High statistics measurement of ^{187}Re beta spectrum for direct neutrino mass determination

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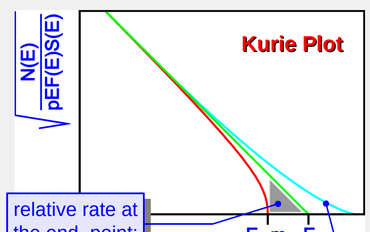
1. Physical Motivations

- Neutrino flavour oscillations ⇒ $m_\nu > 0$
- Oscillation experiments give only Δm^2

➡ Kinematic neutrino mass direct measurements



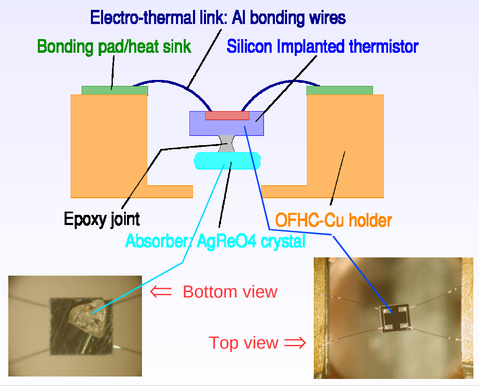
- Magnetic Spectrometers
  - ▲ High energy resolution (1 ÷ 10 eV)
  - ▲ High statistics at E_0
  - ▼ Many corrections
    - Spectrometer response
    - Source effects
    - Atomic/molecular final states
- Thermal Calorimeters
  - ▲ No source/excitation effects
  - ▲ High energy resolution
  - ▲ Measure all energy $E = E_0 - E_\nu$
  - ▼ Slow response
    - Pile-up
    - Low β activity ⇒ low statistics

2. Thermal Microcalorimeters

for m_{ν_e} = 10 eV

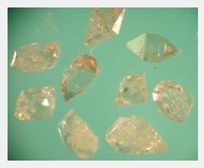
- ^{3}H: E_0 = 18.6 keV ⇒ $r \approx 3\times10^{-10}$
- ^{187}Re: E_0 = 2.5 keV ⇒ $r \approx 10^{-7}$

➡ Array of thermal calorimeters to study the end-point of ^{187}Re β decay

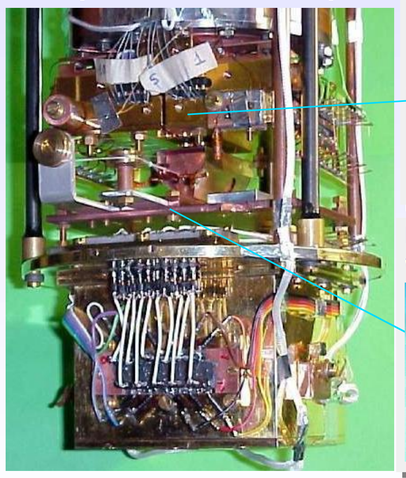


Absorbers

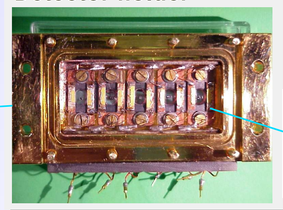
- $AgReO_4$ single crystals
- ^{187}Re fraction ~0.32
- $A_\beta \approx 5.4\times10^{-4}$ Hz/μg
- Mass 250 ~ 350 μg



3. Experimental Set−Up

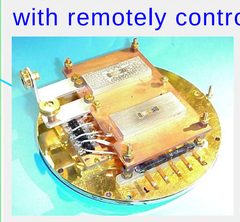


Detector holder



Roman lead shield 3mm above 2mm below

Fluorescence source with remotely controlled shutter



2 × ^{55}Fe (5mCi) primary sources:

Al K_α:	1.5 keV
Cl K_α:	2.6 keV
Ca K_α:	3.7 keV
Ti K_α:	4.5 keV
Mn K_α:	5.9 keV

4. First high statistics measurements

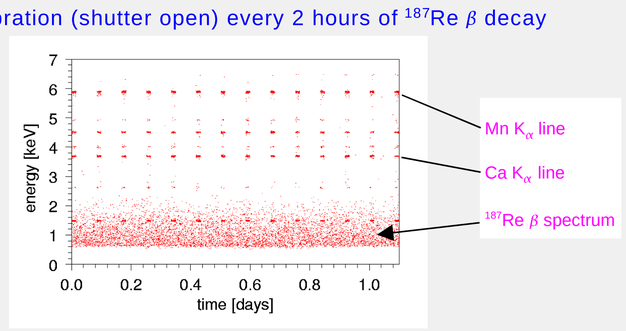
Detector Characterization

- Total installed $AgReO_4$ mass: 2.94 mg
- Total acquired $AgReO_4$ mass: 2.34 mg
  - ⇨ ^{187}Re activity: 1.3 Hz
- Detector performances from measurements with open shutter:

	$AgReO_4$ mass [μg]	T_{op} [mK]	τ_{rise} [ms]	ΔE_{FWHM} at 2.46 keV [eV]
1	340±5		1.29	37.6
2	259±6	57.0	0.83	30.0
3	244±4		0.81	41.1
4	286±4			
5	284±3	55.0	0.90	32.1
6	312±9			
7	323±1	56.0	0.94	32.5
8	376±5	60.0	1.25	48.6
9	272±3	62.0	0.98	45.0
10	241±5	65.0	0.83	32.6

High statistic measurement

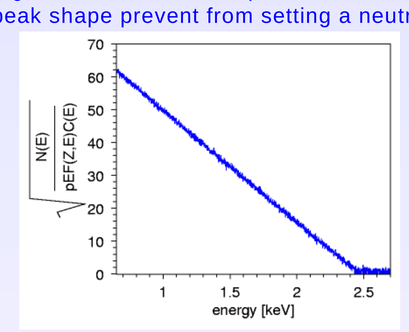
- Elapsed running time with 8 detectors: 3.5 months
- Total statistics ~13242 hours × detector
- 20 min calibration (shutter open) every 2 hours of ^{187}Re β decay acquisition



- Accumulated statistics with shutter closed: ~10830 hours × detector
  - ⇨ more than 6×10^6 ^{187}Re decays
- Data subset selected for preliminary data analysis:
  - ⇨ with shutter closed: ~8655 hours × detector
  - ⇨ ~ 4.9×10^6 ^{187}Re decays
  - ⇨ ~ 1.9×10^6 events between 650 eV (common threshold) and 2.5 keV

5. Data analysis: ^{187}Re β decay spectrum

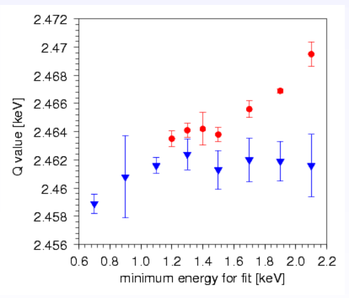
- The high background above the end-point and the so far unexplained peak shape prevent from setting a neutrino mass limit



- Preliminary Kurie plot fit assuming simple gaussian detector response for βs ($\langle\Delta E_{FWHM}\rangle$ = 39 eV), m_{ν_e} = 0, constant background and no pile-up

$$Q = 2461 \pm 1_{stat} \pm 5_{sys} \text{ eV}$$

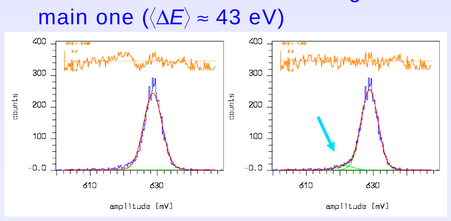
⇨ large systematical uncertainty on Q value due to background



⇦ The fitted Q values depend on the fitting interval:
- ● all detectors
- ▼ selection of detectors with lower background

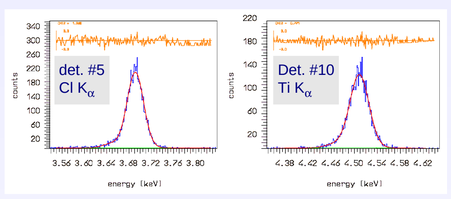
6. Data analysis: detector response and calibration

- All calibration peaks are asymmetric for all detectors
  - ⇨ good fits possible only including a second gaussian on the left
  - ⇨ for all detectors the second gaussian is 35 to 60 eV away from main one ($\langle\Delta E\rangle \approx 43$ eV)



- Detector #5
- Ca K_α peak: E = 3.69 keV
- Second peak:
  ΔE = 45 eV
  A'/A = 0.026

