MARE: Status and Perspectives

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for the Collaboration MARE

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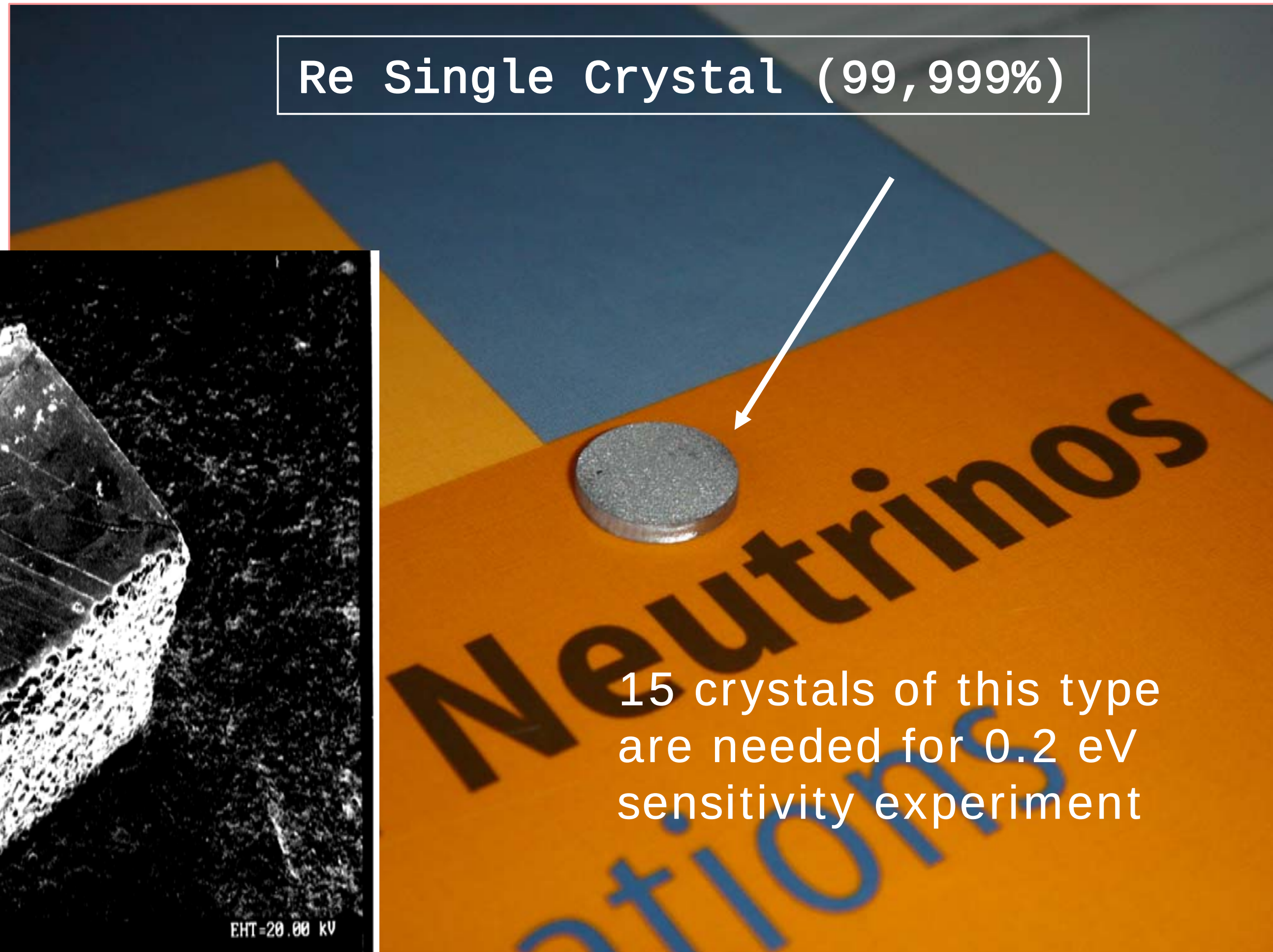
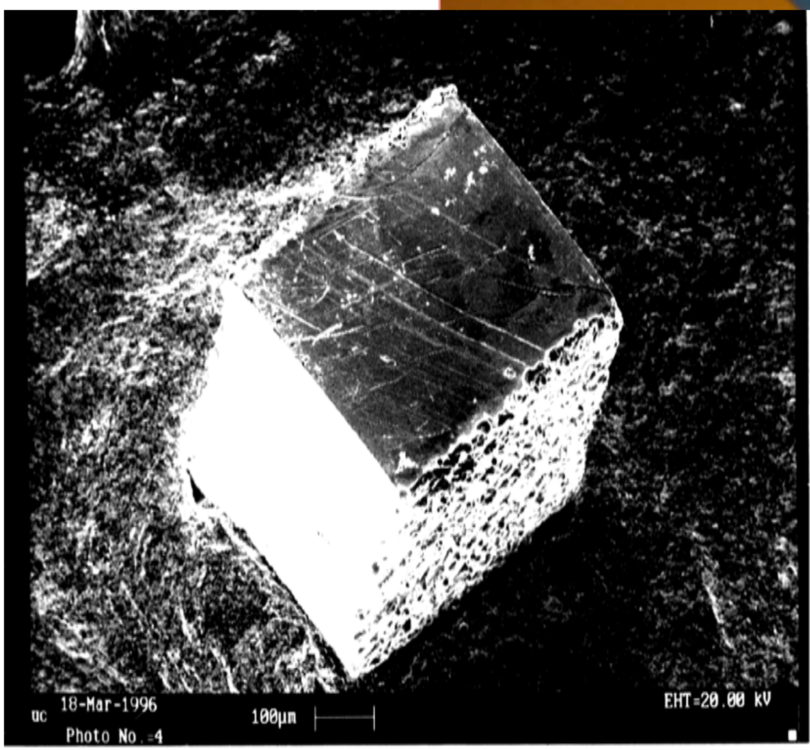
MARE: a LTD experiment in R&D

MARE: Microcalorimeter Arrays for a Rhenium Experiment

Università di Genova e INFN Sez. di Genova
Goddard Space Flight Center, NASA, Maryland, USA
Kirkhhof-Institute Physik, Universität Heidelberg, Germany
Università dell'Insubria, Università di Milano-Bicocca e INFN Sez. di Milano-Bicocca
NIST, Boulder, Colorado, USA
ITC-irst, Trento e INFN Sez. di Padova
PTB, Berlin, Germany
University of Miami, Florida, USA
Università di Roma “L a Sapienza” e INFN Sez. di Roma1
SISSA, Trieste
Wisconsin University, Madison, Wisconsin, USA
...

Rhenium (63% ^{187}Re)

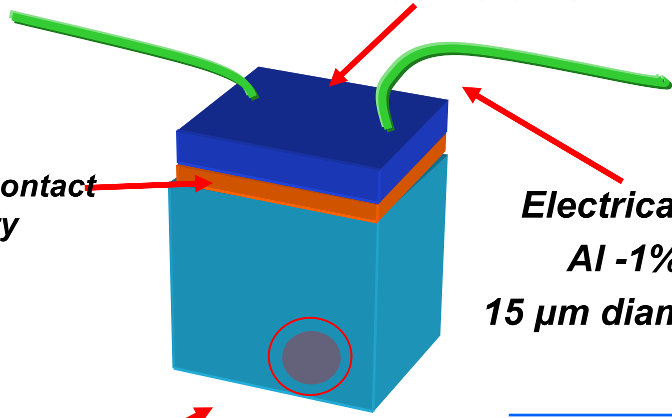




Calorimetric spectroscopy

Thermistor
Ir-Au TES on Si

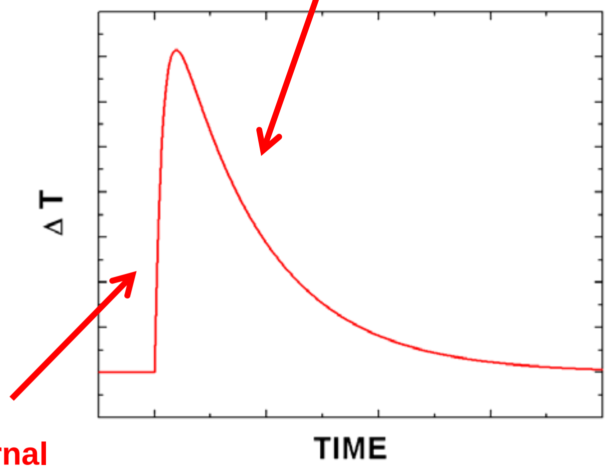
Thermal contact
High purity
epoxy



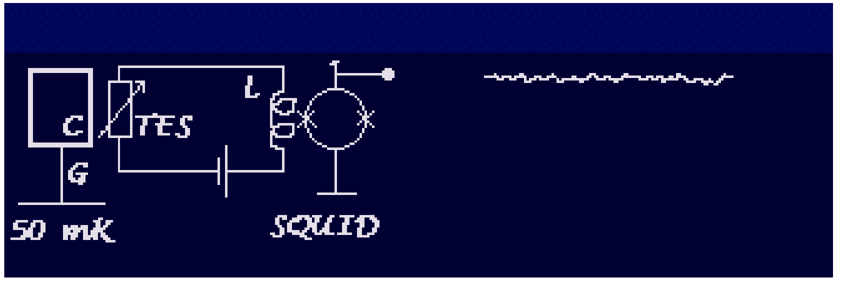
Electrical & Heat link
Al -1% Si wires
15 μm diam., 1mm lengt

