New CUORICINO results and the CUORE project

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on behalf of the CUORE collaboration

Outline:

- CUORICINO
- CUORICINO construction
- CUORICINO detector performance
- CUORICINO results
- CUORICINO background
- Perspectives for CUORE

NOON2004 - 11th -15th February 2004, Tokyo Japan

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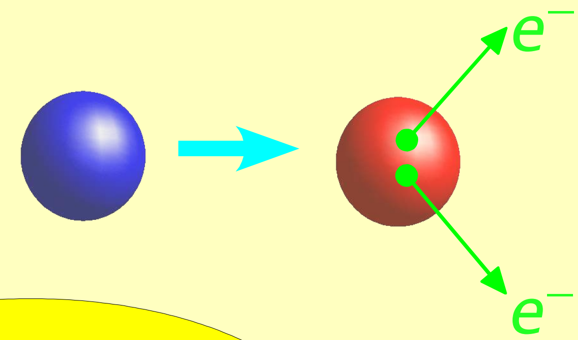
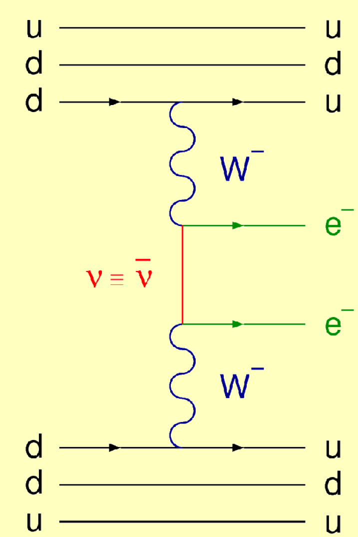
Neutrinoless Double Beta Decay

$\beta\beta$-0ν: $(A, Z) \rightarrow (A, Z+2) + 2e^-$

- **not allowed in Standard Model:**
  - *lepton number violation ($\Delta L=2$)*
  - *Majorana nature of neutrino*
  - *massive neutrino*





$$\beta\beta\text{-}0\nu \Leftrightarrow \begin{matrix} m_\nu \neq 0 \\ \nu \equiv \bar{\nu} \end{matrix}$$

- **expected lifetime:**

Phase space factor

nuclear matrix element

uncertainties

$$\tau^{-1} = G_{0\nu} |M^{0\nu}|^2 |\langle m_\nu \rangle|^2$$

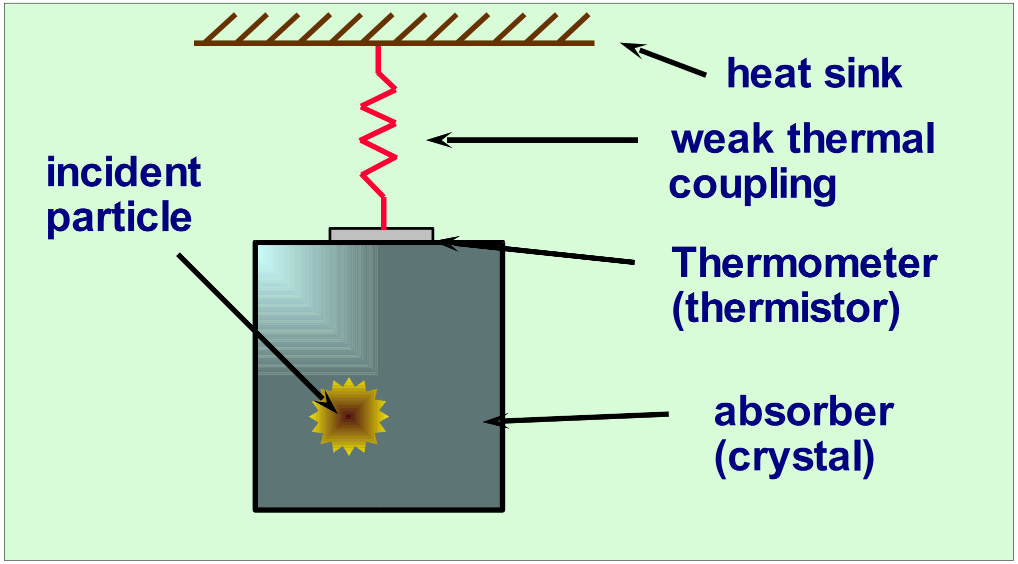
Effective neutrino mass

$$\langle m_\nu \rangle = \sum_k m_{\nu_k} \eta_k |U_{ek}|^2$$

neutrino mixing matrix

⇨ **constraints on $\langle m_\nu \rangle$ can translate in constraints on m_{min}**

Low Temperature Detectors (LTD)



Detection Principle

- $\Delta T = E/C$
  C thermal capacity
  - ⇨ low C
    - ⇨ low T (i.e. $T \ll 1$K)
    - ⇨ dielectrics, superconductors
- ultimate limit to sensitivity: statistical fluctuation of internal energy U
  $\langle \Delta U^2 \rangle = k_B T^2 C$