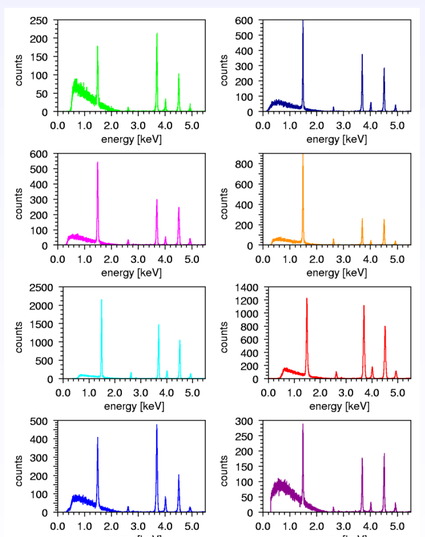
- In $AgReO_4$ the Re 4f atomic level moves to about 40 eV (checked with XPS measurements on our samples)
  - ⇨ Ipothesys: ~40 eV are sometimes trapped in a metastable state: either in the 4f level or through other mechanisms (not yet proved)



peak integral ratio

	Al K_α	Ca K_α	Ti K_α
1	0.025	0.069	0.066
2	0.014	0.040	0.054
3	0.024	0.043	0.062
5	0.026	0.054	0.065
7	0.014	0.053	0.073
8	0.063	0.040	0.055
9	0.015	0.056	0.081
10	0.030	0.024	0.050

- Detectors are calibrated with ΔE = 43 eV and using right peak position



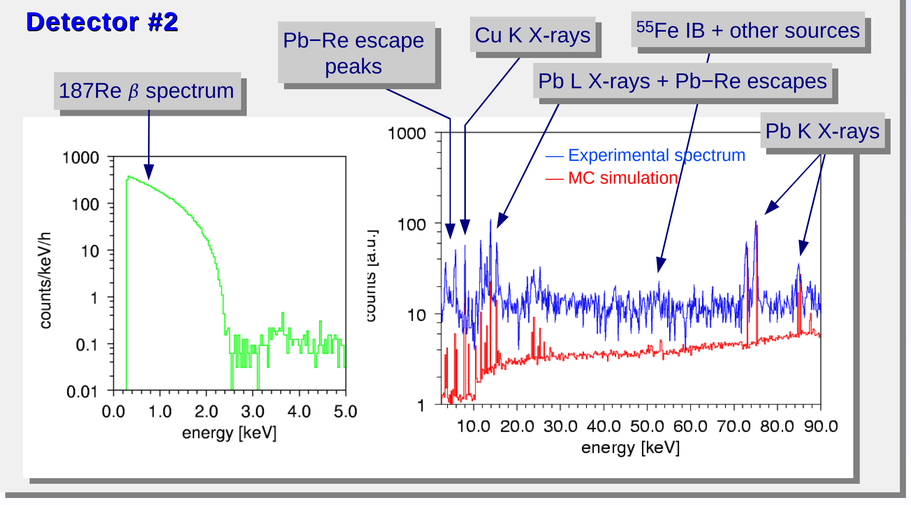
	Baseline noise FWHM [eV]	ΔE_{FWHM} at 1.5 keV [eV]	ΔE_{FWHM} at 2.6 keV [eV]
1	19.6	35.7	37.8
2	21.6	27.3	30.5
3	28.3	39.0	41.5
4			
5	22.6	29.5	32.5
6			
7	22.0	30.0	32.9
8	23.9	44.6	49.2
9	23.8	42.7	45.4
10	22.4	29.8	33.1

- Weighted average energy resolution at β end-point: ΔE_{FWHM} = 38.5 eV
- 2nd degree polynomial to model non-linear detector response (Al, Ca and Ti K_αs)
  - ⇨ $|\Delta E(\text{Cl } K_\alpha)| < 2$ eV

7. Data analysis: background

- The background level above the end point is too high:
  - ⇨ Mostly due to ^{55}Fe internal bremsstrahlung (Q = 231.7 keV, 3.2×10^{-3} γ per 100 ^{55}Fe EC decays)
  - ⇒ confirmed by MC simulation