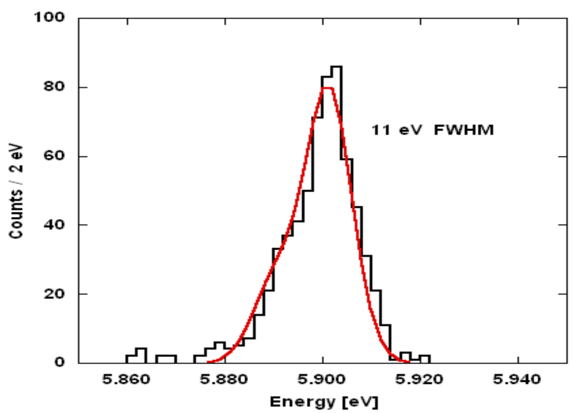
Re Crystal
surfaces cleaned to optical level
annealed at 1300ºC in UHV

FALL TIME
(Depends on C, G, Bias Power)



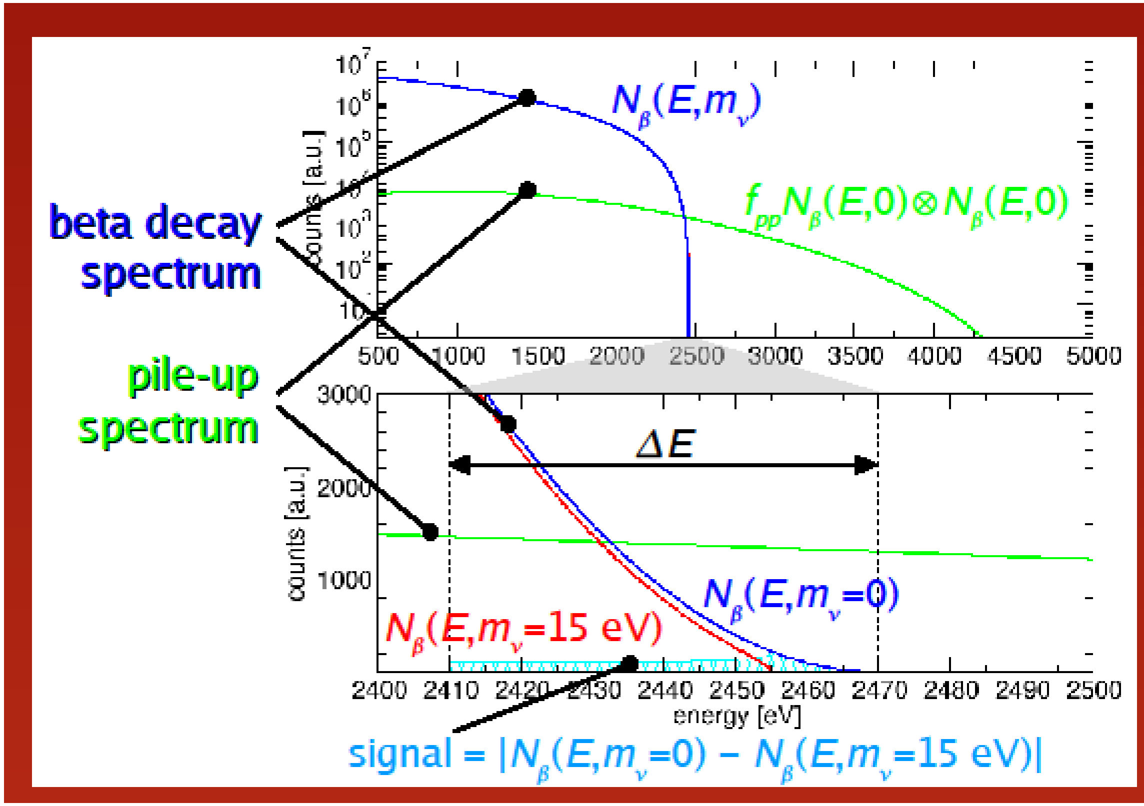
RISE TIME
(Depends on internal Parameter Absorber-TES)



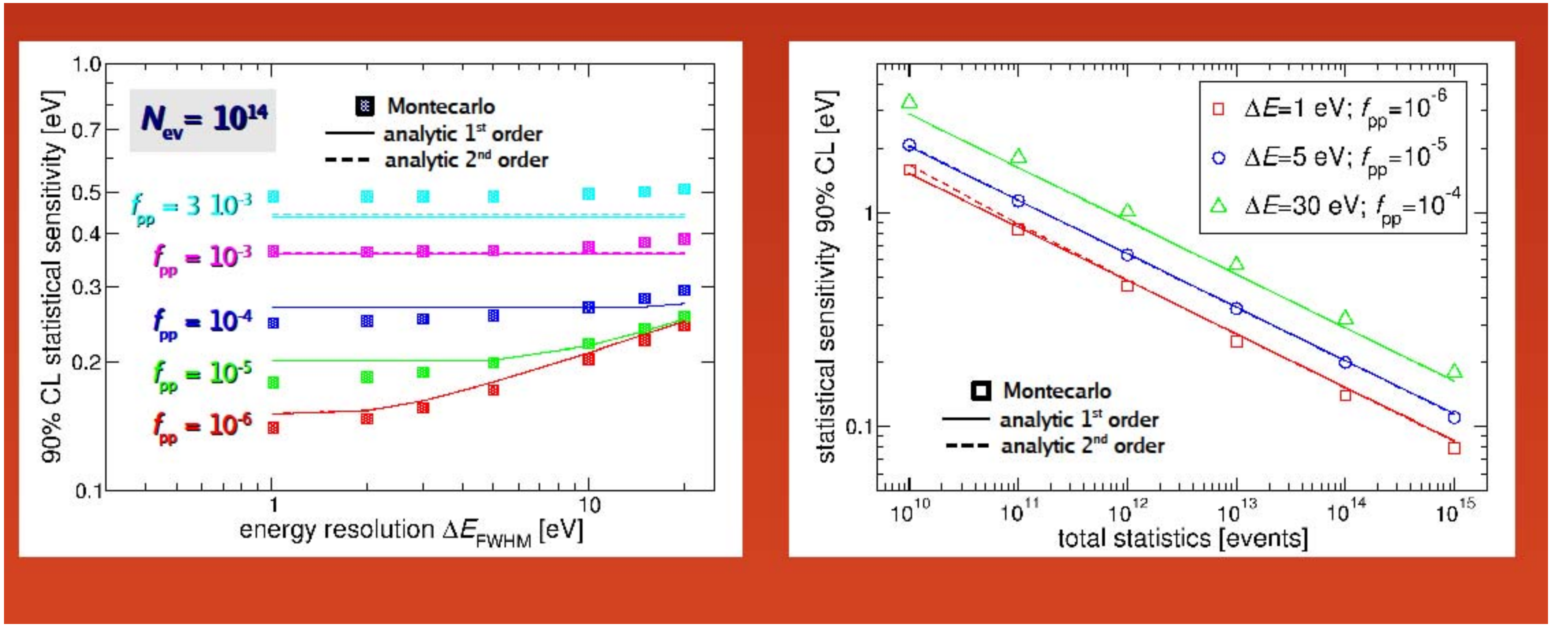


MARE measurement challenges

- Statistics → 10^{14}
- Unresolved pileup → 10^{-7}
- Energy Resolution → 1 eV
- Energy calibration → 10^{-4}
- Background → negligible!
- BEFS → know at very precise level
- Possible unknown systematics → under continuous investigation (we are at the frontiers…)



