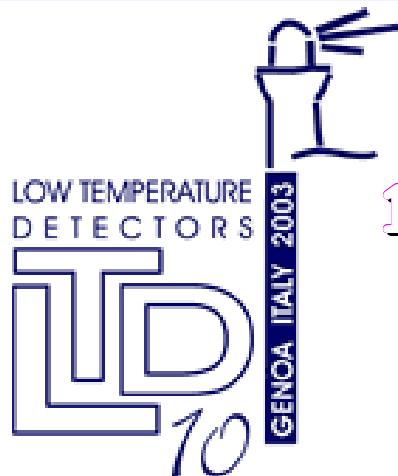


New limits from the Milano neutrino mass experiment with thermal microcalorimeters

Monica Sisti

INFN - Sezione di Milano

on behalf of the Milano, Como and Trento groups



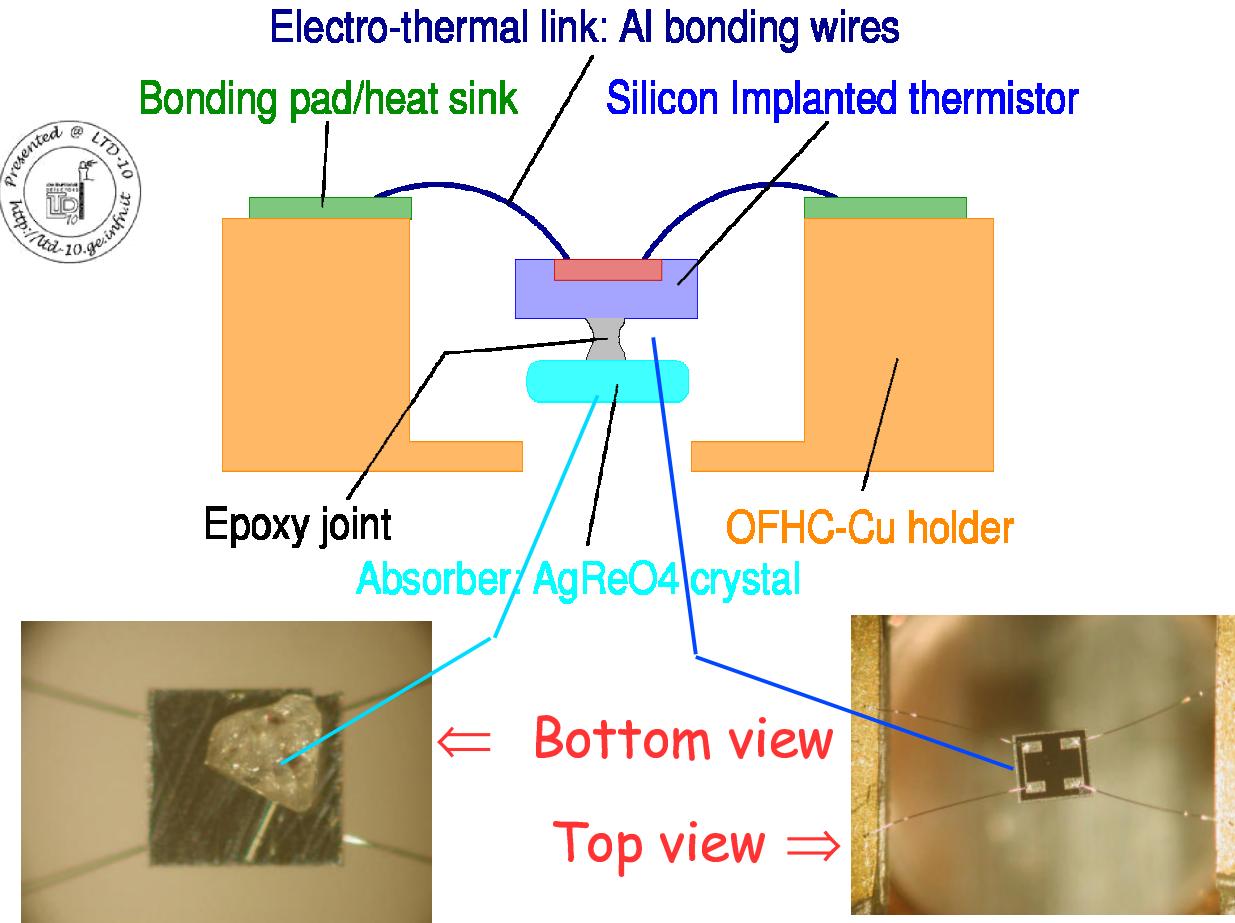
10th International Workshop on
Low Temperature Detectors
Genova, July 7th - 11th 2003



Milano μ -calorimeters for ^{187}Re β decay study

Neutrino mass measurement with arrays
of 10 AgReO_4 μ -calorimeters.