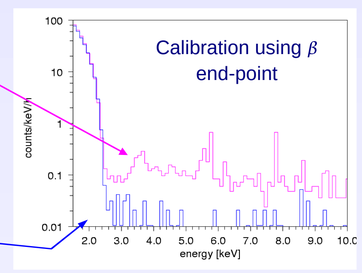
Detector #2



8. Background study: dedicated measurement

- Long measurement with ^{55}Fe source removed and same detector−array
- Different shielding conditions for the detectors: one holder with lead shield and one without lead shield

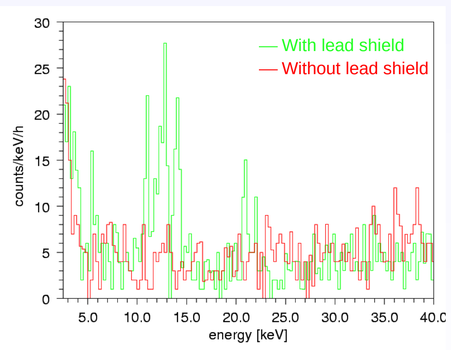
Detector #2
- 788 hours with ^{55}Fe source and shutter closed: ~ 0.122 c/keV/h above β−endpoint
- 928 hours without ^{55}Fe source: ~ 0.011 c/keV/h above β−endpoint



⇒ background reduced ~ a factor of 10 without ^{55}Fe source

- Remaining contributions to background due to:
  - ⇨ overlapping ^{187}Re events (up to 5 keV): pile-up
  - ⇨ environmental radioactivity
  - ⇨ cosmic rays (electromagnetic showers)

⇒ comparison between summed spectra of detectors inside the shielded copper holder and inside the unshielded copper holder (calibration using β end−point):



9. Expected sensitivity

Montecarlo simulations

- A_β: single detector activity
- τ_{rise}: assumed time resolution for pile−up discrimination
- unresolved pile-up fraction: $F \approx A_\beta\ \tau_{rise}$
- Σ_{m_ν}: 68% C.L. sensitivity on m_{ν_e}
- no background and simple gaussian detector response
  - ⇨ sensitivity for $m_{\nu_e} \approx 10$ eV could possible with 1 year measurement

$N_{det} \times t_{meas}$ [y]	A_β [Hz]	τ_{rise} [ms]	ΔE_{FWHM} [eV]	Σ_{m_ν} [eV]
10	0.1	0.50	30	10.0
10	0.1	0.05	30	9.1
10	0.1	0.50	10	8.2
10	1.0	0.50	30	6.2
50	0.1	0.05	10	4.0

- To achieve the expected sensitivity:
  - ⇨ background reduction
  - ⇨ understanding of detector response
  - ⇨ better time resolution τ_{rise}
  - ⇨ improve pile-up discrimination algorithm

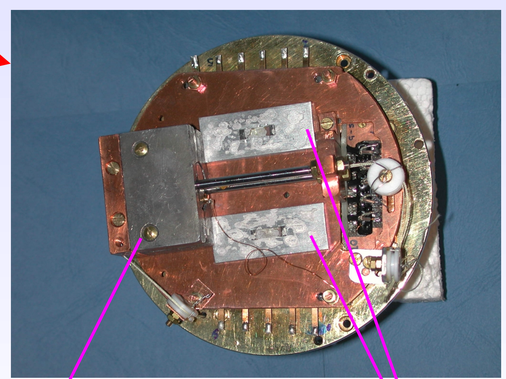
⇒ New high statistics measurement with improved performance

10. New high statistics measurement

- 10 new detectors for the array:
  - ⇨ total $AgReO_4$ mass: 2.68 mg
  - ⇨ ^{187}Re activity: 1.45 Hz
- Internal lead shield removed from both detector holders
- Improved experimental set−up:
  - ● ^{55}Fe source shutter now made of Roman lead to shield IB
  - ● fixed impedance in place of 1K−pot needle valve to reduce microphonic noise

	$AgReO_4$ mass [μg]	Baseline noise FWHM [eV]	τ_{rise} [ms]
1	272±3		
2	259±6		
3	280±6	34.1	0.75
4	250±2	15.4	0.77
5	284±3		
6	228±3		
7	281±4		
8	282±3		
9	269±6	17.2	0.50
10	278±1	25.3	0.40

⇒ new measurement has just started



Roman lead box hosting ^{55}Fe source during closed−shutter periods

Fluorescence source targets

References

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Web sites

http://crio.mib.infn.it/wig/silicini/welcome.html
http://crio.mib.infn.it/wig/