Sensitivity and uncertainties of array based experiment

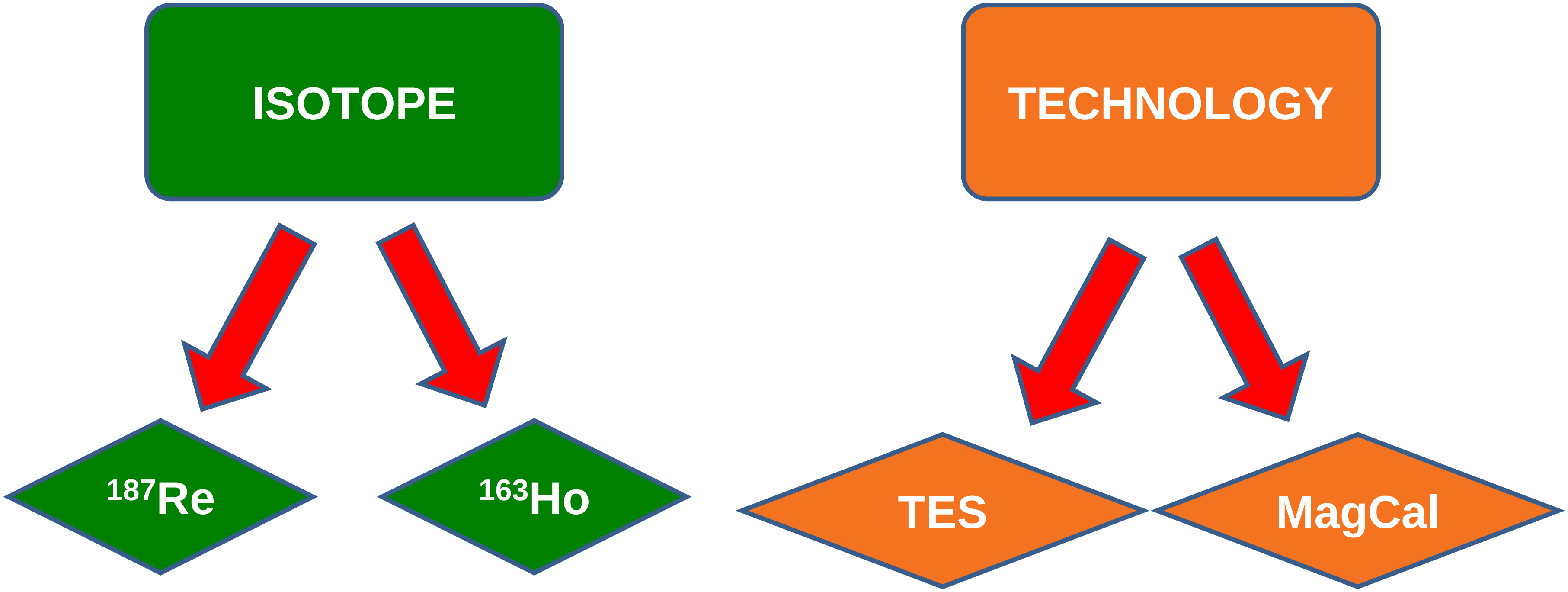


source of uncertainty	*quantity describing the uncertainty*	*maximum uncertainty for $\Delta m_\nu^2 < 0.01\ eV^2$*
error on energy resolution ΔE	$\sigma_{err}(\Delta E)/\Delta E$	0.02
error on single pixel energy calibration K	$\sigma(K)/K$	0.0004
spread in energy resolution ΔE in the array	$\sigma_{spread}(\Delta E)/\Delta E$	0.1
underlying constant background	N_{bkg}/N_{ev}	10^{-8}

A.Nucciotti

MARE-I: assessment of methods and technology

- The full MARE experiment is still in the R&D phase and multiple options are being evaluated.
- Mainly: 2 options for β–isotopes, 2 option for the detector technology

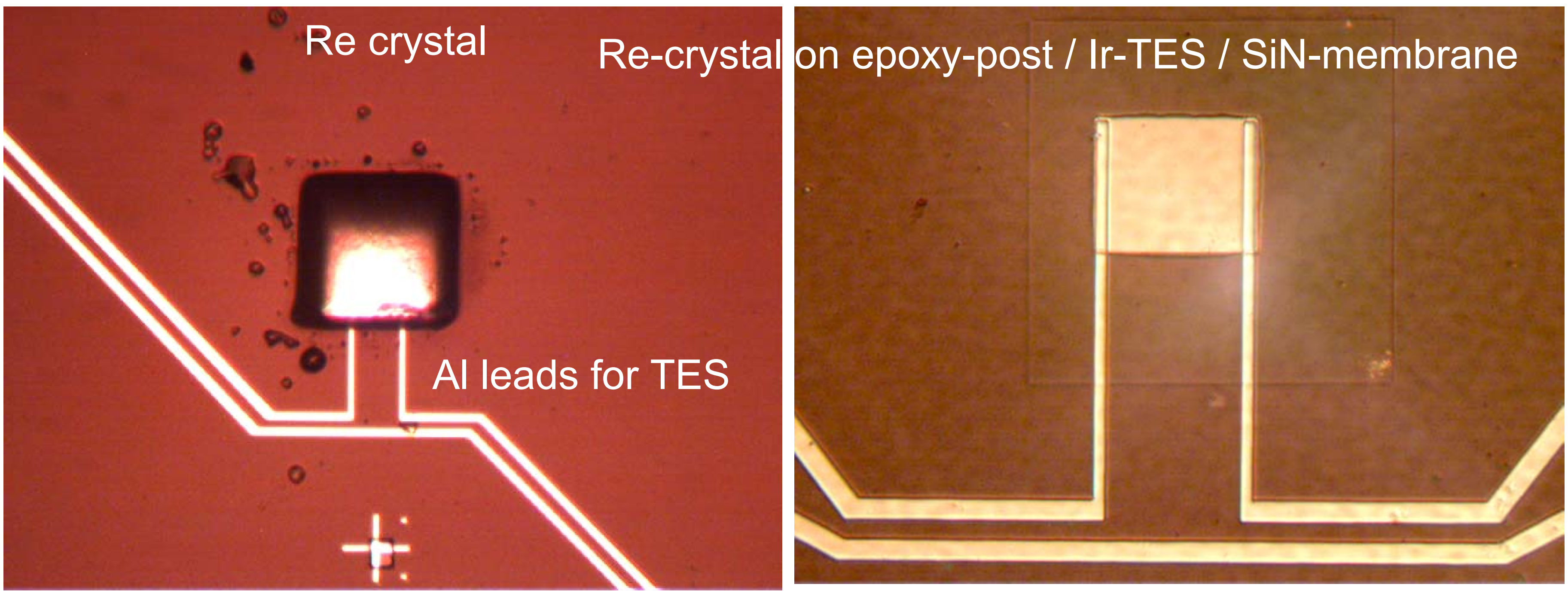


Current Developments

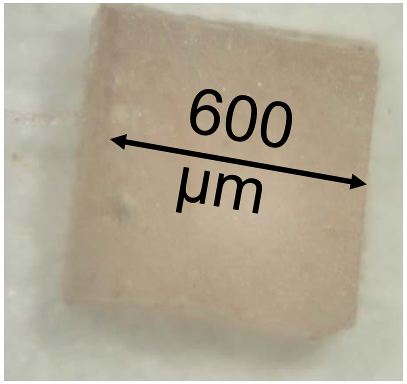
- Re-TES array: Genoa, Miami
- AgReO –Si array: Milan-Wisconsin-Goddard
- MUX Readout: PTB-Genoa
- Kinetic Inductance Sensors: Como-IRST-Trento
- Magnetic Calorimeter: Heidelberg
- GEANT simulation and data Analysis: U.Florida-Miami
- MC modeling for experiment design: Milan
- Ho-163: Genoa-Lisboa/ISOLDE CERN-Goddard)
- Production and study of E.C. isotopes:GSI

Re-TES detector prototypes (Genoa)

- Improve detector pulse rise-time to usec;
- Improve energy resolution from 10 eV (presently) to few eV;
- Large arrays (K-pixels) in order to achieve 10^4 -10^5 detectors in small volume;
- Provide an array design fully compatible with the requirements of a high precision experiment (high reproducibility, stability, fully energy calibrated,…);
- Multiplexed read-out with large bandwidth (> 300 KHz) per channel;