- lower pile-up
- higher statistics



Absorbers

AgReO_4 single crystals

^{187}Re fraction ~ 0.32

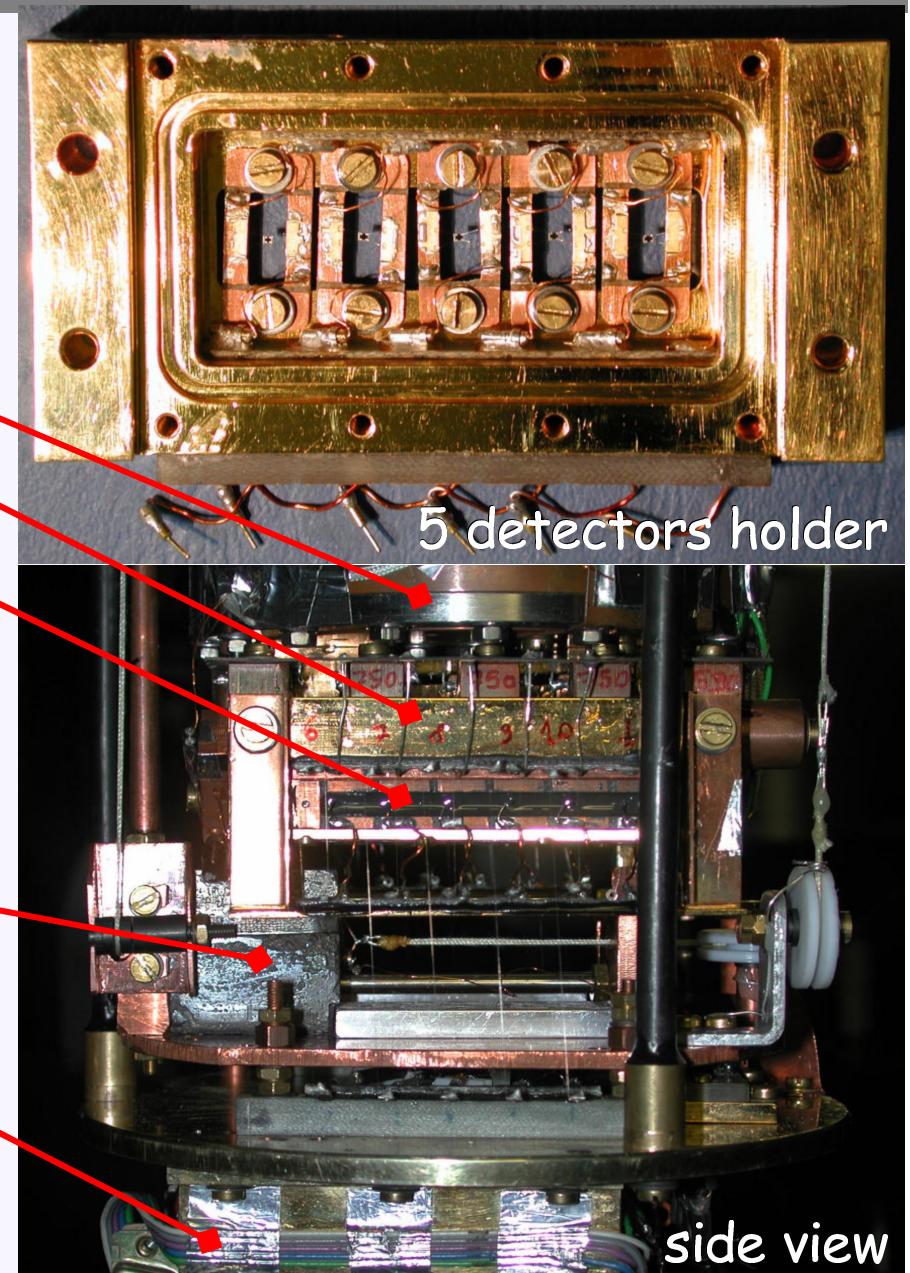
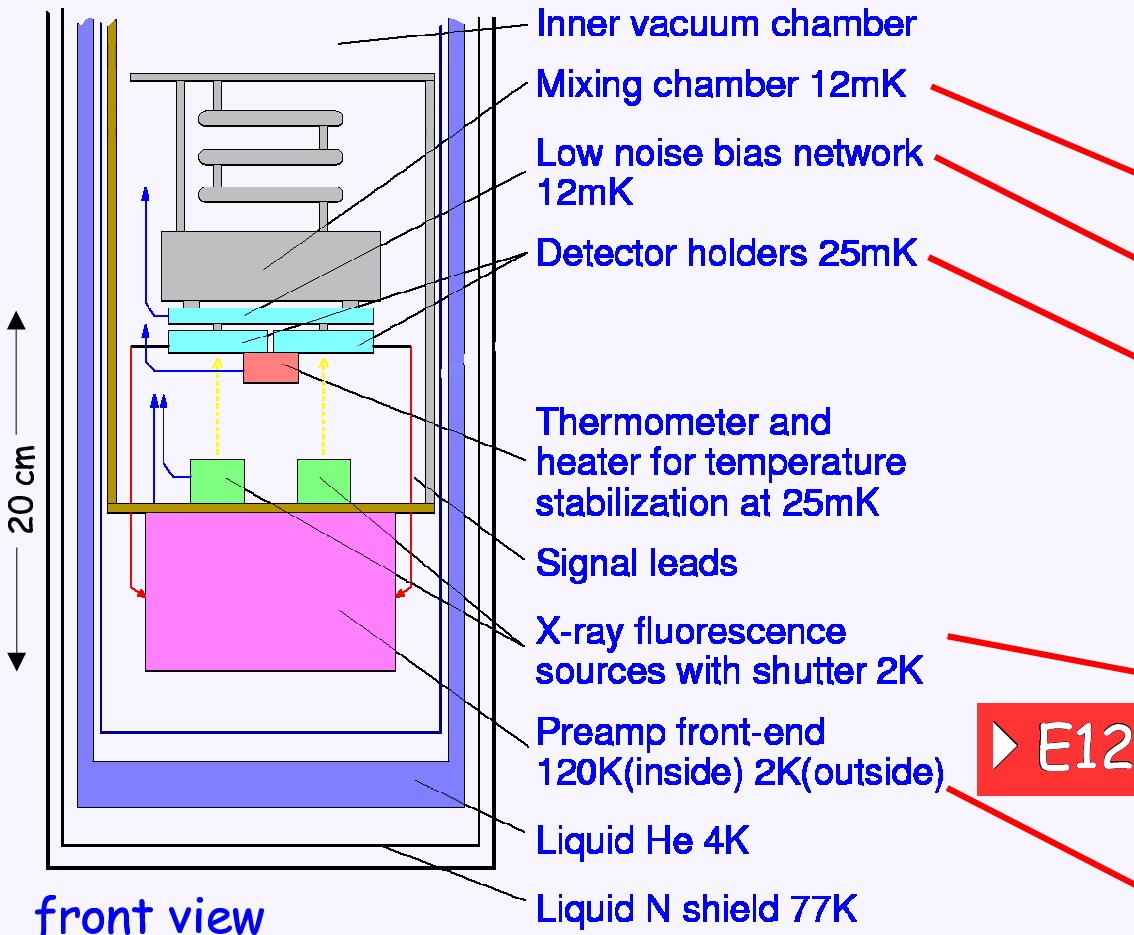
$A_\beta \approx 5.4 \times 10^{-4} \text{ Hz}/\mu\text{g}$

