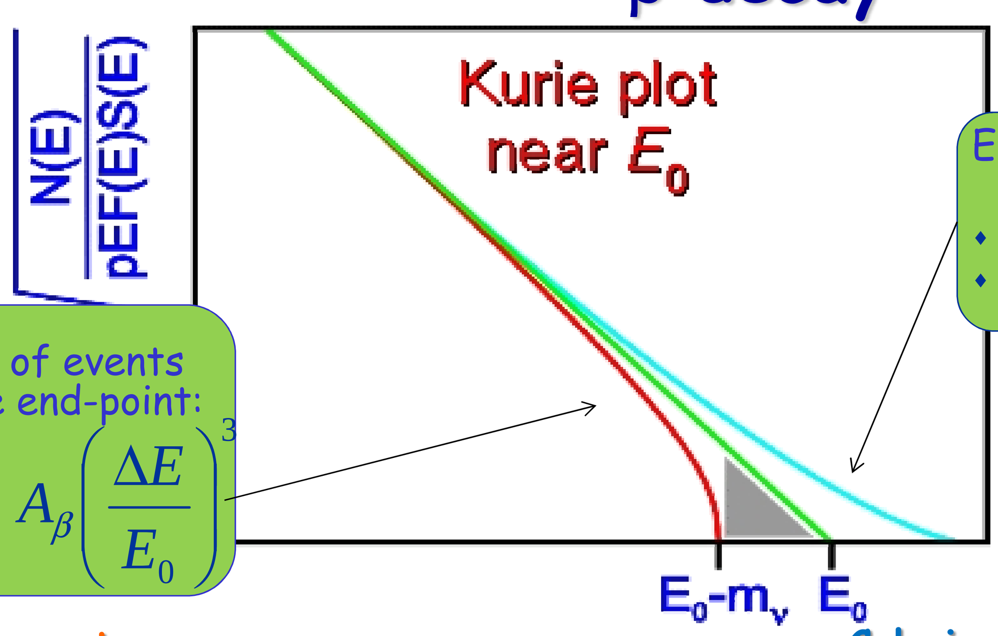
Direct and calorimetric measurement of m_ν: single β decay



Effect of real conditions:
- finite energy resolution
- background and pile-up events

Fraction of events under the end-point:

$$F_{\Delta E}(0) \approx A_\beta \left(\frac{\Delta E}{E_0}\right)^3$$

m_ν=$(\Sigma m_i^2 |U_{ei}|^2)^{1/2}$

Spectrometers: 2 eV with ^{3}H (E_0=18.6keV)
Calorimeters: 15 eV with ^{187}Re(E_0=2.47keV)

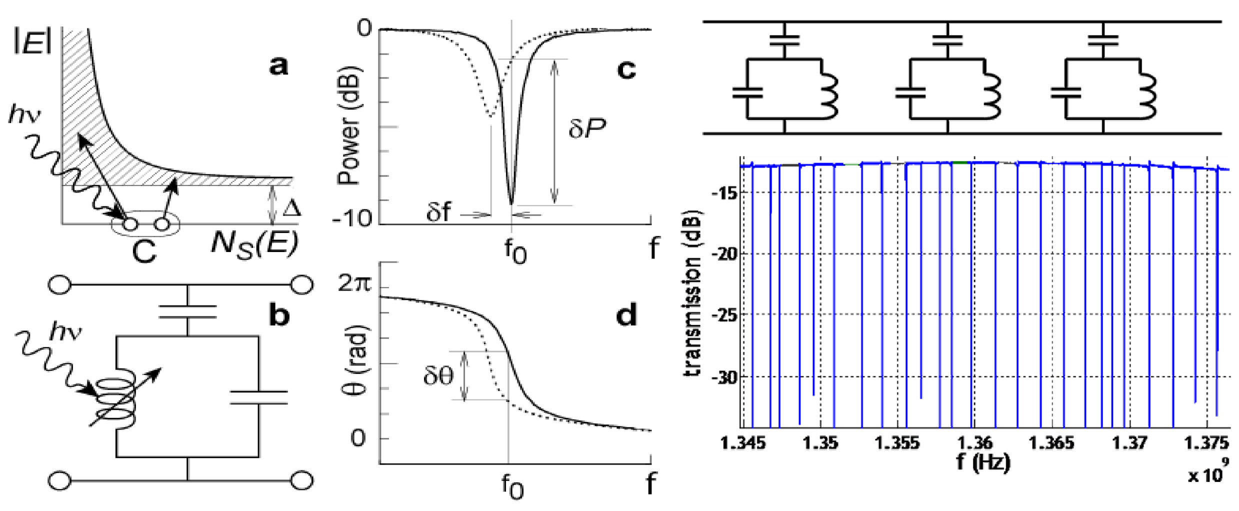
Spectrometers:
- High statistics
- The source is external to the detector
- Autoabsorption & backscattering
- Excited states not detected