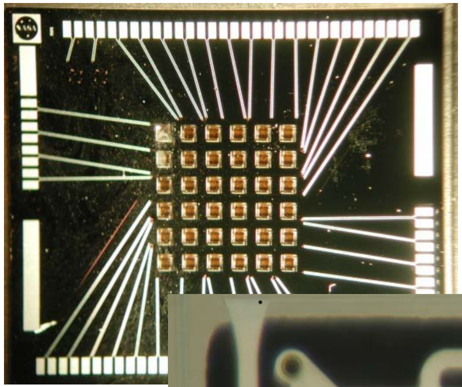


Pilot experiment of 72 detector array (Milan)



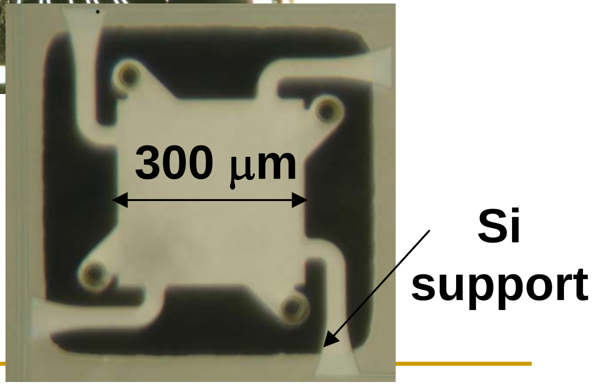
Single crystal of silver perrhenate ($AgReO_4$) as absorber

- mass ~ 500 mg per pixel (Ab~ 0.3 decay/sec)
- regular shape (600x600x250 mm3)
- low heat capacity due to Debye law

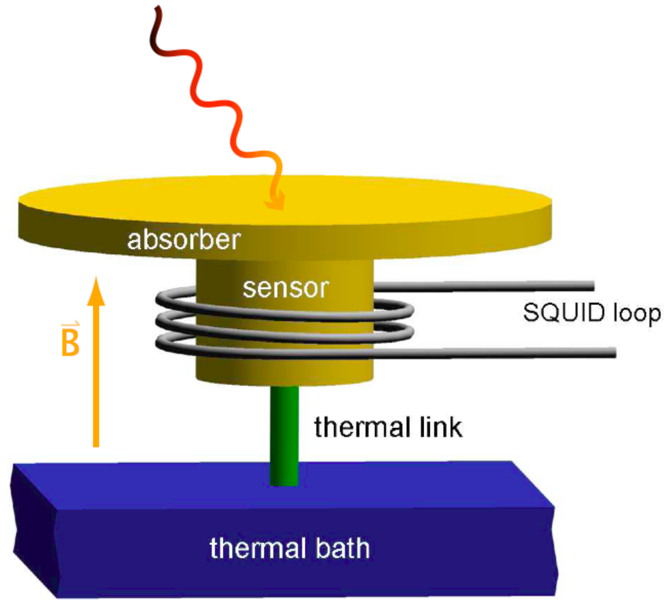


6x6 array of Si thermistors (NASA/GSFC)

- pixel: 300x300x1.5 mm3
- high energy resolution
- developed for X-ray spectroscopy



Metallic Magnetic Calorimeters



❖ Operation at low temperatures (T<100mK)

small heat capacity

large temperature change

small thermal noise

❖ Main differences to resistive calorimeters

no dissipation in the sensor

no galvanic contact to the sensor

temperature rise upon absorption:

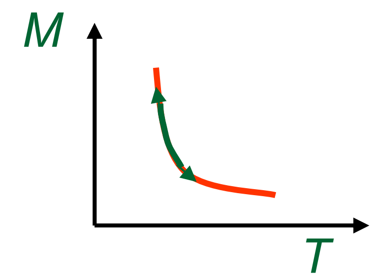
$$\delta T = \frac{E}{C_{\mathrm{tot}}}$$

recovery time:

$$\tau = \frac{C_{\mathrm{tot}}}{G}$$

paramagnetic sensor:

Au:Er



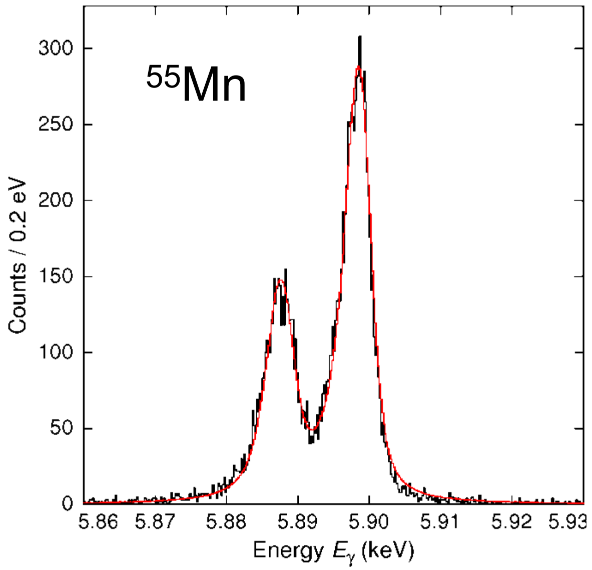
signal size:

$$\delta M = \frac{\partial M}{\partial T}\delta T = \frac{\partial M}{\partial T}\frac{E_\gamma}{C_{\mathrm{tot}}}$$

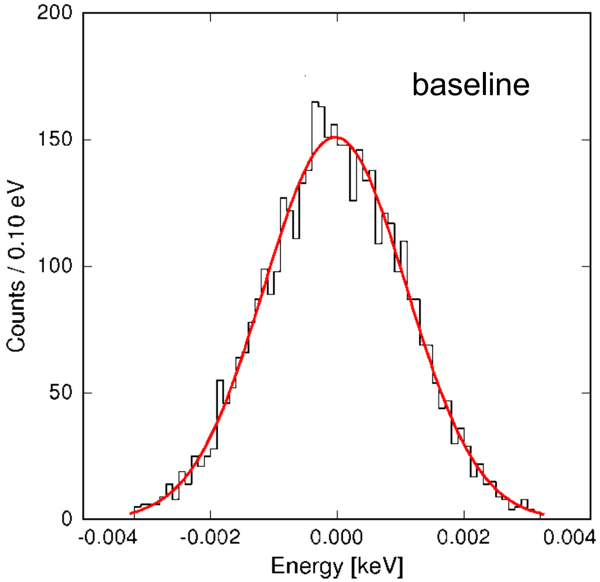
❖ Planar sensors on meander shaped pickup coils