Mass $250 \sim 300 \mu\text{g}$



Experimental set-up

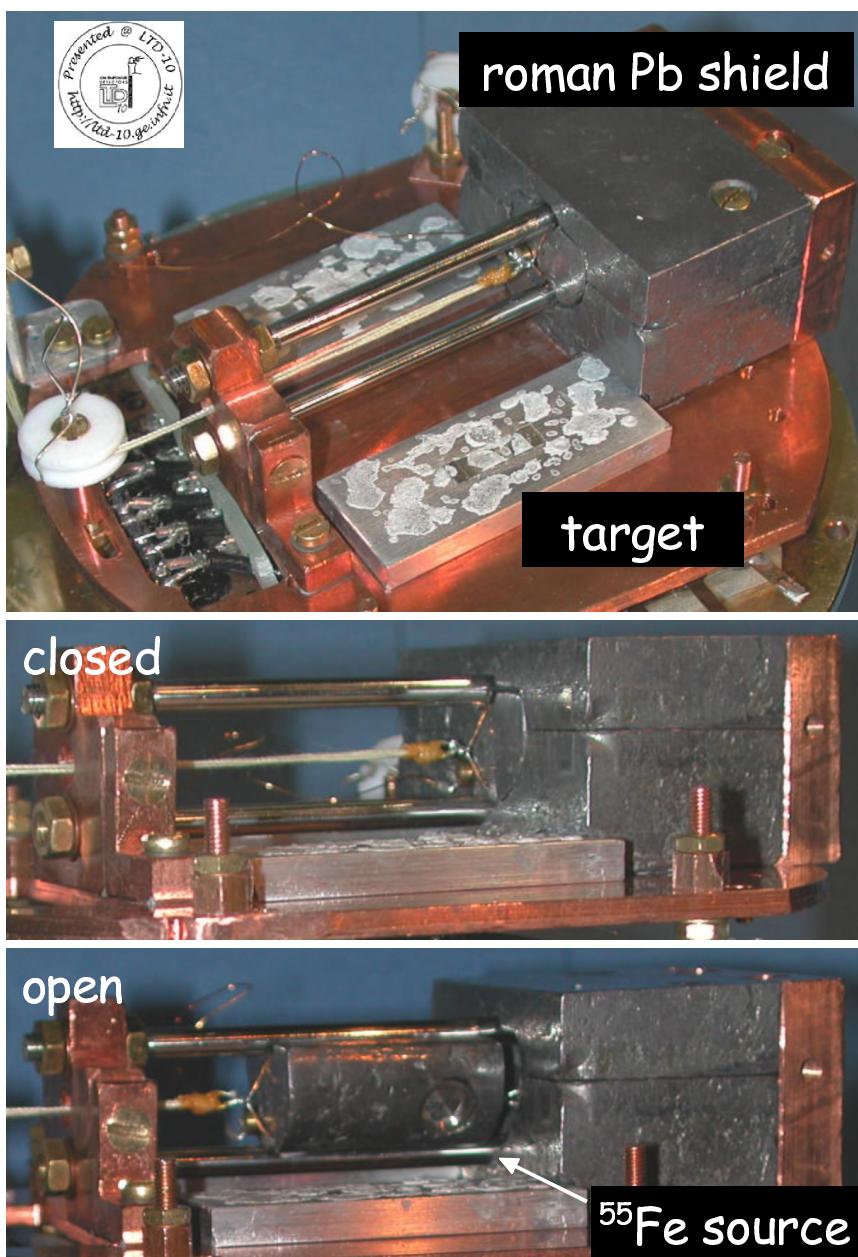
Dilution refrigerator set-up for 10 detector experiment



