NOW2010

Conca Specchiulla
September 4-11, 2010

MARE & KATRIN

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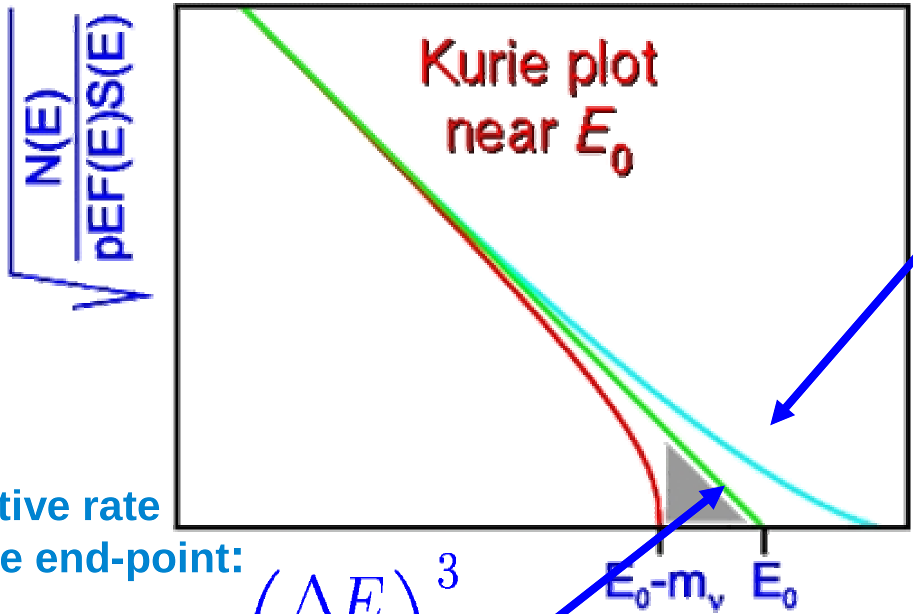
Outlook

- Direct neutrino mass measurement
- Experimental approches for direct measurements: Spectrometers vs Calorimeters
- The KArlusruhe TRItium Neutrino experiment: KATRIN
- Prospects for Re experiments: MARE
- Conclusion

Direct neutrino mass measurement

neutrino oscillations evidence → $m_\nu \neq 0$
BUT oscillation experiments give only Δm^2!

direct neutrino mass measurement



effective rate at the end-point:

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

effect of:
- **energy resolution**
- **background**
- **Pile up**

$$K(E_\beta) = (E_0 - E_\beta)\sqrt[4]{1 - \frac{m_\nu^2}{(E_0 - E_\beta)^2}}$$

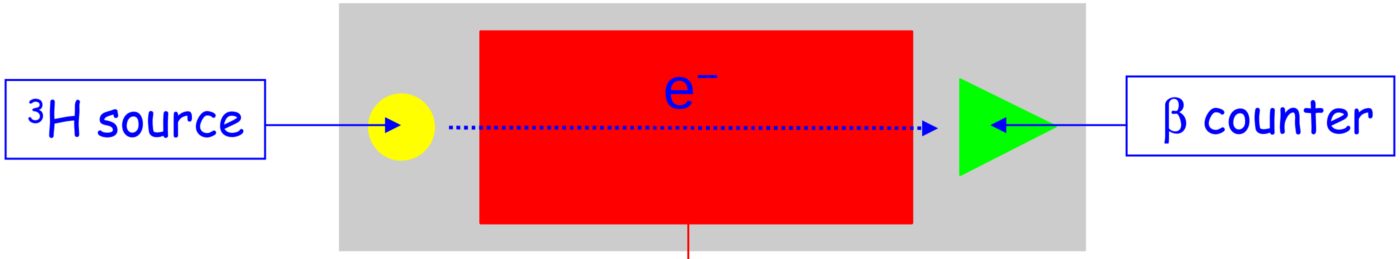
$m_\nu = (\Sigma m^2_i |U_{ei}|^2)^{1/2}$

2 eV → ^3H (E_0=18.6keV) & spectrometers

15 eV → ^{187}Re(E_0=2.47keV) & calorimeters

Different approaches to direct measurement

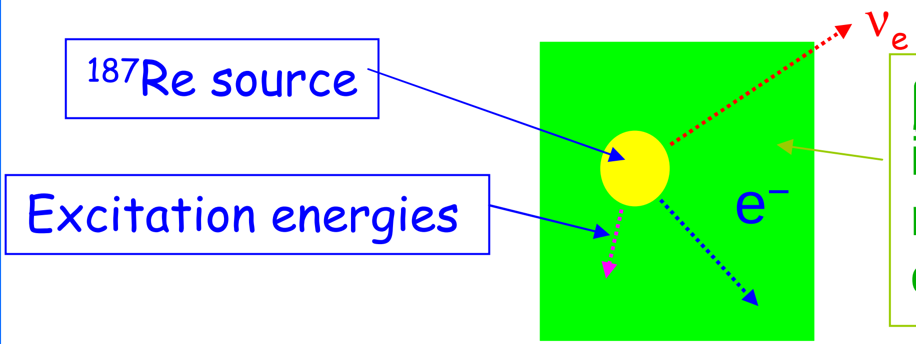
- **Spectrometers: source ≠ detector**



β analyzer

- differential or integral spectrometer: βs from the ^{3}H spectrum δE are magnetically and/or electrostatically selected and transported to the counter

- **Calorimeters: source ⊆ detector**



β calorimeter
ideally measures all the energy E released in the decay except for the ν_e energy

Calorimeter vs Spectrometer

General experimental requirements

- High statistics at the beta spectrum end-point:
  - low end point energy E_0
  - high source activity and high efficiency
- high energy resolution ΔE (same order of magnitudine of m_ν sensitivity)
- high Segnal to Noise ratio
- small systematics effects

Spectrometer: β source ≠ detector

Advantages:

✓high statistics
✓high energy resolution

Disavantages:

× systematics due to source effect
× systematics due to decay to excitated states
× background

Calorimeter: β source $\subseteq$ detector

Advantages:

✓no backscattering
✓no energy losses in the source
✓no solid state excitation
✓no atomic/molecular final state effects

Disavantages:

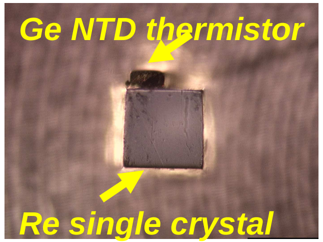
× limiteted statistics
× systematics due to pile-up
× background