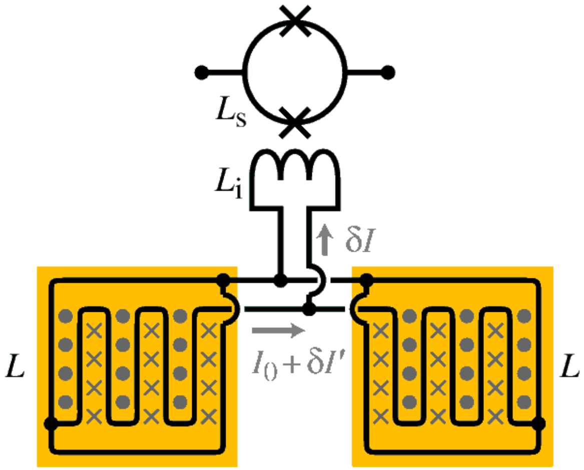
❖ Energy resolution

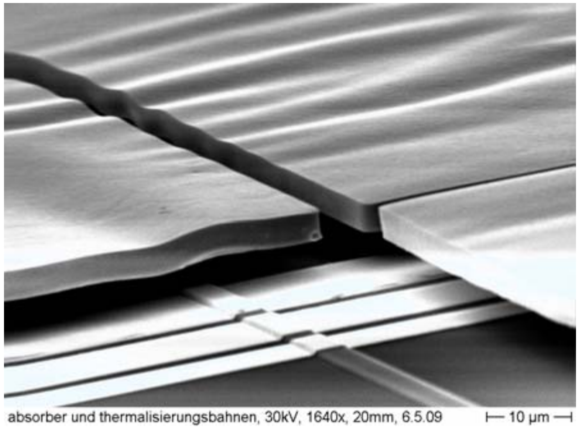
ΔE_{FWHM} = 2.8 eV @ 6 keV



ΔE_{FWHM}= 2.65 eV @ 0 keV



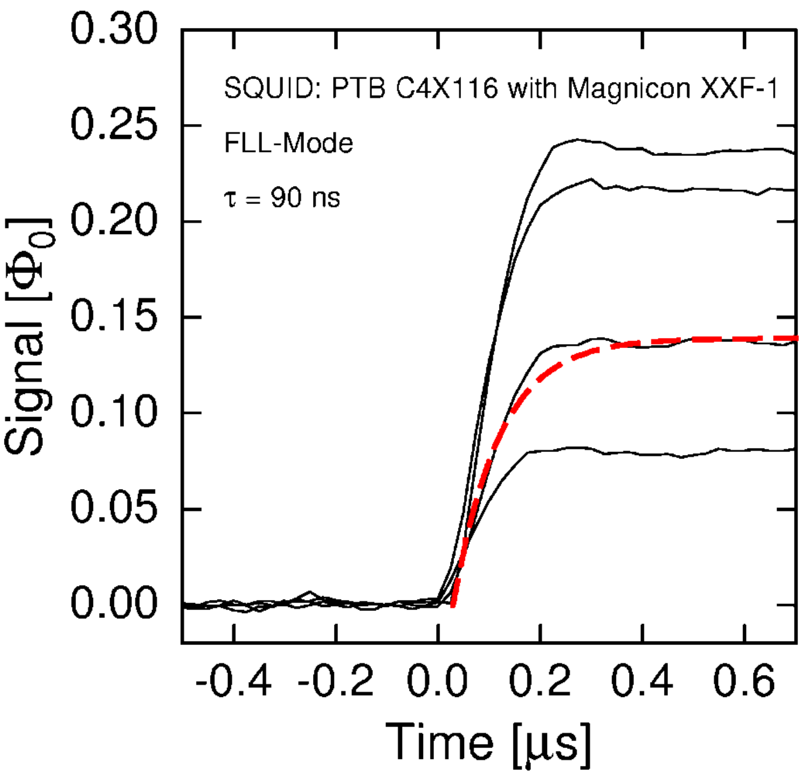


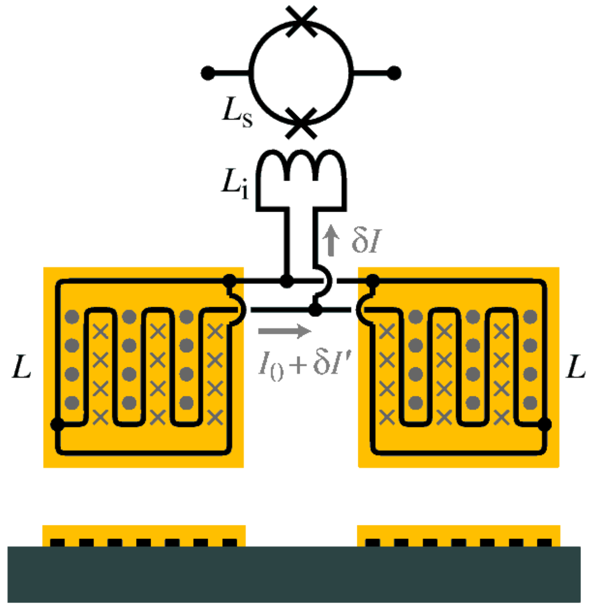


→ Expected energy resolution for next produced detectors <2 eV

Micro-fabricated x-ray detectors

- Planar sensors on meander shaped pickup coils
- Energy resolution
- Rise time



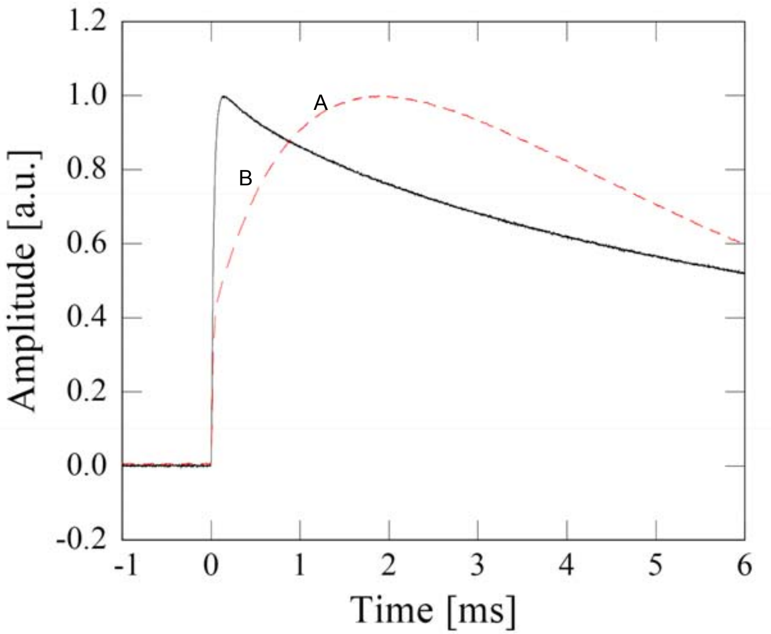


rise time: 90 ns @ 30 mK
as expected from Korringa-constant for Er in Au

MMC for Neutrino Mass experiments

❖ Optimization of MMCs with superconducting rhenium absorber

- minimization of the rise-time
- investigation of energy down-conversion in superconducting absorbers
- investigating the energy resolution achievable with superconducting absorber



Improvements in the rise-time:
A.manualy assembled detector ~1ms
B.sensor deposited directly on the Re absorber ~20μs

Achievable rise-time ≤1μs

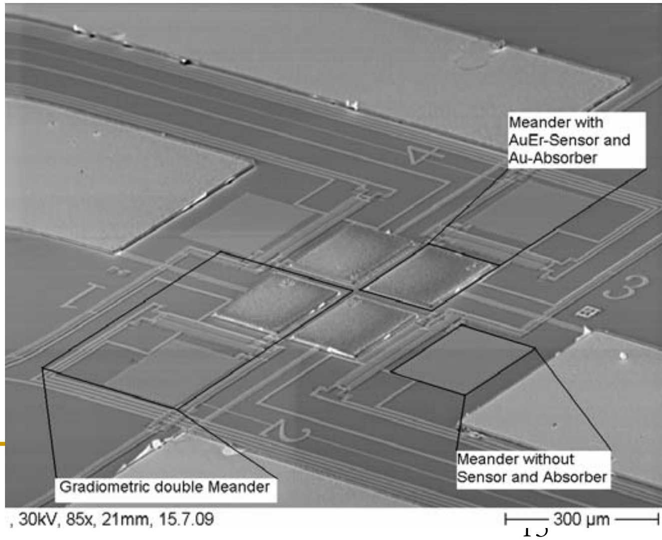
MMC for Neutrino Mass experiments

- Optimization of MMCs with superconducting rhenium absorber

  - minimization of the rise-time
  - investigation of energy down-conversion in superconducting absorbers
  - investigating the energy resolution achievable with superconducting absorber

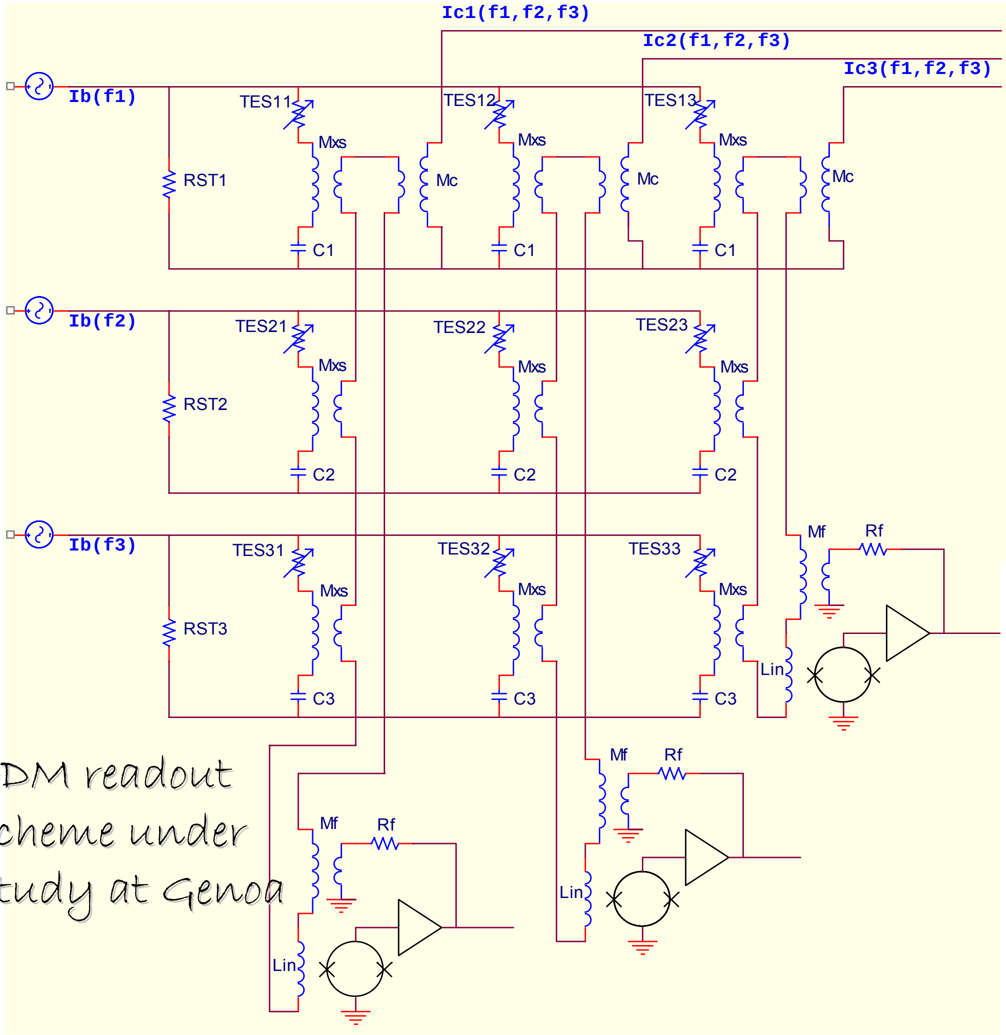
- Calorimetric investigation of new candidates for the neutrino mass direct measurements by electron capture decay