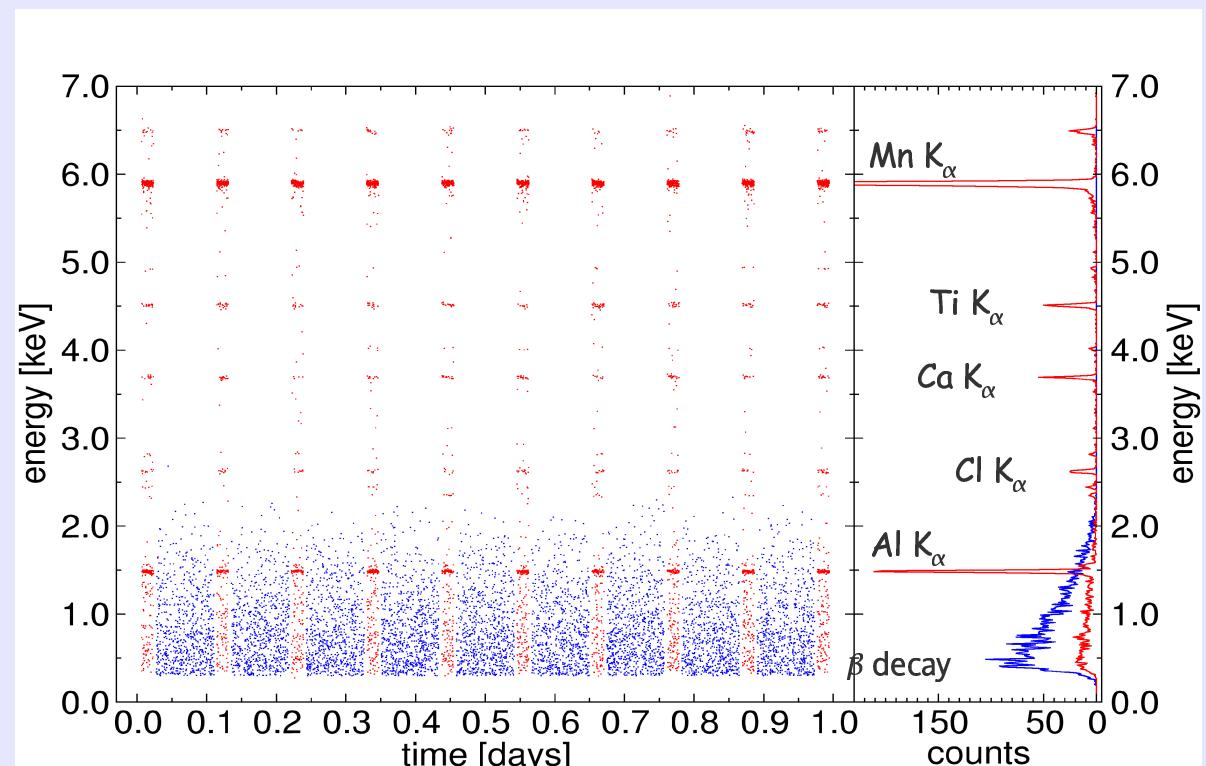
side view



X-ray fluorescence source for periodic calibration



- remotely controlled for continuous stability control
→ 1 cycle: 25 minutes open, 2 hours closed
- primary sources: $2 \times ^{55}\text{Fe}$ 5 mCi ► U11
- roman lead to shield ^{55}Fe Inner-Bremsstrahlung
- fluorescence target:
 $\text{Al K}_\alpha \rightarrow 1.5 \text{ keV}$ $\text{Cl K}_\alpha \rightarrow 2.6 \text{ keV}$
 $\text{Ca K}_\alpha \rightarrow 3.7 \text{ keV}$ $\text{Ti K}_\alpha \rightarrow 4.5 \text{ keV}$ ► U09



Measurement statistics and Detector performance

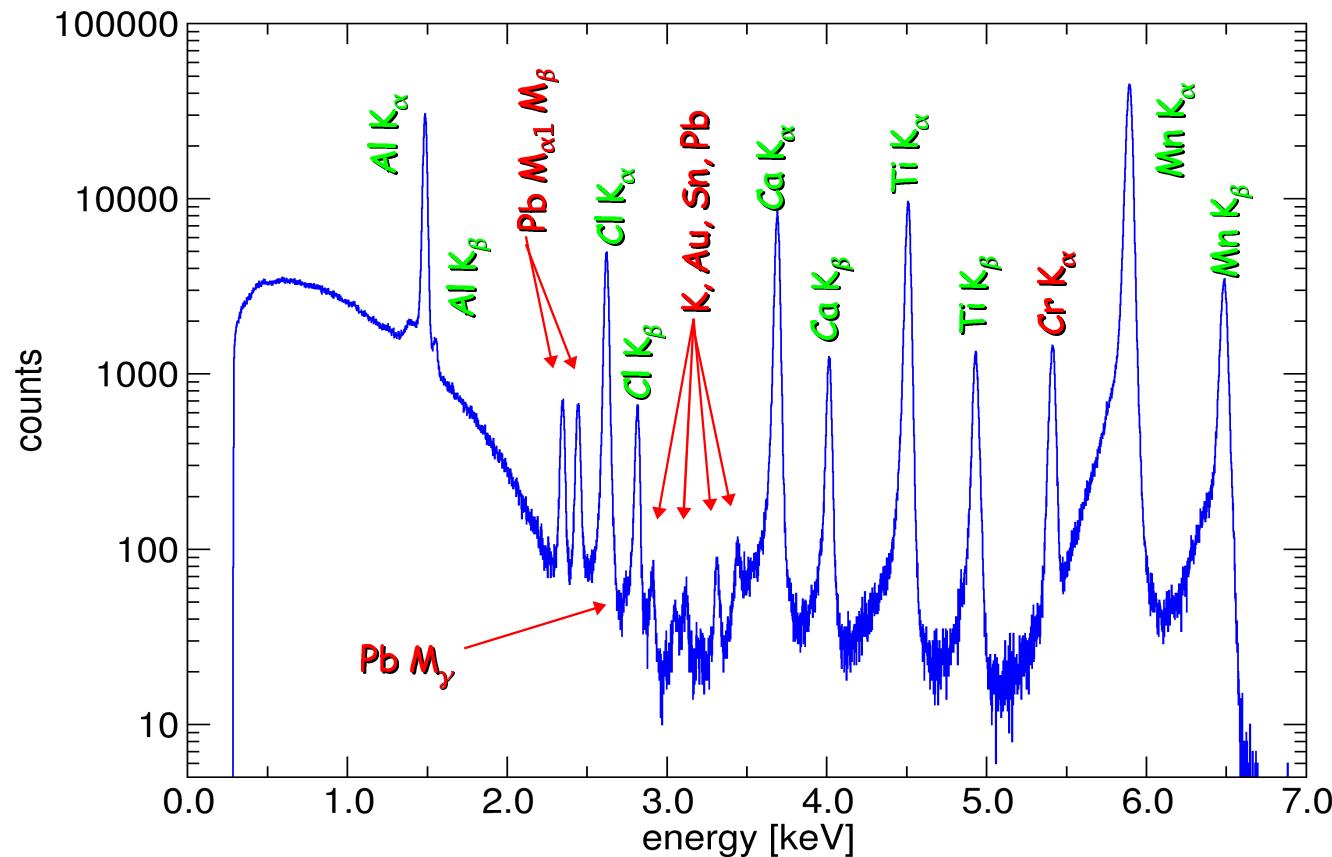
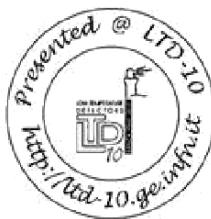
- Measurement started on June 21st 2002 and ended on April 29th 2003
 - ▷ 313 days of measurement (including daily service to cryostat, test calibrations, ...)
- Total acquired AgReO_4 mass: 2.174 mg $\Rightarrow {}^{187}\text{Re}$ activity: 1.17 Hz
- total statistics of β decay acquisition: 168 days \rightarrow "beta acquisition efficiency": 54%
 - ▷ 8751 hours \times mg (AgReO_4)
 - ▷ $16.8 \times 10^6 {}^{187}\text{Re}$ decays
- total statistics of calibration (X-ray source open): 42 days \Rightarrow 2168 hours \times mg (AgReO_4)
- Total effective measuring time: 210 days \rightarrow "measurement efficiency": 67%