Precursors of ^{187}Re experiments

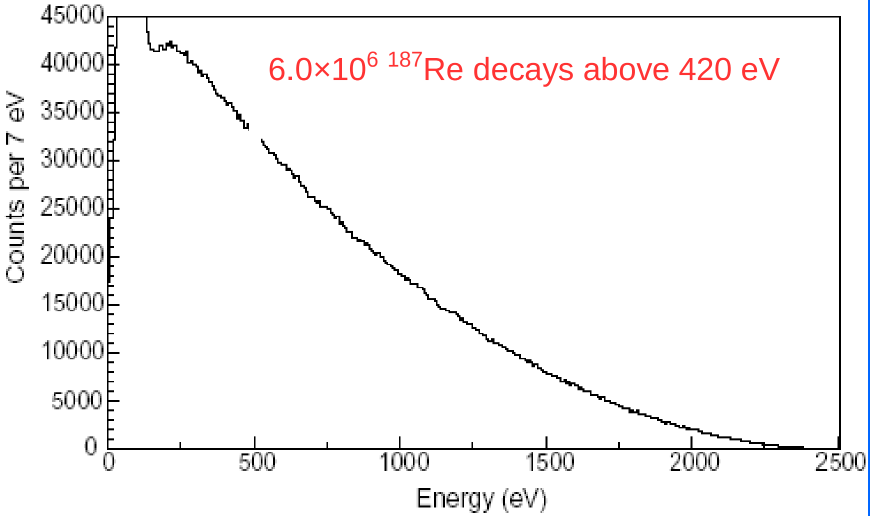
MANU (1999)

Genova

- 1 crystal of metallic Re: 1.6 mg
- ^{187}Re activity ≈ 1.6 Hz
- Ge-NTD thermistor
- ΔE=96 eV FWHM
- 0.5 years live-time
- $m_\nu^2 = -462^{+579}_{-679}$ eV^2



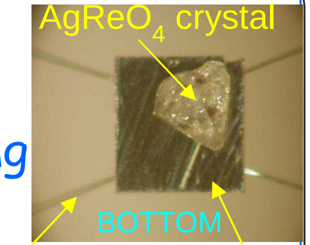
- **$m_\nu \leq 26$ eV (95 % C.L.)**

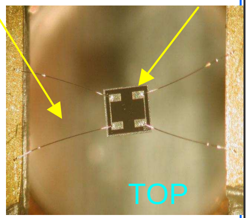


MIBETA (2002-2003)

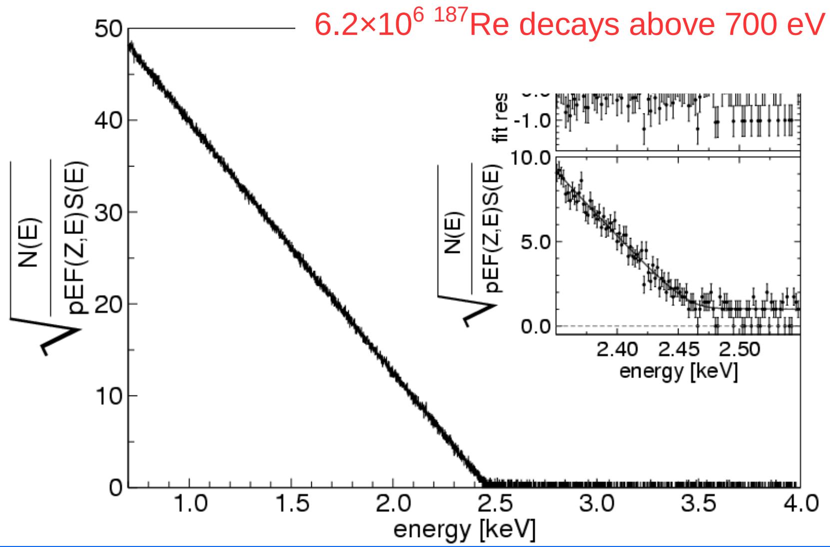
Milano, Como, Trento

- 10 $AgReO_4$ crystals: 2.71 mg
- ^{187}Re activity = 0.54 Hz/mg
- Si thermistors (ITC-irst)
- ΔE= 28.5 eV FWHM
- 0.6 years live time
- $m_\nu^2 = -112 \pm 207_{stat} \pm 90_{sys}$ eV^2