  - ^{163}Ho, ^{157}Tb, ^{194}Hg, ^{202}Hg
  - Development of micro-structured MMCs for ion implantation at ISOLDE
  - First detector with implanted ^{163}Ho ready to run

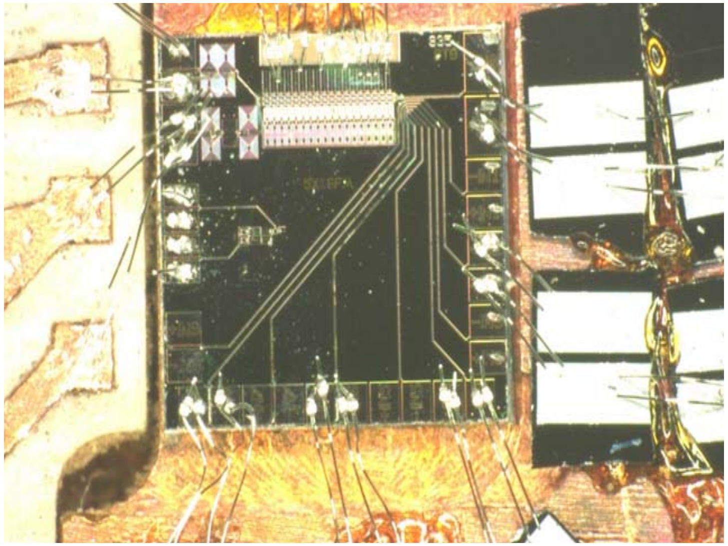


Genoa-PTB development on MUX readout

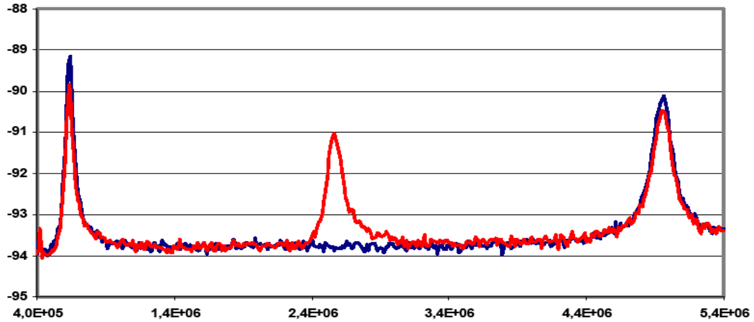
Enhanced Bandwidth requirement respect to X- ray det. readout



FDM readout scheme under study at Genoa

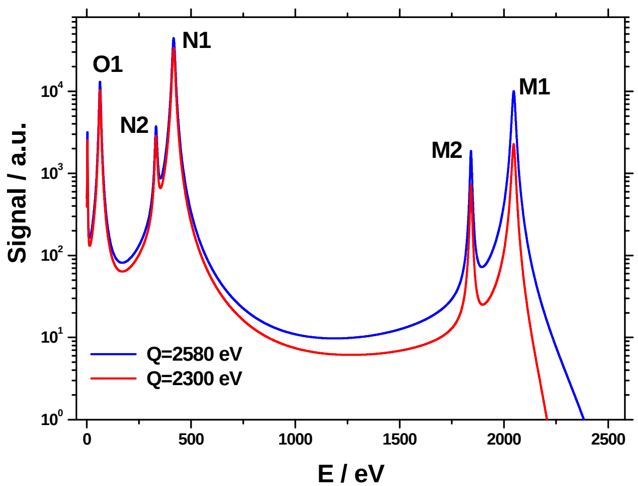


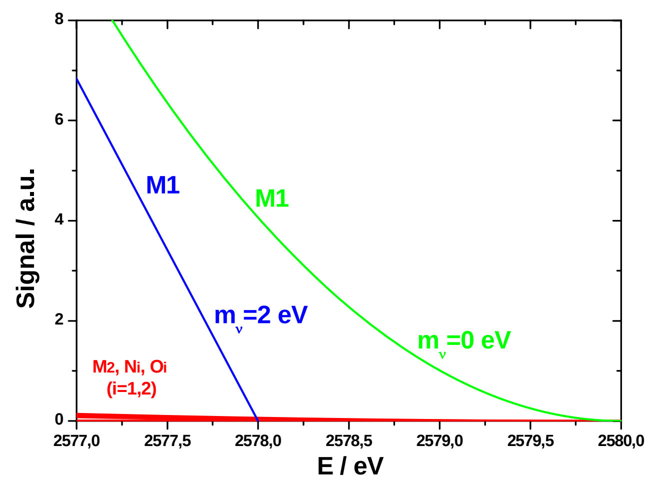
PTB SQUID under test at Genoa



A second isotope for neutrino mass calorimetric measurements: ^{163}Ho

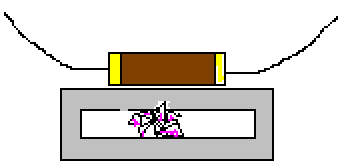
- We have already (10 year ago) performed some test experiment with Ho-163 (F.Gatti, etal.1997)
- $^{163}Ho \rightarrow ^{163}Dy^{*} + \nu_e$
- $^{163}Dy^{*}$ decays via Coster-Kronig transition nS, $nP_{1/2}$
- Breit Wigner M,N,O lines have an end-point at the Q value→ finite neutrino mass causes a kink at the end-point similarly to beta spectra of 187-Re.
- The major issue has been the preparation of the absorbers and the overall detector performance that was unsatisfactory due to the not uniform absorber.

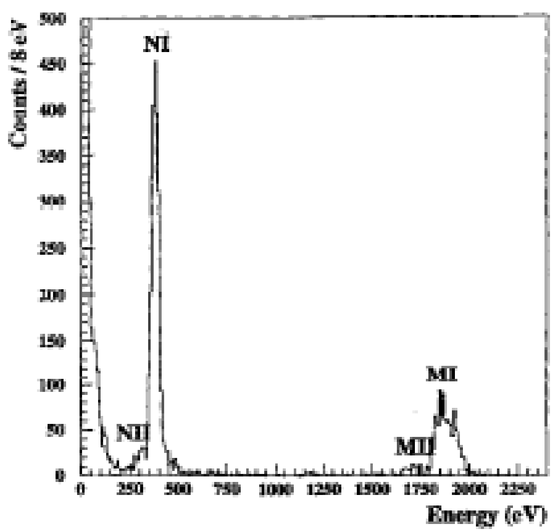


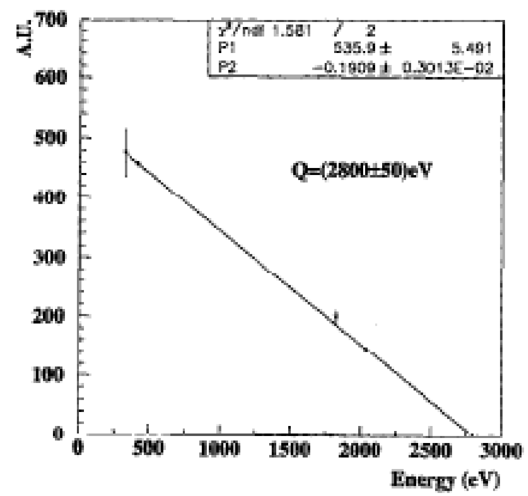


Previous test

- In the past we made a tentative experiment to verify the feasibility of a measurements
- Ho-163 Cl solution from ISOLDE (E Laesgaard) after a tentative made by INR-Moscow (purification failed)
- Many effort for production of electroplated tin foils from organic solution at high voltage
- Final result was an admixture of fine salt grain onto tin matrix
- → not satisfactory E resolution