► U12 for data analysis

	AgReO ₄ mass [μg]	T _{op} [mK]	R _{op} [M Ω]	shutter ON [h]	shutter OFF [h]	Beta threshold [eV]	ΔE_{FWHM} baseline [eV]	ΔE_{FWHM} at 1.5 keV [eV]	ΔE_{FWHM} at 2.6 keV [eV]	τ_{rise} [μs]
1	272.0 \pm 3.0	104.0	1.3	996.7	4037.2	350	20.1	23.7	26.3	440
2	259.0 \pm 6.0	91.3	1.9	991.7	4069.2	350	19.4	23.2	26.6	340
3	280.3 \pm 6.5	104.0	1.3	1005.9	4105.2	350	25.8	28.7	30.5	670
4	227.7 \pm 3.2								bad performances	375
5	249.7 \pm 2.0	107.1	1.2	996.3	3803.2	470	21.0	25.4	28.9	590
6	284.0 \pm 3.0	86.9	2.2	1006.7	4075.2	350	22.5	25.7	29.2	500
7	281.0 \pm 3.7								broken crystal	370
8	282.0 \pm 3.4	72.2	4.0	1013.9	4106.4	400	24.6	29.3	33.4	510
9	268.7 \pm 5.9	96.7	1.6	981.5	4017.1	400	18.4	21.3	24.9	430
10	278.3 \pm 1.5	101.3	1.4	981.9	3967.1	700	23.9	29.2	34.5	445
TOT: 7974.65 32180.7							21.9	25.5	29.1	
Array summed spectrum										

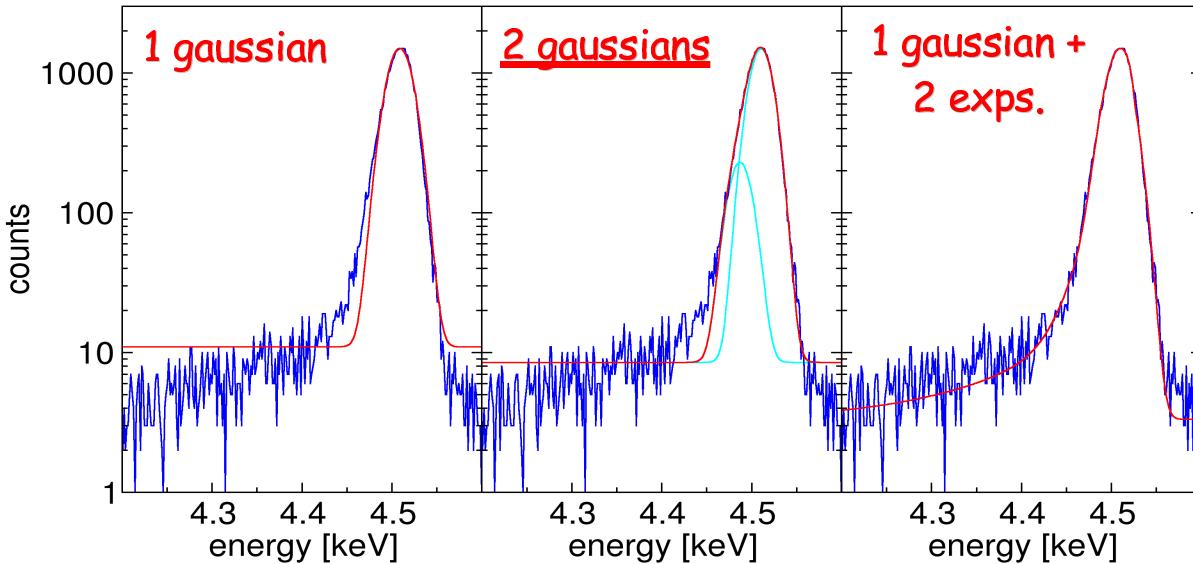
Summed X-ray spectrum

- 7975 hours×detector with fluorescence source open
- many extra peaks due to fluorescence of surrounding materials
- Cl K_α nominal position ($E_{Cl\text{ K}\alpha}=2.6217 \text{ keV}$) missed by 0.5 eV
- X-ray peaks have non-gaussian shape



Detector response function

- are the response functions for X-rays and for β s from ^{187}Re decay the same?



◆ $\lambda(6 \text{ keV}) \approx 3 \mu\text{m}$
 ◆ Absorber dimension $\approx 300 \mu\text{m}$