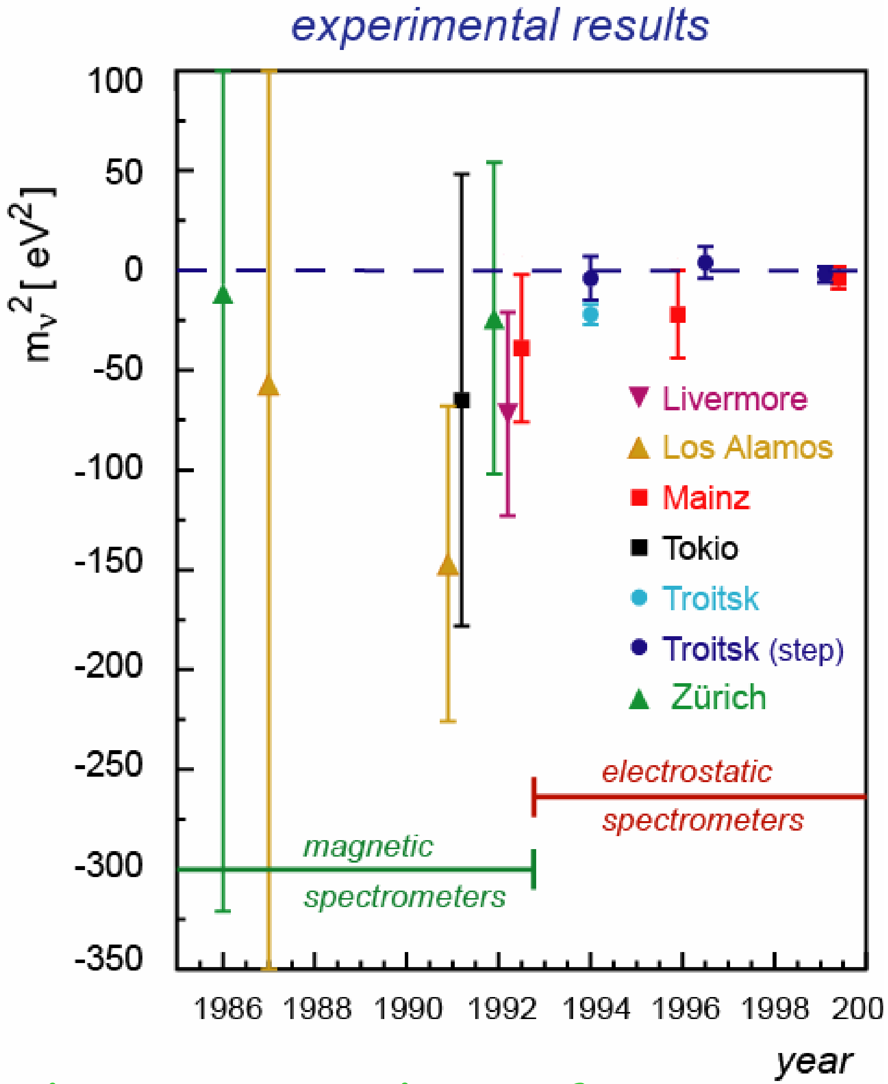


- **$m_\nu < 15$ eV (90% CL)**



History of tritium Beta decay experiments

	m_ν
ITEP *T_2 in complex molecule* *magn. spectrometer (Tret'yakov)*	17-40 eV
Los Alamos *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 9.3 eV
Tokio *T - source* *magn. spectrometer (Tret'yakov)*	< 13.1 eV
Livermore *gaseous T_2 - source* *magn. spectrometer (Tret'yakov)*	< 7.0 eV
Zürich *T_2 - source impl. on carrier* *magn. spectrometer (Tret'yakov)*	< 11.7 eV
Troitsk (1994-today) *gaseous T_2 - source* *electrostat. spectrometer*	< 2.5 eV
Mainz (1994-today) *frozen T_2 - source* *electrostat. spectrometer*	< 2.3 eV



Mainz & Troitsk have reached their intrinsic limit of sensitivity

The KArlshure TRItium Neutrino experiment: KATRIN

Physics Goal: 1 order of magnitudine improvement on m_ν

2 eV → 0.2 eV

Statistic

Count rate at the b-endpoint falls off very steeply, small background!

Improvement of statistics (x10^3):

- stronger tritium source and larger spectrometer
- larger measuring period (100 d → 1000 d)

Systematics

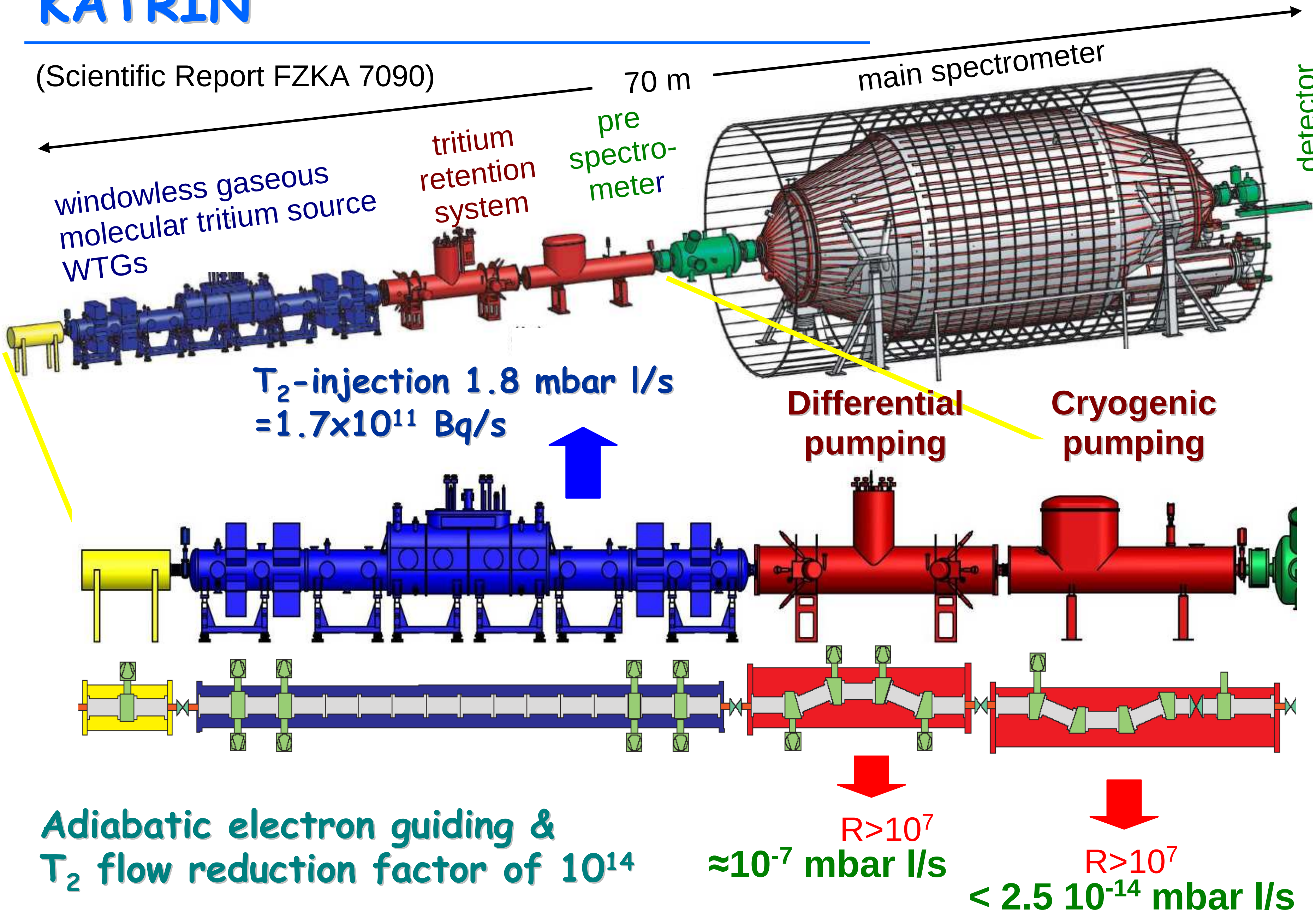
Aim: systematic uncertanties = statistical errors

Improvement of systematics (x0.1):

- improved energy resolution spectrometer with ΔE=0.94 eV (factor 4)
- reduced systematic errors for energy losses in source →windowless gaseous tritium source