Calorimeters:
- Source embedded in the detector
- No autoabsorption & backscattering
- Excited states (~ 100μs) detected
- Low statistics
- Pile up

Microresonator detectors

Ionizing particle E > 2Δ (gap parameter, ~meV)
↓
Cooper Pairs break
↓
Quasi-particles produced (N ~ hν/Δ)
↓
Complex conductance changes

$$\frac{\delta f_r}{f_r} = -\frac{\alpha}{2}\frac{\delta L_s}{L_s} \qquad \delta Q^{-1} = \alpha \frac{\delta R_s}{\omega L_s}$$



Every interacting particle events results in a resonant frequency and phase change

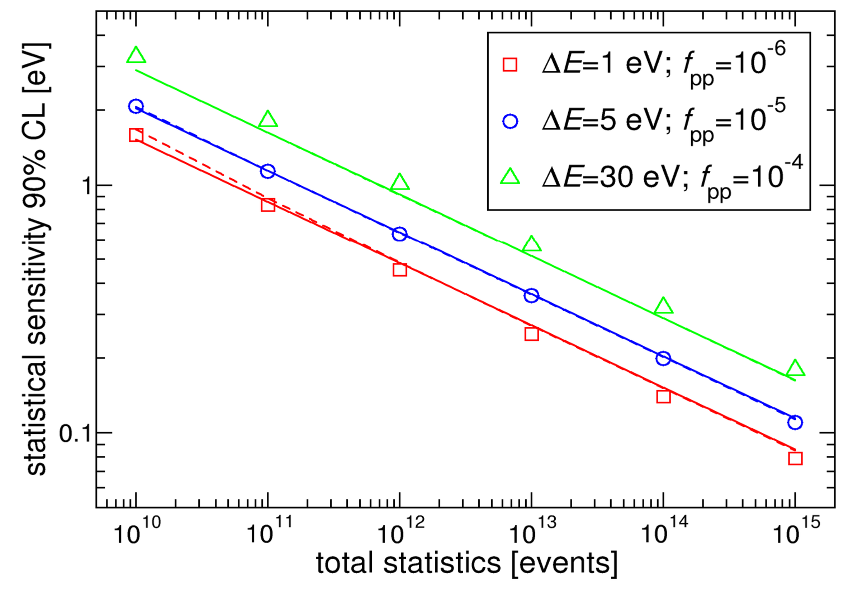
Microresonators work in frequency domain: with a single feedline coupled to a microwave amplifier thousands channels multiplex is possible

4-12 GHz cryo amp

Metal nitrides, especially TiN, possess properties consistent with high detector sensitivity

MARE Experiment

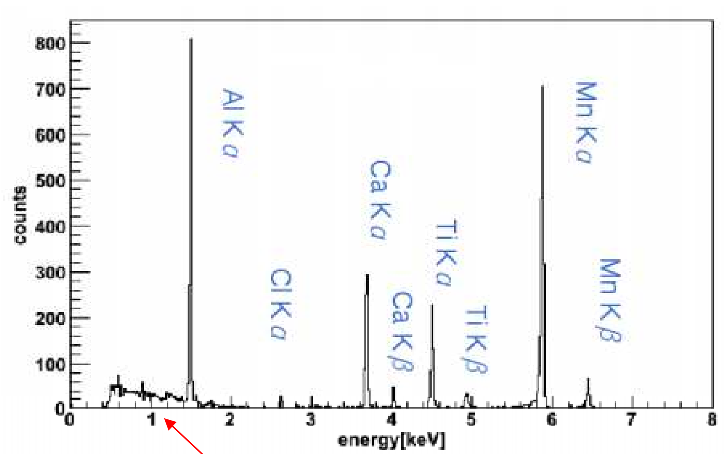
The international project MARE (Microcalorimeter Arrays for a Rhenium Experiment) aims at the direct and calorimetric measurement of the electronic antineutrino mass with sub-electronvolt sensitivity with a large number of detectors (~ 10^4) by studying the neutrino-involved decay.