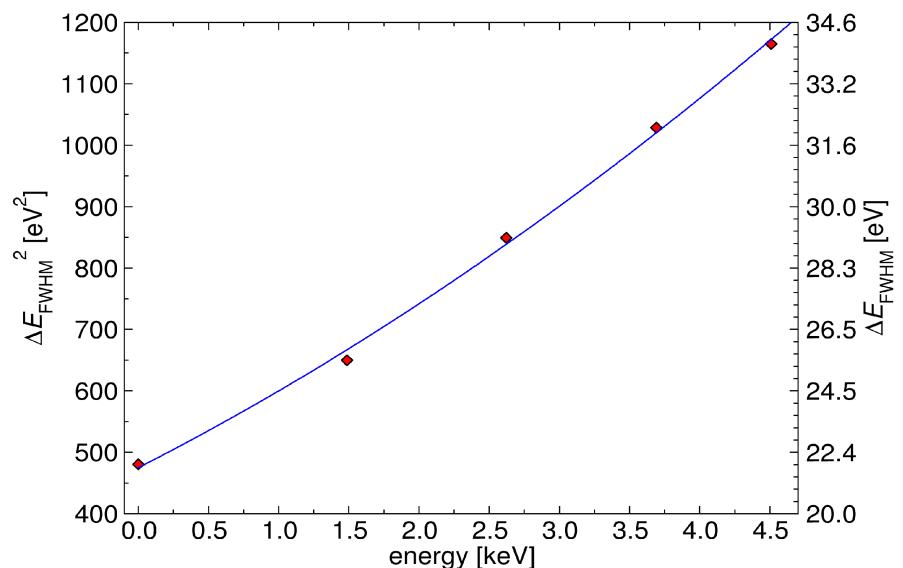
► U09

Ti K $_{\alpha}$ line: $E = 4.511 \text{ keV}$

- Energy resolution depends on energy

► U12

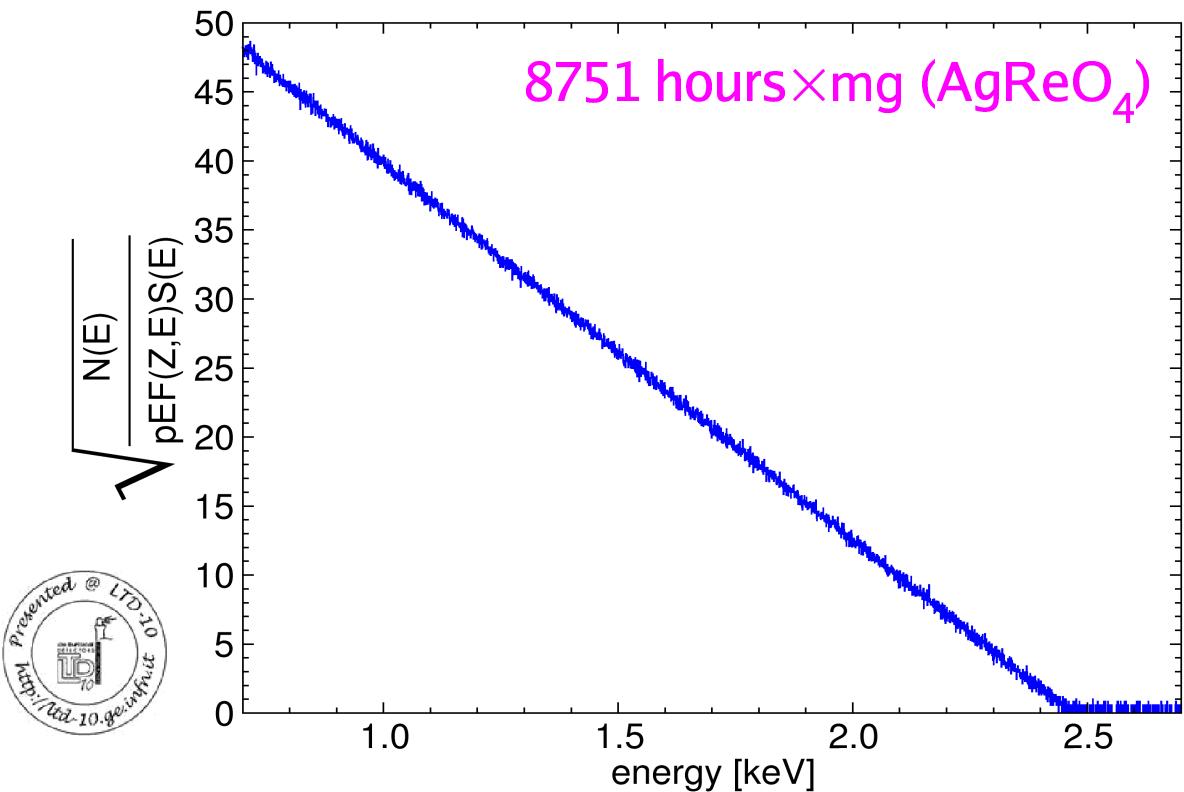
$\Delta E_{\text{FWHM}} = 28.5 \text{ eV}$
 at $E = 2.466 \text{ keV}$
 $(^{187}\text{Re } \beta \text{ end-point})$



^{187}Re β spectrum - summed Kurie plot

- 6.2×10^6 ^{187}Re decays collected above 700 eV
- Fit with the function: $F = (f_{\text{th}} + f_{\text{pup}} + f_{\text{bck}}) \otimes f_{\text{det}}$ under various assumptions for:
 - ✓ f_{det} : constant/energy dependent FWHM, single/double gaussian response
 - ✓ f_{back} : constant/linear background spectrum below β spectrum
 - ✓ f_{th} : Buhring theoretical spectrum/Buhring parametrizations

► U12



- f_{th} → theoretical spectrum
- $f_{\text{pup}} = f_{\text{th}} \otimes f_{\text{th}}$ → pile-up spectrum
- f_{bck} → background spectrum
- f_{det} → detector response function

Free fit parameters:

- β end-point
- m^2_{ν}
- β spectrum normalization
- pile-up spectrum normalization
- background level