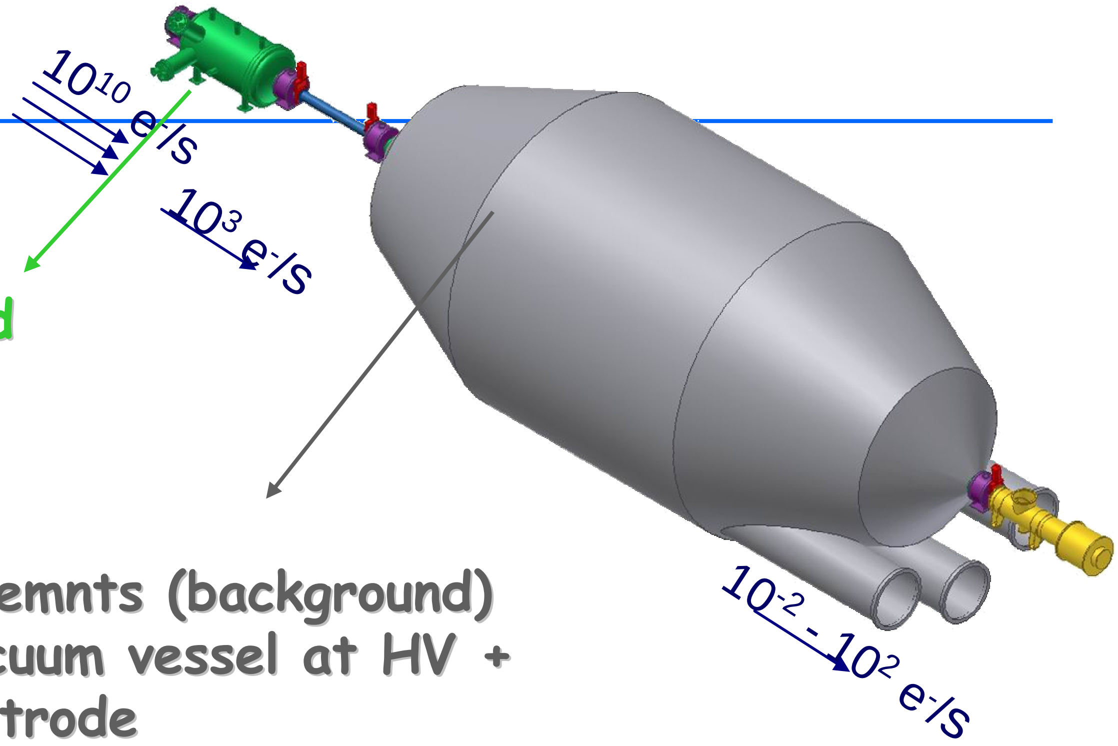
KATRIN

(Scientific Report FZKA 7090)



Adiabatic electron guiding &
T_2 flow reduction factor of 10^{14}

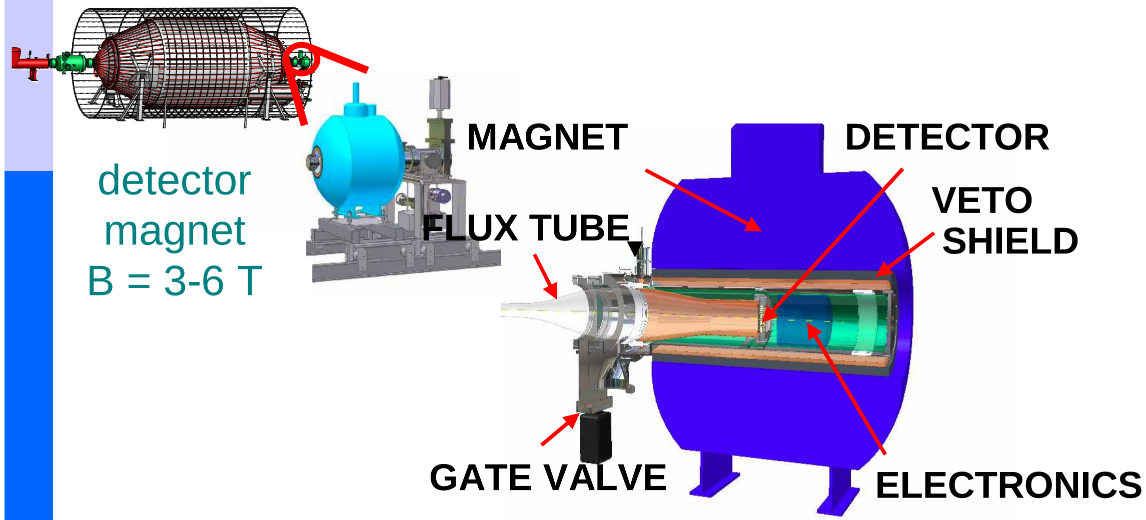
KATRIN



- filter out all β-decay electrons without m_ν info
- reduction of background from ionising collisions

- large energy resolution
- high luminosity
- ultrahigh vacuum requiremnts (background)
- simple construction: vacuum vessel at HV + "massless" screening electrode

detector magnet B = 3-6 T



- Si-Pin diode
- detection of transmitted β-decay electrons
- low background for endpoint investigation
- high energy resolution
- 148 pixels

KATRIN sensitivity

Expectation for 3 full beam years

→ Statistical & Systematic errors contribute equal ($\sigma_{syst} \sim \sigma_{stat}$)

KATRIN discovery potential:

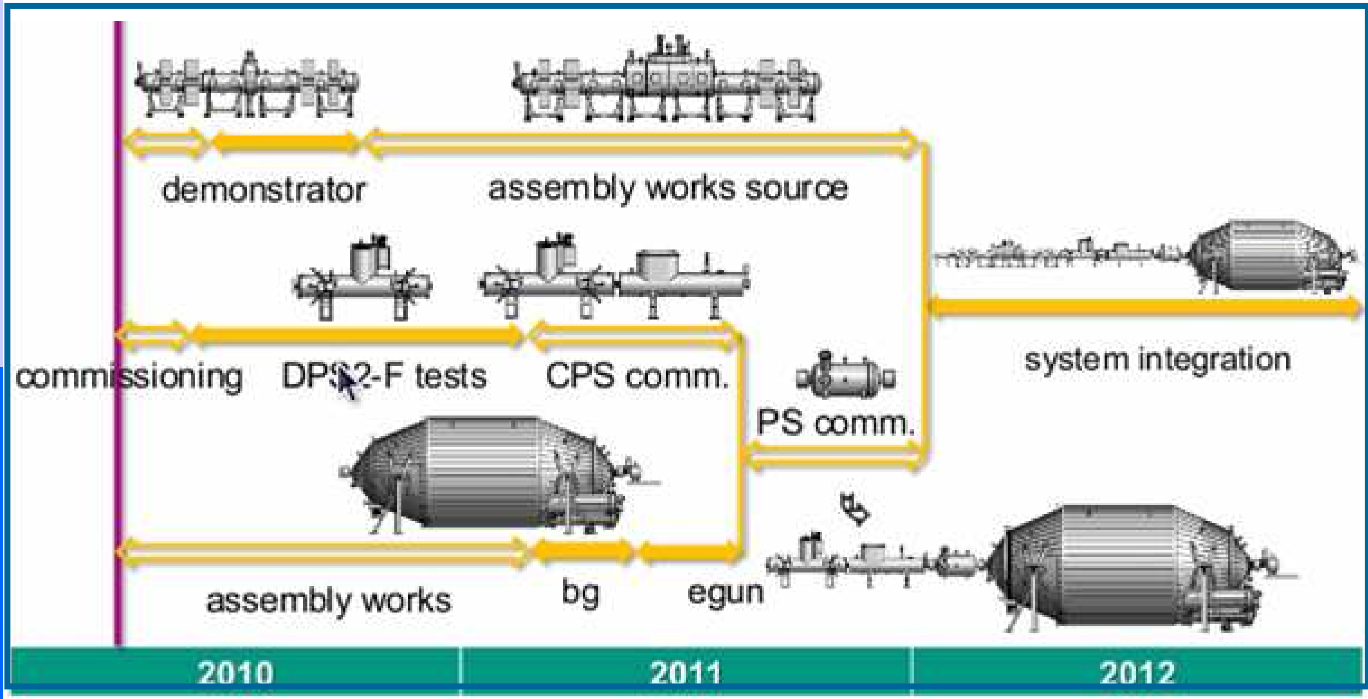
m_ν = 0.35 eV (3σ)

m_ν = 0.3 eV (5σ)

Sensitivity:

$m_\nu \leq$ 0.2 eV (90% CL)

Commissioning of the completed set-up in 2012

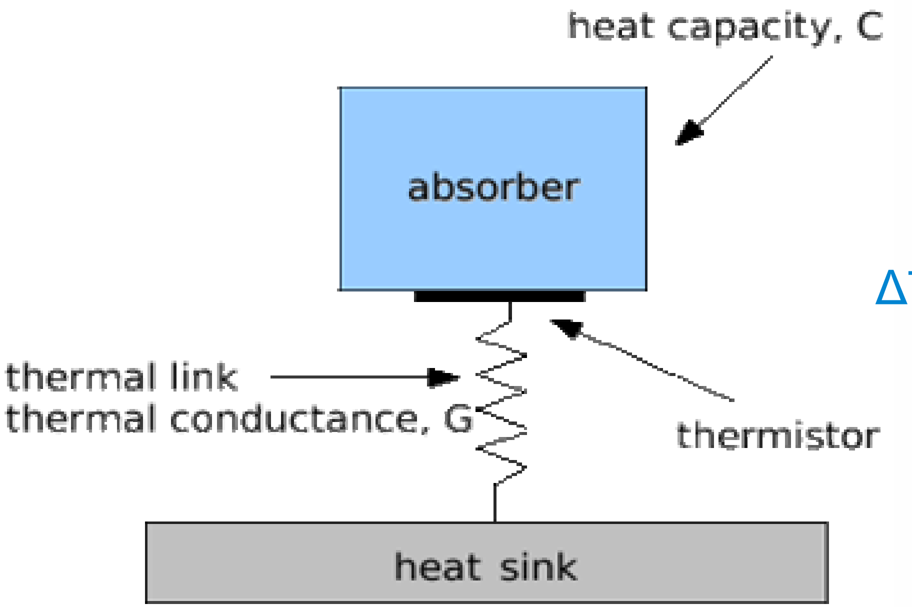


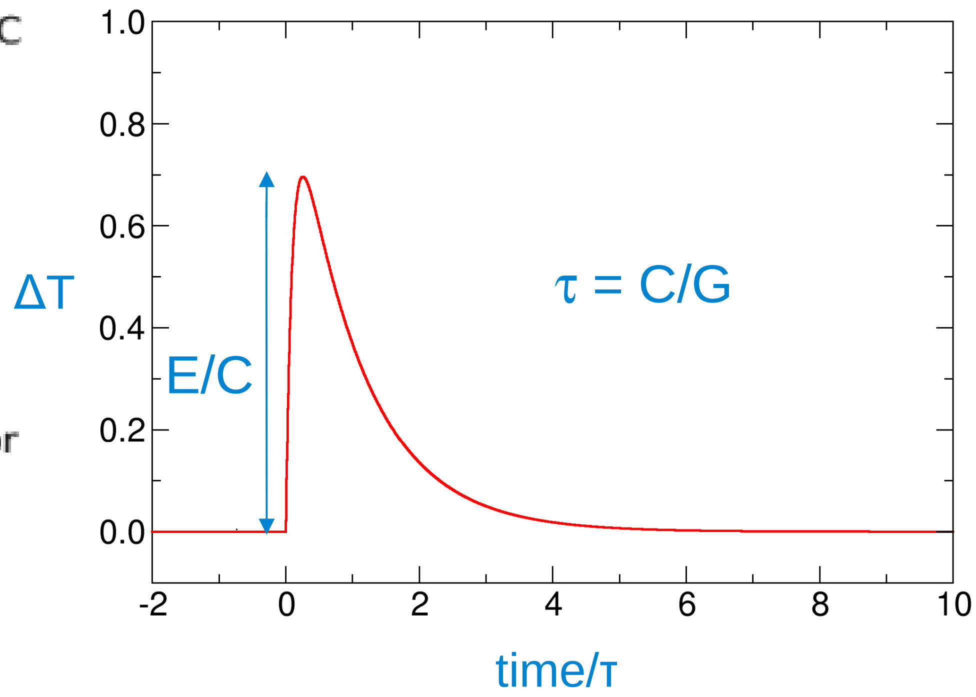
T. Thummler talk at NEUTRINO2010

Introduction to direct neutrino mass measurement and KATRIN

2012-2018 regular data taking for 5-6 years (3 full beam year)

Cryogenic Detectors





Detection Principle:

- $\Delta T = E/C$ where C is the total thermal capacity
  - low C: $C \sim (T/\Theta_D)^3$ in superconductors & dieletric below T_C
    - low T (10 ÷ 100 mK)
- ultimate limit to energy resolution:
  - statistical fluctuation of internal energy $\Delta E = (k_B T^2 C)^{1/2}$
- detect all deposited energy, including short-lived excited states (100 μs)
- achieve very good energy resolution in the keV range