But ^{163}Ho is very actractive

- Advantages:
  - tunable source activity independent form the absorber masses
  - Minimization of the absorber mass to the minimum required by the full absorption of the energy cascade → resolution less dependent from the activity
  - Rise-time much less of 10 us for SiN suspended detector
  - Higher Counting rate per detector → 10^2 c/s
  - Self calibrating experiment
  - Easiest way to reach higher count rate with presently better performing detectors

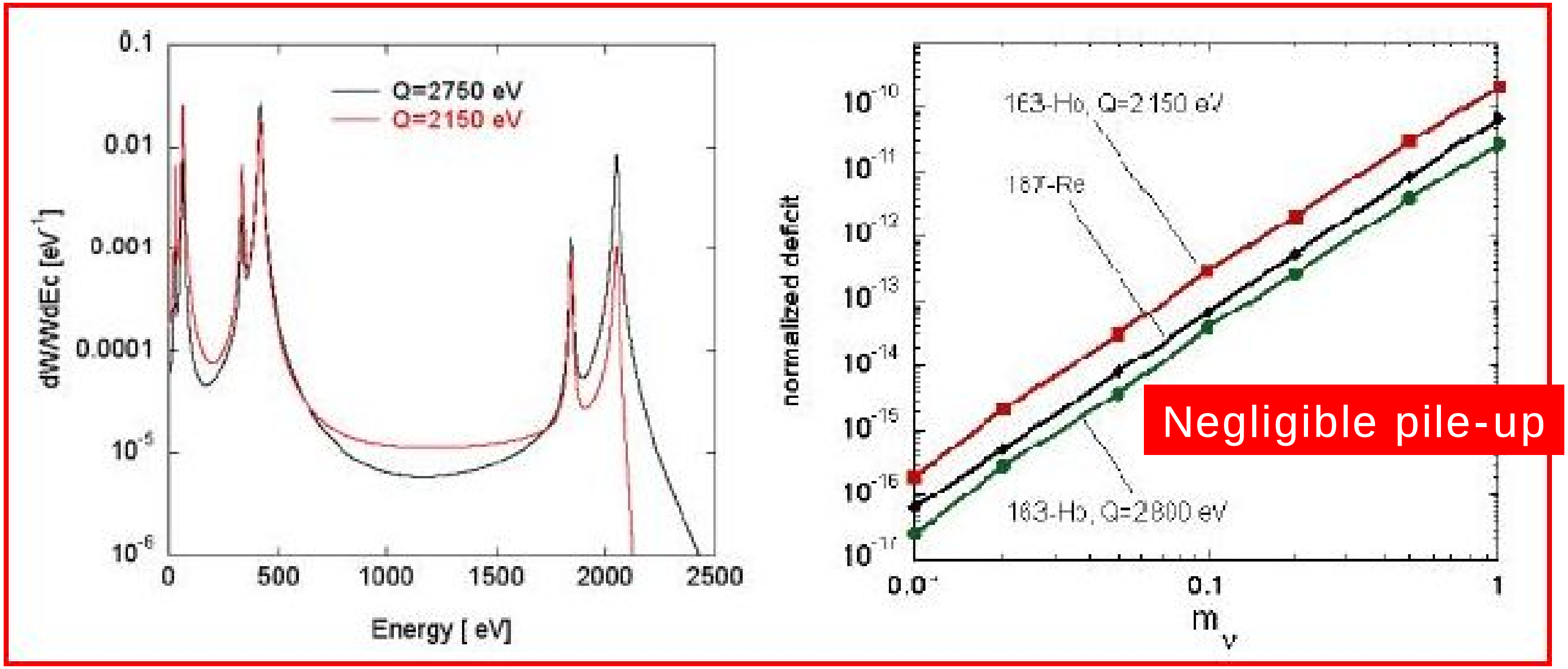
- Implantation tests have been done at ISOLDE (CERN) as product of spallation of Ta target by energetic proton and magnetic selection

- First sample contains high level of radioactive impurities

- Defined an alternative solution: neutron activation of enriched ^{162}Er , chemical processing form achieve metal state, implantation at ISOLDE or LISBOA facility