A.Nucciotti, E. Ferri and O. Cremonesi Astropart. Phys., 34 (2010) 80 [arXiv:0912.4638v1]

Two possible nuclides:

• ^{187}Re: Q_β = 2,47 keV:



^{187}Re β spectrum with X-ray calibration peak

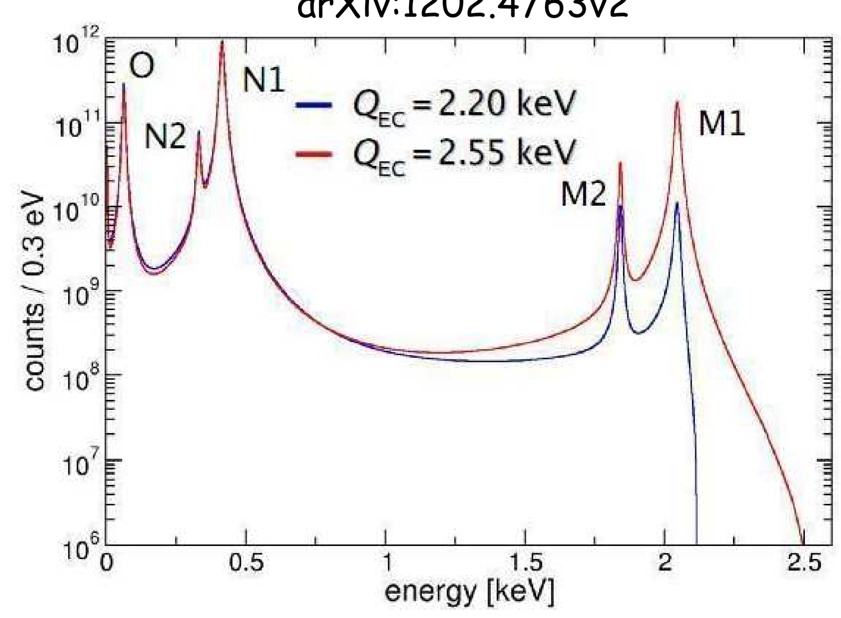
Requirements for both nuclides:
- High energy resolution (~ eV)
- Fast response detectors (~ tens μs) to avoid pile-up effects
- Multiplexable array detectors

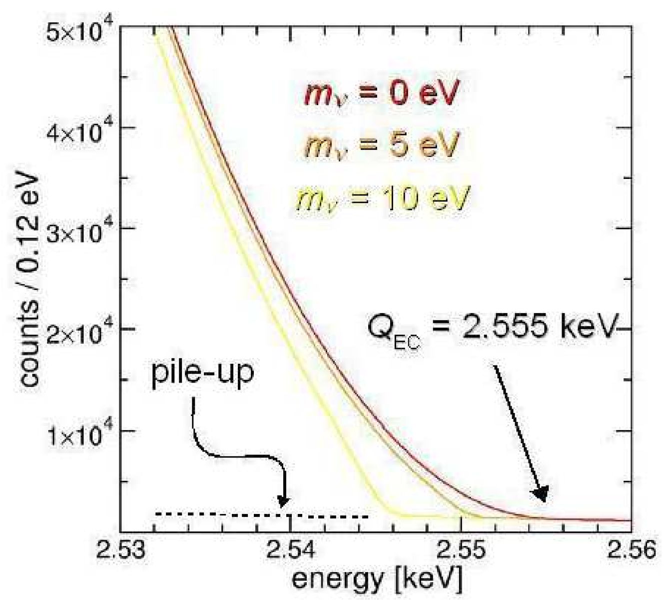
• ^{163}Ho: Q_{EC} ~ 2,3 ÷ 2,8 keV:

^{163}Ho + e$^-$ → ^{163}Dy* + ν_e A. De Rujula and M. Lusignoli, Phys. Lett. B 118 (1982) 429