MARE: Microcalorimeter Array for a Rhenium Experiment

Goal: a sub-eV direct neutrino mass measurement complementary to the KATRIN experiment

MARE-1: collection of activities aiming at isotope/technique selection

- ^{187}**Re** – high statistics measurement
  - asses systematics
  - test large arrays
  - lower limit to few eV
- ^{163}**Ho** – high statistics measurement – R&D for ^{163}Ho production
  - measure Q_{EC}
  - study spectrum shape
  - asses systematics

Different techniques:

- TES – Transition Edge Sensor
- MMC – Magnetic MicroCalorimeter
- MKID – Microwave Kinetic Inductance Detector

↳
- **multiplexed readout**
- **large arrays**

MARE 1

MARE-1 in Milan: Milano/Como/IRST/Wisconsin/NASA

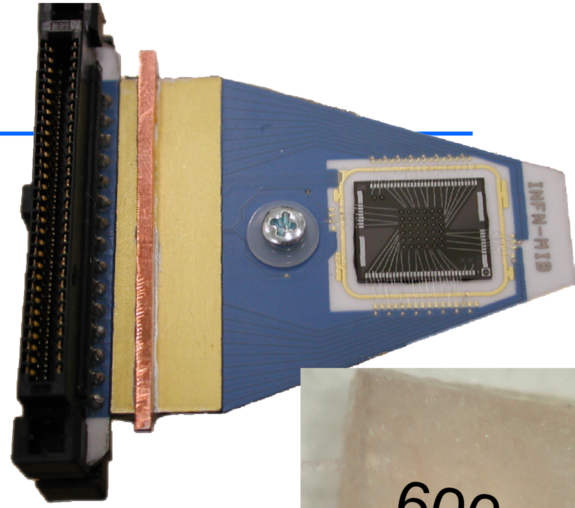
- $m_{\nu e} < 2\ eV/c^2$
- 10^{10} events - 300 sensors
- 8 arrays of Si:P thermistors with $AgReO_4$ absorbers
- energy resolution 25 eV @ 2.6 keV

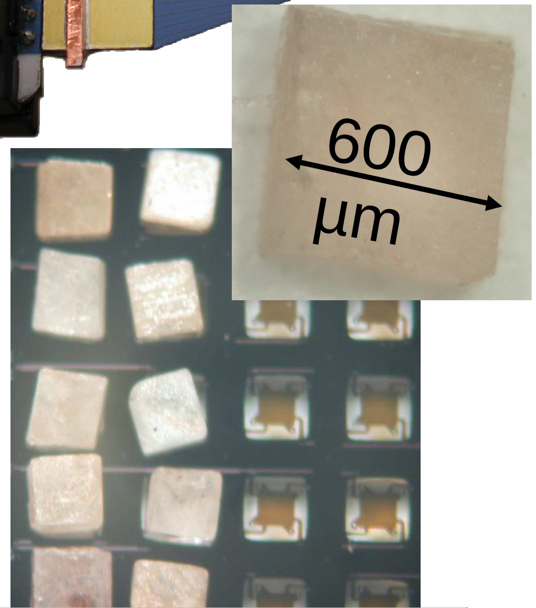
The first phase is needed:
- because it's the only possible one with present technology
- To investigate systematics in thermal calorimeters

very important to cross-check spectrometer results

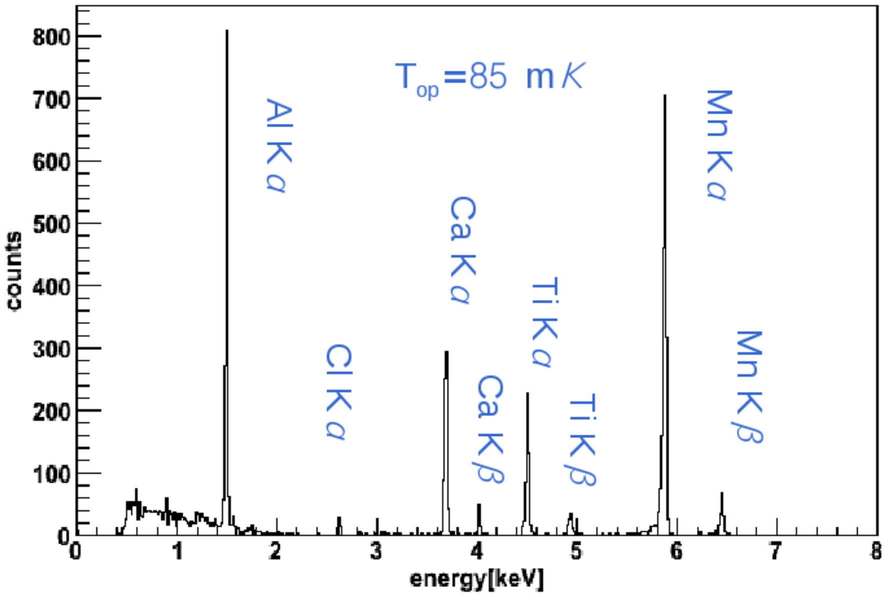
MARE 1 in Milan

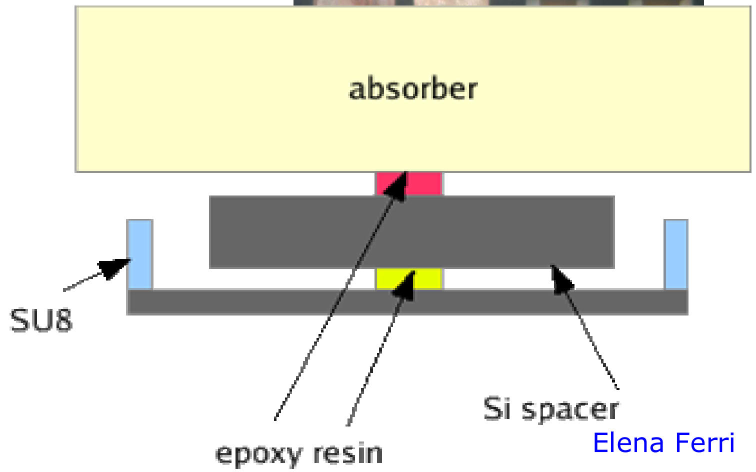
- **6x6 NASA/GSFC arrays**
  - pixel 300x300x1.5 μm^3
  - developed for X-ray spectroscopy with HgTe absorber (ASTRO-E2)
- **flat $AgReO_4$ single crystal**
  - mass ~ 500mg per pixel (A_β ~ 0.3 dec/sec)
- **Detector R&D results**
  - best operating T ≈ 85mK
  - $\Delta E \approx 30$ eV, $\Delta\tau \approx 250$ μs