^{187}Re end-point energy

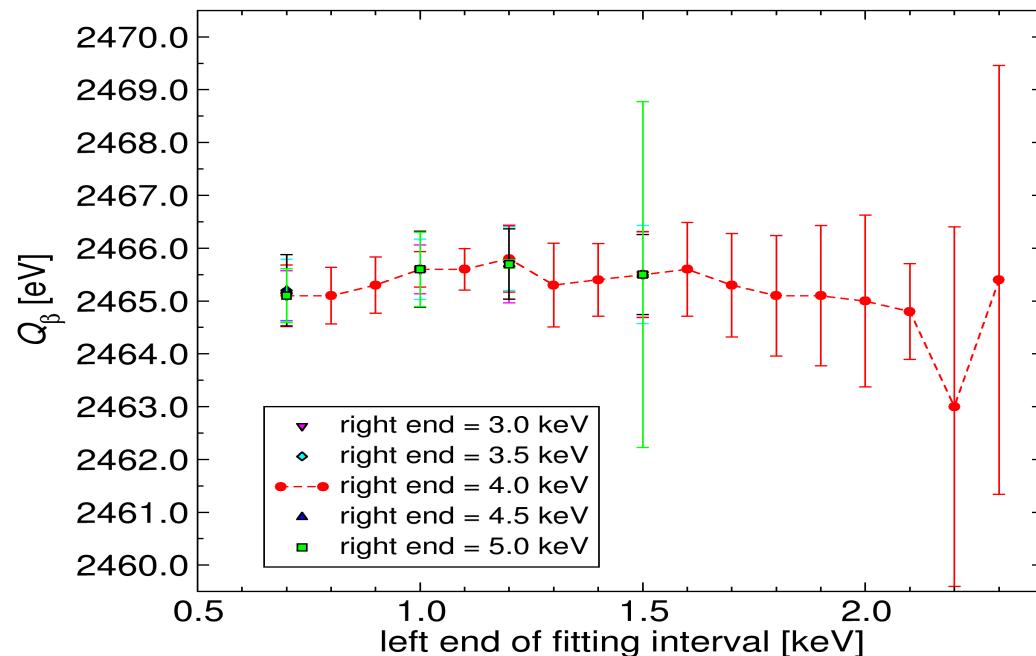


$$Q = 2465.3 \pm 0.5_{\text{stat}} \pm 1.6_{\text{sys}} \text{ eV}$$

Fitting interval: 0.9 ÷ 4 keV

Preliminary

→ Most precise value for ^{187}Re



Q value is stable with respect to
fitting interval



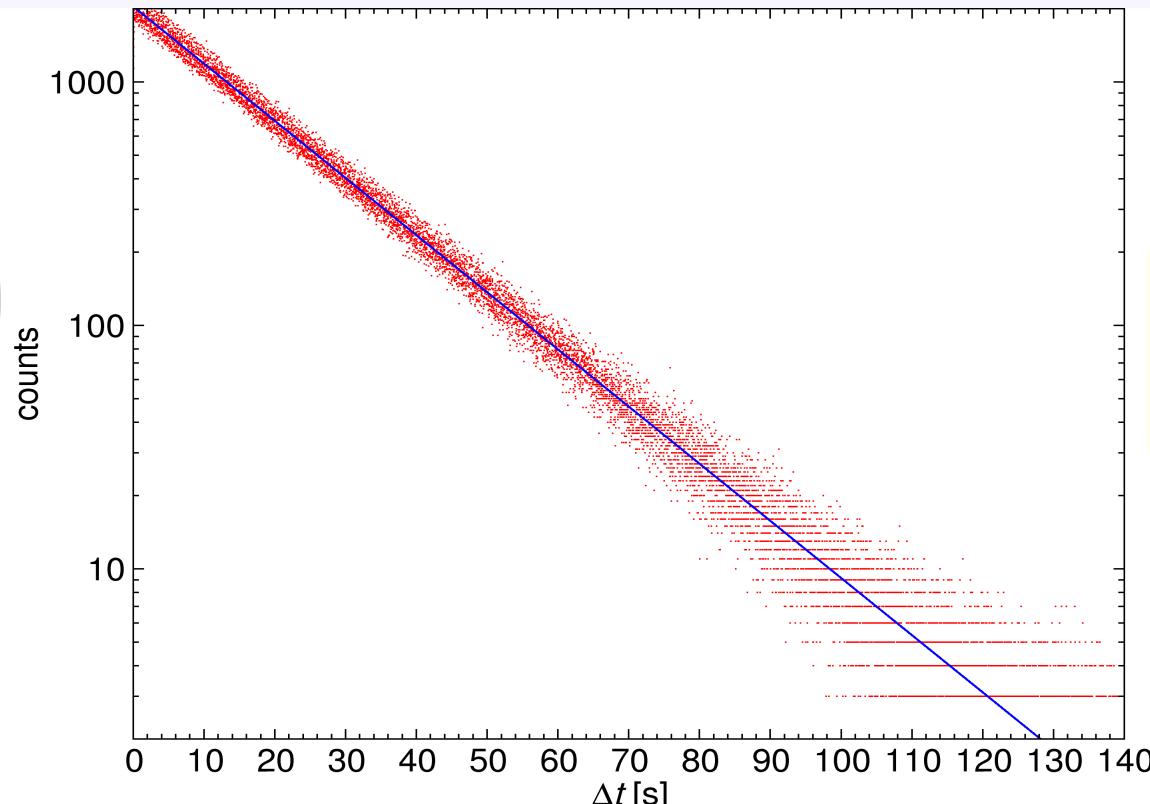
good description by fit function F

→ evaluation of systematics in different energy intervals
is in progress ...

187Re half lifetime

$$\tau_{1/2} = 43.2 \pm 0.2_{\text{stat}} \pm 0.1_{\text{sys}} \text{ Gy}$$

- ◆ From distribution of time intervals Δt between ^{187}Re β decays
- ◆ statistical error mainly from uncertainties in the masses
- ◆ systematic error mainly from uncertainties in the pile-up discrimination
 - ▷ most precise published value; especially relevant for geochronology



$$\begin{aligned} - N(\Delta t) &= A e^{-r \Delta t} \\ r &\equiv \beta \text{ decay rate} \\ r &\propto 1 / \tau_{1/2} \end{aligned}$$

Neutrino mass



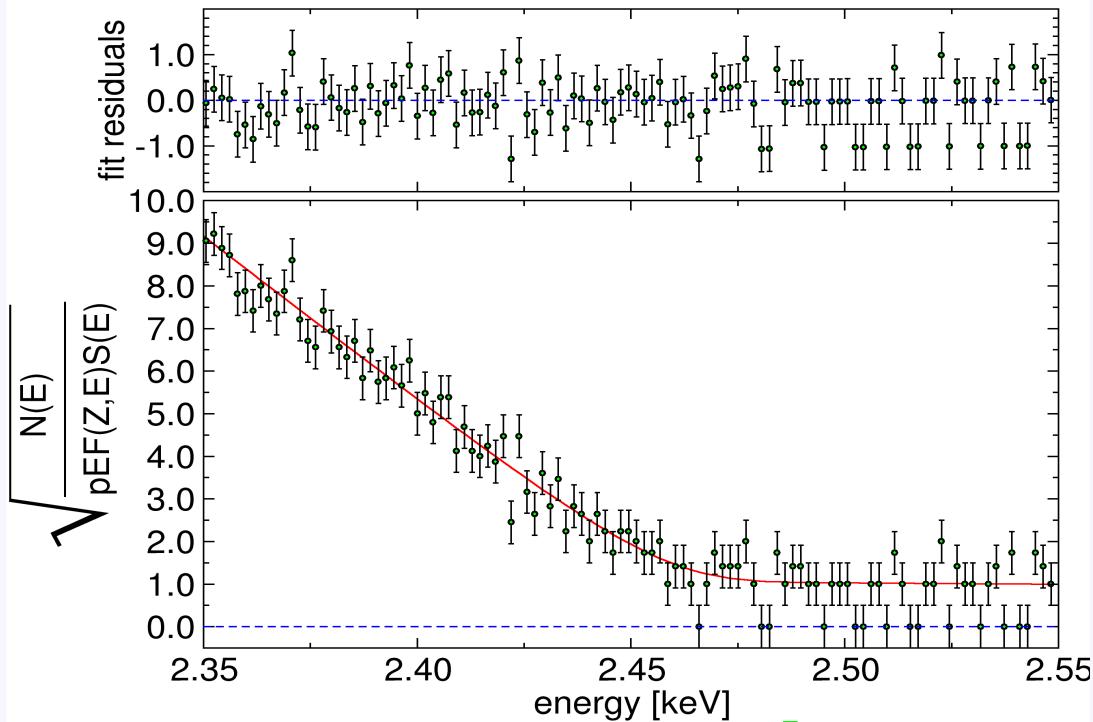
$$m_\nu^2 = -112 \pm 207_{\text{stat}} \pm 90_{\text{sys}} \text{ eV}^2$$