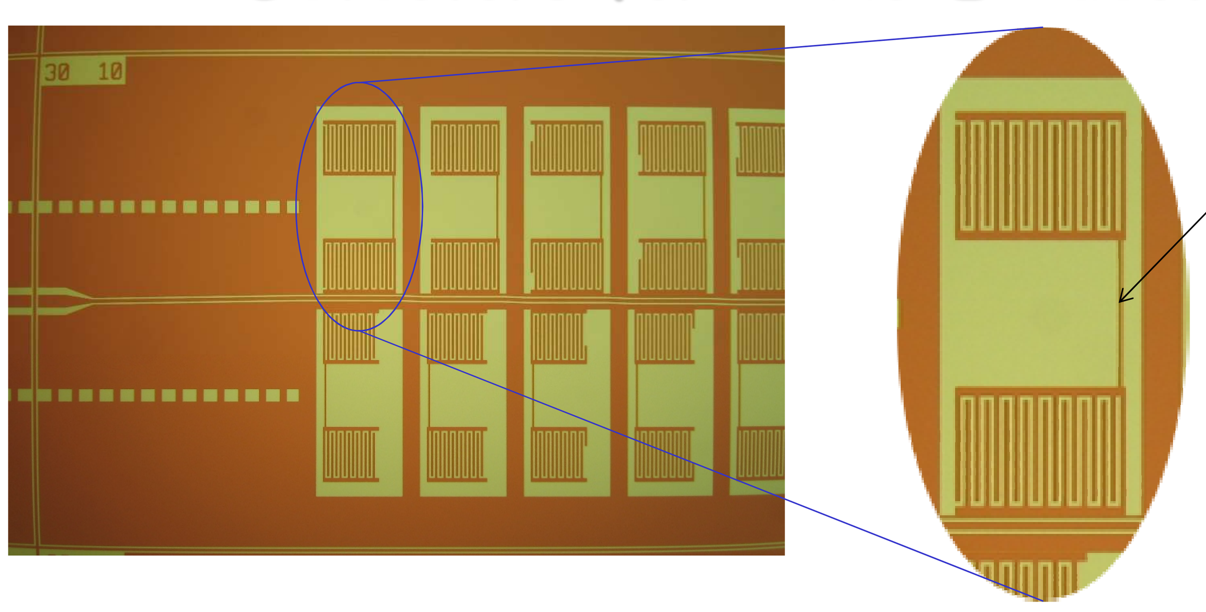
Measurement of Dy atomic de-exitation (mostly auger e$^-$)

M. Galeazzi, F. Gatti, M. Lusignoli, M. Nucciotti, S. Ragazzi, M. Gomez, arXiv:1202.4763v2





Detectors for ^{163}Ho EC decay endpoint measurement



The length of the inductive section is much shorter than the wavelength at resonator frequency, ensuring uniform response.

The ^{163}Ho will be embedded in the inductive part of the resonator. 10^{12} Ho nuclei are needed for a count rate of 10 Hz

The Ho needs to be deep enough to ensure low escape probability for 2 keV electrons.

But very thick films are difficult to grow

Nitrides with like TiN, TaN and HfN, will be investigated
A thickness of ⇒ 0.5μm can be enough

The fundamental noise of a pair-breaking detector for phonon counting applications is set by the statistics of the energy cascade process that produces quasi-particles and low energy phonons:

$$N_{qp} = \eta h\nu/\Delta \sim \eta h\nu/(1.75 k_B T_c)$$

Considering a sensor material with T_c = 4.6K, and assuming a typical conversion efficiency of 0.6, for a 2 keV decay event $N_{qp} \approx 1.7\cdot10^6$ quasi particles are produced; we expect then a theoretical resolution

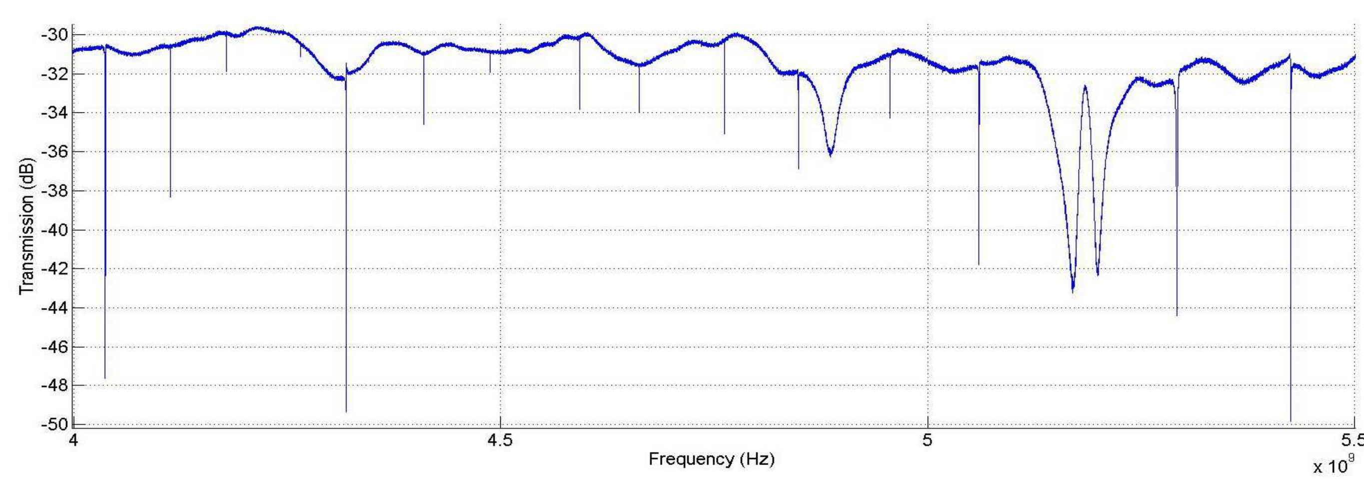
$$\Delta E_{th} = 2keV/N_{qp}^{1/2} = 1.5\ eV$$