Calibration Spectrum





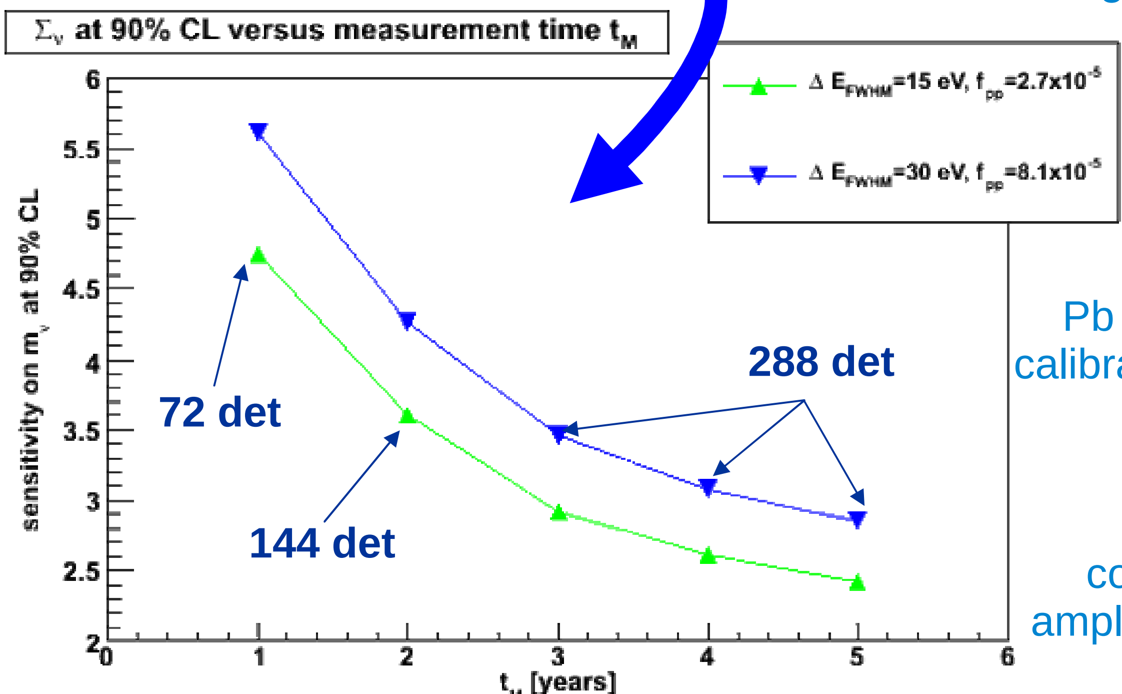
MARE 1 in Milan: MC sensitivity

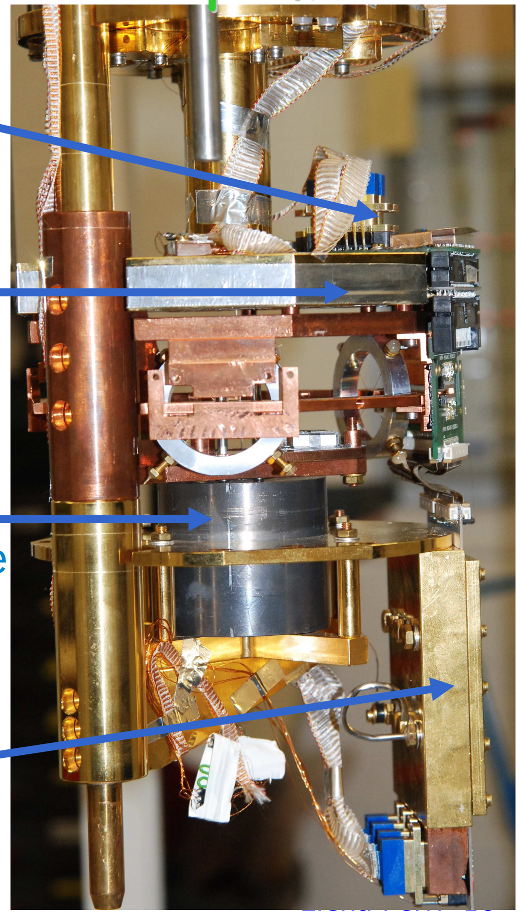
Detectors

ΔE_{FWHM} ~ 15 eV e τ_R ~ 100 µs
1 year and 72 channels → $\Sigma(m_\nu)$ ~5eV
3 years and 288 channels → $\Sigma(m_\nu)$ ~ 3eV

ΔE_{FWHM} ~ 30 eV e τ_R ~ 300 µs
1 year and 72 channels → $\Sigma(m_\nu)$ ~6eV
3 years and 288 channels → $\Sigma(m_\nu)$ ~ 3eV

- setup designed for 8 arrays
- 288 $AgReO_4$ crystals
- now starting with 2 arrays (72 ch.)
- gradual deployment
  - ▷ **further detector optimization**