$$m_\nu < 15 \text{ eV} (90 \% \text{ C.L.})$$

Fitting interval: 0.9 ÷ 4 keV

Preliminary



- ◆ gaussian response function with $\Delta E_{\text{FWHM}} = 28.5 \text{ eV}$
- ◆ free constant backg.: $7 \times 10^{-3} \text{ c/keV/h}$
⇒ S/N (Q-30 eV ÷ Q) ~ 12
- ◆ free pile-up fraction $f_{\text{pile-up}}$: 1.9×10^{-4}
⇒ $\chi^2/\text{d.o.f.} = 0.905$

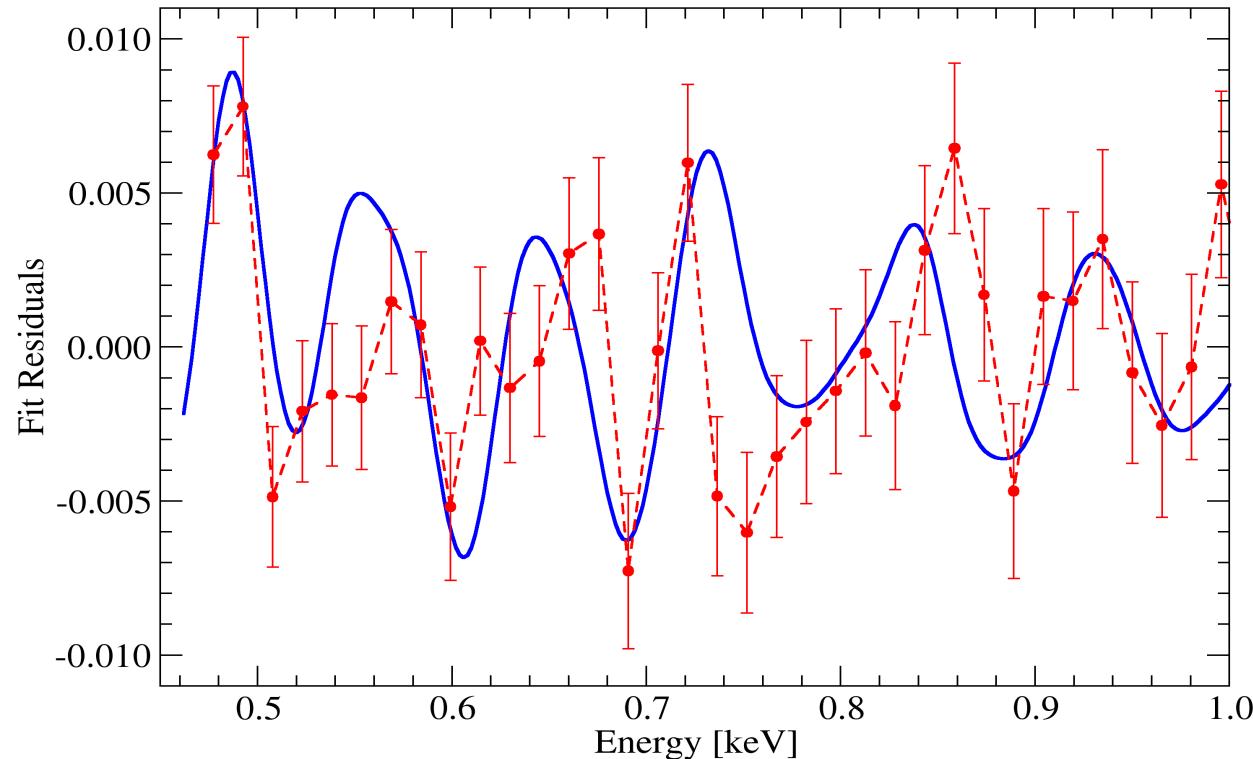
► U12

→ evaluation of systematics in different energy intervals
is in progress ...

Beta Environmental Fine Structure (BEFS)

- Theoretical prediction for $\Delta E_{FWHM} = 30\text{eV}$
- Experimental data:
 - threshold: 470 eV
 - statistics: $32157 \text{ h} \times \text{det}$ (added old meas.)

→ analysis still in progress ...



Preliminary

Outlook and Future

- ❖ High statistic measurement of ^{187}Re spectrum run uninterrupted for more than 10 months with big reproducibility
- ❖ A preliminary limit $m_{\nu} < 15 \text{ eV (90% C.L.)}$ has been set on the electron antineutrino mass
- ❖ A measurement for the “internal” calibration of the detectors to investigate the energy response function is foreseen this fall ► U11

- A new Milano calorimetric neutrino mass search has been proposed with improved sensitivity on $m_{\nu} \Rightarrow$ goal: $m_{\nu} \sim 2\text{-}3 \text{ eV}$ before KATRIN experiment starts ➔ U10
- R&D phase will start soon!



"Internal" calibration of AgReO₄ detectors

- Escape peaks allow internal calibration
 - ▷ $\lambda(6 \text{ keV}) \approx 3 \mu\text{m}$
 - ▷ $\lambda(70 \text{ keV}) \approx 400 \mu\text{m}$
- Escape peaks following incident X-rays are intrinsically broad \Rightarrow seen in previous high statistic measurement with Pb-Re K-K escapes
 - ▷ $\Gamma_{\text{escape KK}} = \Gamma_{\text{PbK}} + \Gamma_{\text{ReK}} \approx 60.2 \text{ eV} + 42.1 \text{ eV} = 102 \text{ eV}$



► U11

► U09

Internal calibration with ⁴⁴Ti

- γ rays @ 78.4 keV
- no intrinsic broadening

Re K-edge @ 71.7 keV

γ -X escape peaks have only ReK intrinsic width (~ 42 eV)