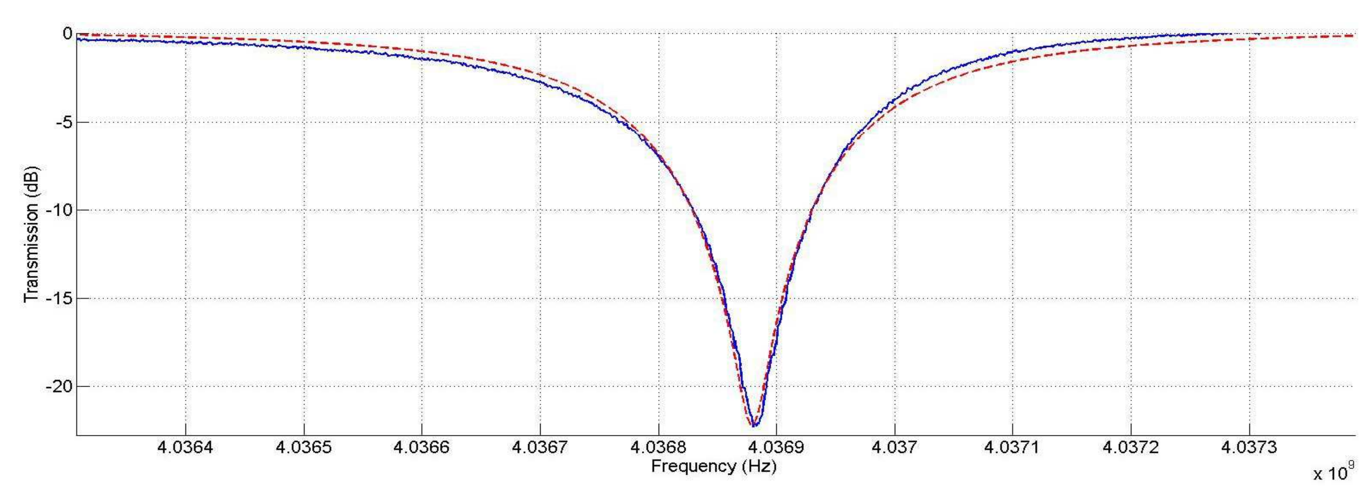
Considering also the Fano factor (F < 1), the theoretical energy resolution will be slightly better.

Stoichiometric nitrides metals have a high T_c ⇒ recombination time becomes too short, increasing the recombination noise: $(N_{qp}/\tau_R)\Delta^2$

↓

Sub-stoichiometric materials, with lower T_c, are considered





Resonances can be fitted by the analytical formula:

$$T_{21} = C(f)\left[1 - \frac{\frac{Q}{Q_c} e^{i\phi_0}}{1 + 2jQ\left(\frac{f - f_0}{f_0}\right)}\right]$$

Jiansong Gao, Fitting the resonance data from network analyzer, 2005, (unpublished manuscript)

For our resonators, we obtained Q = $7\cdot10^4$÷10^5 and Q_c = 10^5÷10^6.
Consequently, since Q^{-1}=Q_c^{-1}+Q_i^{-1}, Q_i = $2\cdot10^5$÷ $4\cdot10^5$

Sweeping the temperature from 30mK up to ~1K it is possible to extract the gap parameter. For TiN a gap parameter of 0.7 meV has been measured, wich, accordingly to the BCS theroy, means T_c ~ 4.6K.

Poster presented at 12th Pisa Meeting on Advanced Detectors – Elba 2012