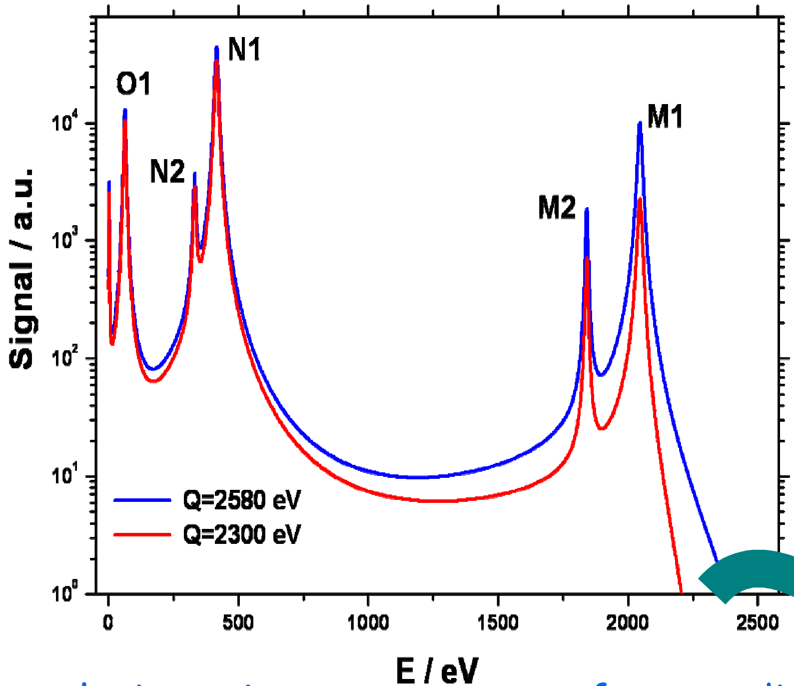
Load Resistence 50 MΩ

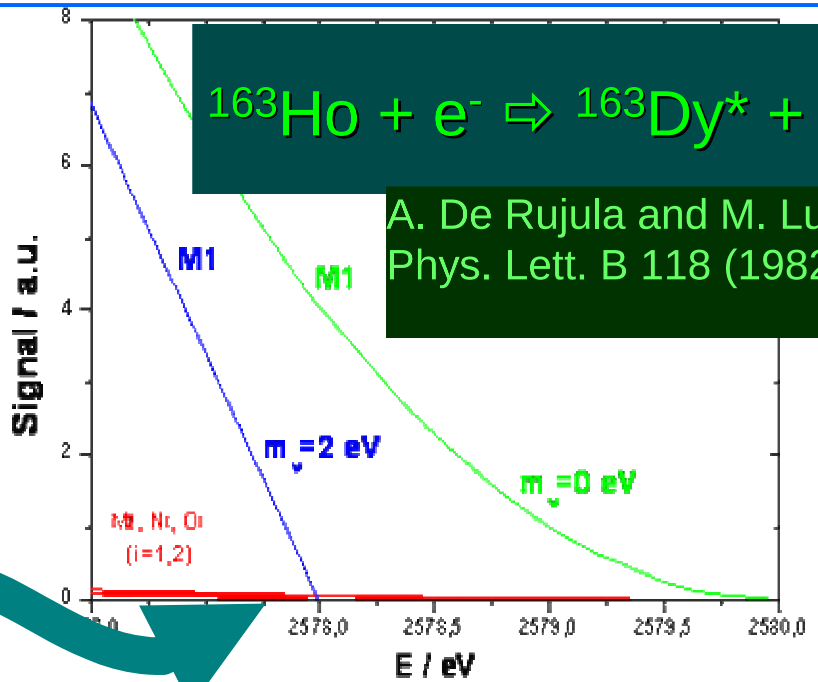
detector holder

Pb shield for calibration source

cold pre-amplifier stage

^{163}Ho Electron Capture measurement





^{163}Ho + e$^-$ ⇨ ^{163}Dy* + ν_e

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

- calorimetric measurement of non-radiative Dy atomic de-excitations (mostly non radiative)
- 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 spectrum of ^{187}Re
- fraction of events at end-point may be as high as for ^{187}Re:
  depends on Q_{EC} (2.3÷2.8 keV), but Q_{EC}?
- $\tau_{1/2}$ ≈ 4570 y: few active nuclei are needed
  ► can be implanted in any suitable absorber
- new NASA/Goddard TES arrays (ΔE = 2eV) can be implanted with ^{163}Ho
- 163 Ho production by neutron irradiation of ^{162}Er enriched Er
- no high statistics and clean calorimetric measurement so far

MARE 1 activities

- **Isotope physics investigation and systematics assessment**
  - ^{163}Ho + Si-impl/TES (U Genova - U Milano-Bicocca – U Lisbon/ITN)
  - $AgReO_4$ + Si-impl (U Milano-Bicocca - U Como - NASA/GSFC – UW Madison)
- **Sensor-Absorber coupling (^{187}Re/^{163}Ho) and single pixel design**
  - ^{187}Re + TES (U Genova – U Miami – U Lisbon/ITN)
  - ^{187}Re + MMC (U Heidelberg)
  - ^{163}Ho + TES (U Genova)
  - ^{163}Ho + MMC (U Heidelberg)
  - ^{163}Ho/^{187}Re + MKID (U Milano-Bicocca -JPL/Caltech - U Roma - FBK)
- **Multiplexed sensor read-out**
  - SQUID multiplexing (U Genova - PTB)
  - SQUID microwave multiplexing (U Heidelberg)
- **Software tools**
  - Data Analysis (U Miami)
  - Montecarlo simulations (U Miami - U Milano-Bicocca)

MARE 2 statistical sensitivity: Re & Ho options

- only statistical analysis
- 50000+ detectors gradually deployed
  - ▷ arrays distributed in many laboratories around the world
  - ▷ about $10^{13} \div 10^{14}$ events after 5 years

Exposure required for 0.2 eV m_ν sensitivity

^{187}Re

A_β [Hz]	τ_R [μs]	ΔE [eV]	N_{ev} [counts]	exposure [det × year]
1	1	1	0.2×10^{14}	7.6×10^{5}
10	1	1	0.7×10^{14}	2.1×10^{5}
10	3	3	1.3×10^{14}	4.1×10^{5}
10	5	5	1.9×10^{14}	6.1×10^{5}
10	10	10	3.3×10^{14}	10.5×10^{5}

bkg = 0

→ 5000 pixels/array
8 arrays
10 years
400 g ^{nat}Re

^{187}Ho

A_β [Hz]	τ_R [μs]	ΔE [eV]	N_{ev} [counts]	exposure [det × year]
1	1	1	2.8×10^{13}	9.0×10^{5}
1	0.1	1	1.3×10^{13}	4.3×10^{5}
100	0.1	1	4.6×10^{13}	1.5×10^{4}
10	0.1	1	2.8×10^{13}	9.0×10^{4}
10	1	1	4.6×10^{13}	1.5×10^{5}

Q_{EC} = 2200 eV
bkg = 0

→ 5000 pixels/array
3 arrays
1 year
~2×10^{17} ^{163}Ho nuclei

need for new sensor R&D and new read-out techniques

Conclusion

- Investigation of the kinematics of β-decay = only model independent measurement of the absolute neutrino mass scale

- **MARE** staged approach based on microcalorimeters -Re β-decay. The **MARE** project 1st phase is just starting. R&D improvements on the detector technology are crucial for the 2nd phase.

  ^{187}Re calorimetry is complementary to tritium experiments and can give sub-eV sensitivity to m_ν.

- **KATRIN** is the ultimate tritium β-decay experiment: it will reach a sensitivity of 0.2 eV on m_ν. Expected data taking in 2012.