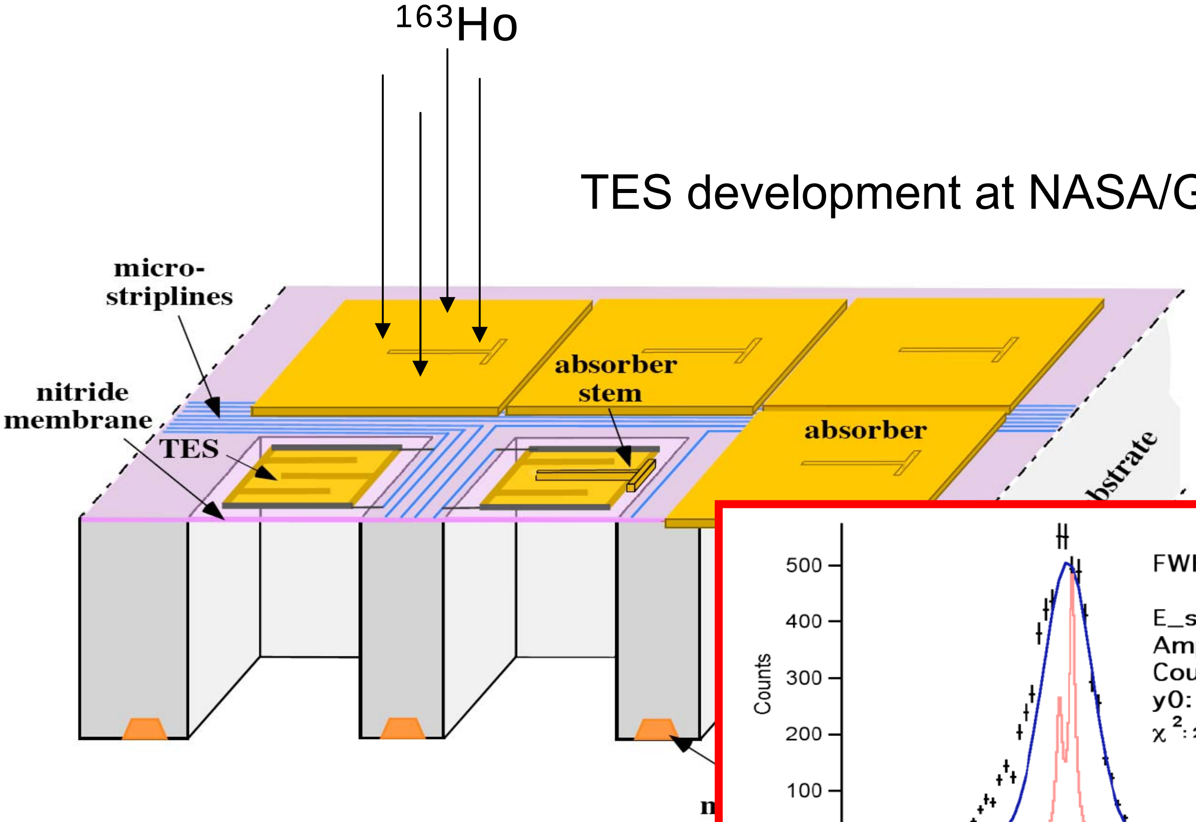
^{163}Ho sensitivity

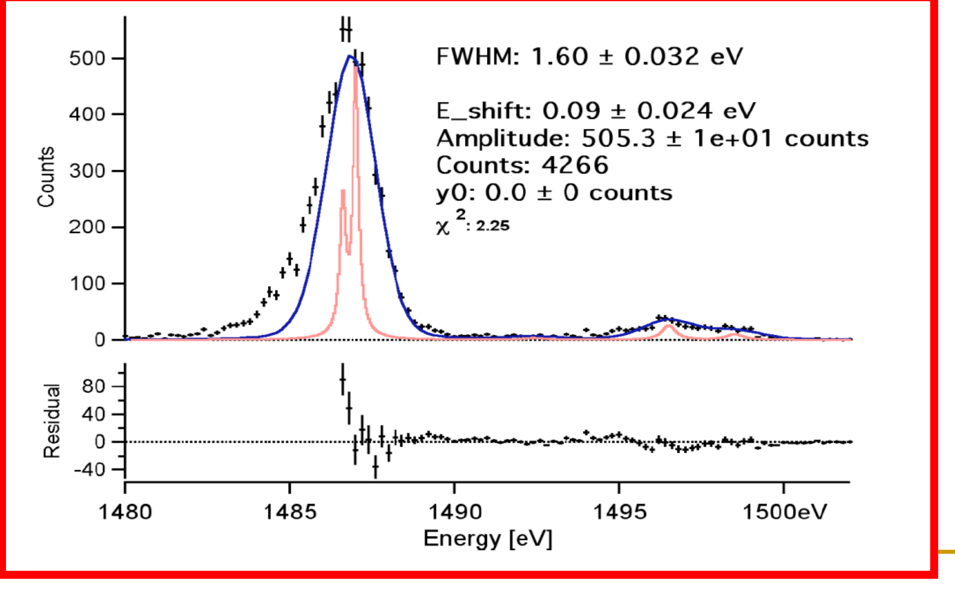
- With 2eV detectors (X-ray type) a great step forward in overall sensitivity and detector integration for neutrino mass should be achieved
- 187-Re and 163-Ho should provide very low systematic measurement



Ho-163 in Goddard Array

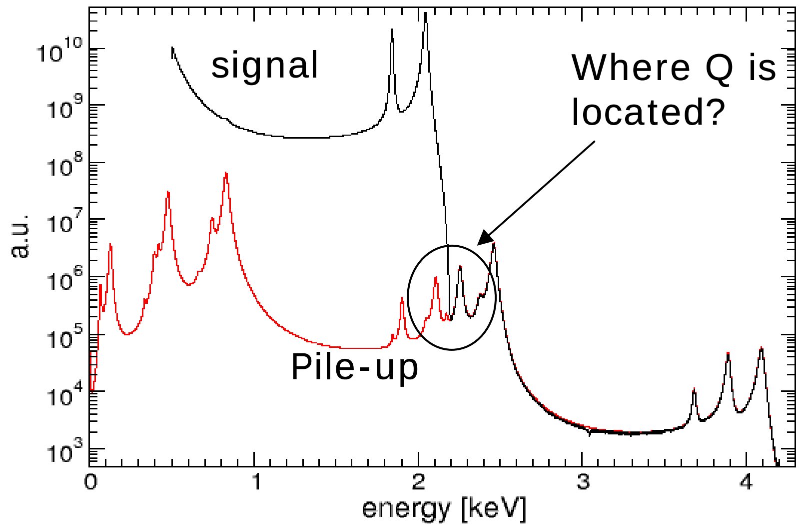
TES development at NASA/GSFC





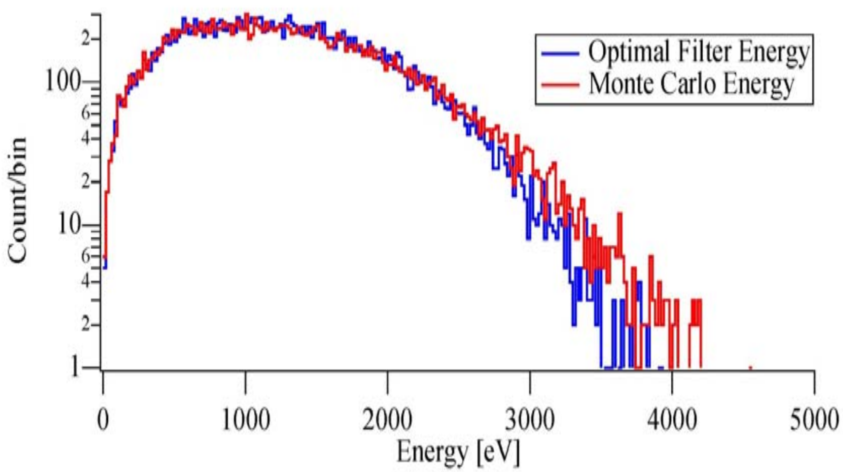
^{163}Ho studies

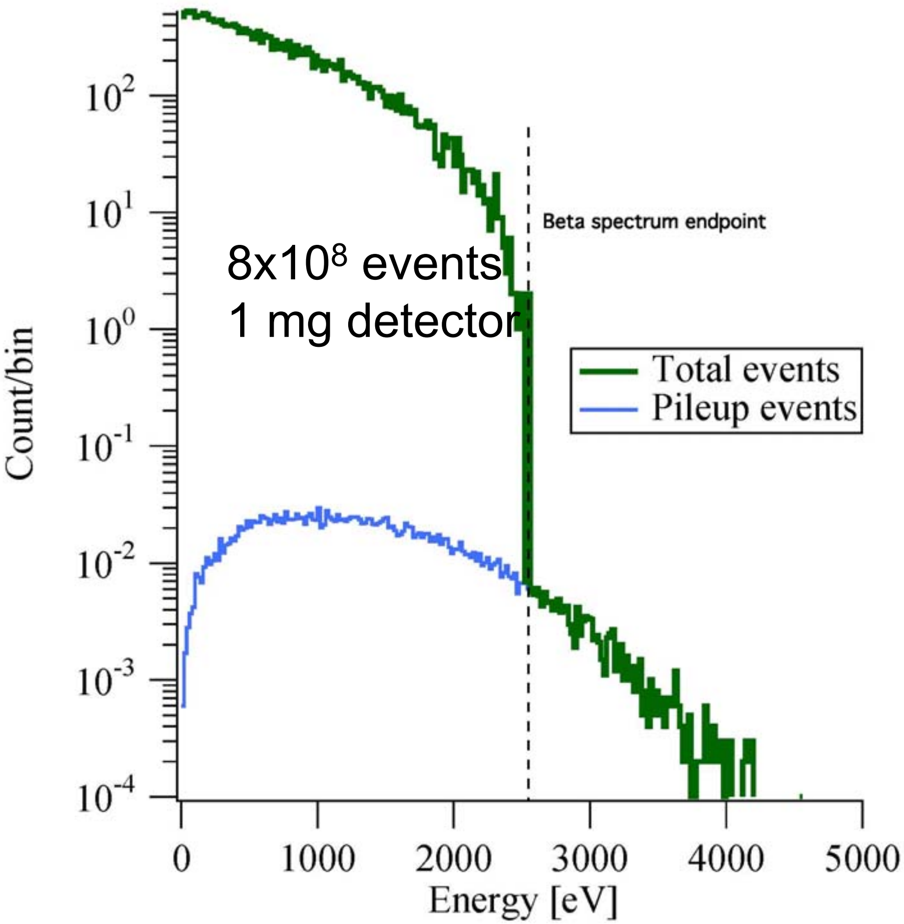
- Study of the B.-W. shape far from the maximum and intrinsic line-width, other possible systematics
- Simulation under way for simulating sensitivity in realistic condition including the pile-up and the uncertainties on Q value
- A high spectral resolution measurement is needed to fix the Q value and other decay parameters.



GEANT simulation of whole experiment (Miami-Florida)

1. Unidentified pileup
2. Effect of the decay position in the absorber
3. Efficiency and systematics of the analysis tools
4. Background events originating from radioactive decays in the surrounding cryostat material (cosmics activated)





Summary

- MARE-I developments are going to the end
  - An array of 72 channel is starting taking data taking for testing multiple detector experiment
  - Study for detector-abosber coupling for Re or Ho are under way and have define the strategy
  - Detectors with **1-2 eV energy resolution** and **0.1 us time resolution** are becoming available
  - Electronics, Simulation, Data Analysis have defined the roadmap
- Technology almost ready and but need to be fully exploited and scaled to high detector multiplicity.
- In the next 1-2years a decision on the isotope and detector technology should be made and a prototype for MARE II detector built.
- MARE-II is a challenging experiment, but feasible.
- Full development could start immediately after that (if funding is available both in the US and Europe)
- We are more confident that MARE will provide fully complementary results to KATRIN