Thermal Detectors Properties

- ▲ high energy resolution
- ▲ large choice of absorber materials
- ▲ true calorimeters
- ▼ slow $\tau = C/G \sim 1 \div 10^3$ ms

example: 760 g of TeO_2 @ 10 mK

$C \sim T^3$ (Debye) $\Rightarrow C \sim 2\times10^{-9}$ J/K

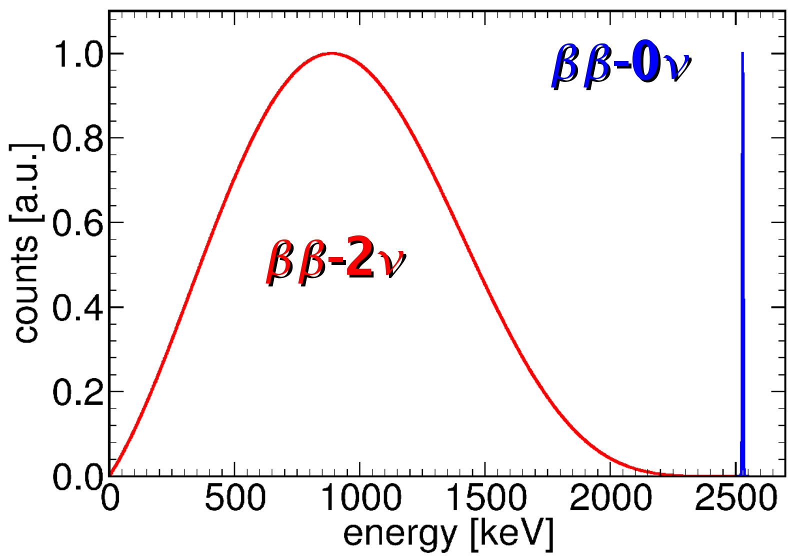
1 MeV γ-ray $\Rightarrow \Delta T \sim 80\ \mu$K

$\Rightarrow \Delta U \sim 10$ eV

TeO2 LTD's

Calorimeters

- source ⊆ detector
  - large N_{nuclei}
  - high energy resolution ΔE
  - high efficiency
- measure $E = E_{\beta_1} + E_{\beta_2}$
- signature: a peak at $Q_{\beta\beta}$



TeO_2 thermal calorimeters

- Active isotope ^{130}Te
  - natural abundance: a.i. = 33.9%
  - transition energy: $Q_{\beta\beta}$ = 2529 keV
  - encouraging predicted half life $\langle m_\nu \rangle \approx 0.3$ eV $\Leftrightarrow \tau_{1/2}^{0\nu} \approx 10^{25}$ years
- Absorber material TeO_2
  - low heat capacity
  - large crystals available
  - radiopure

$\tau_{1/2}^{0\nu}$ sensitivity

measuring time [y]

detector mass [kg]

detector efficiency

$$\sum(\tau_{1/2}^{0\nu}) \propto \epsilon \cdot \frac{a.i.}{A} \sqrt{\frac{M\, t_{meas}}{\Delta E \cdot bkg}}$$

isotopic abundance
atomic number

energy resolution [keV]

background [c/keV/y/kg]

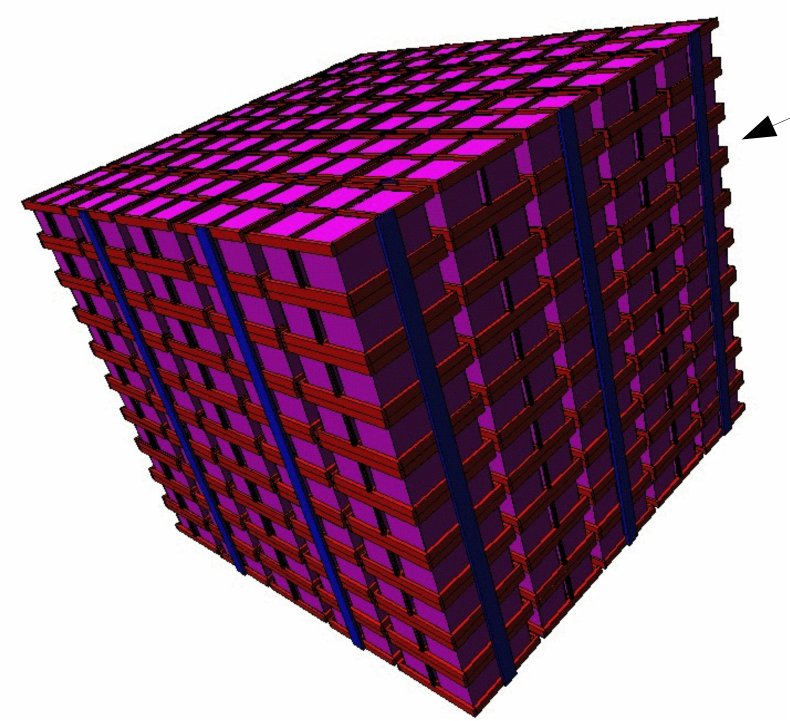
The CUORE project

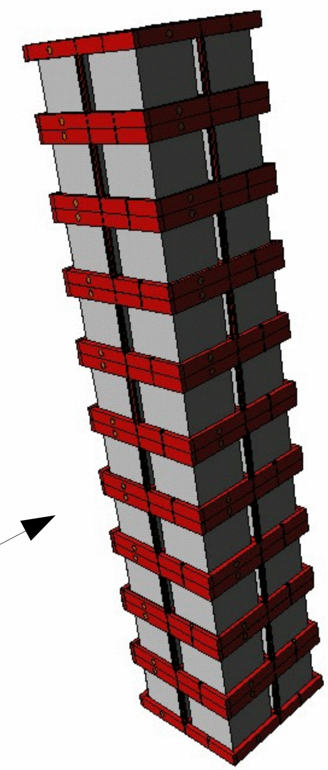
Cryogenic Underground Observatory for Rare Events

- **array of 1000 TeO_2 crystals 5×5×5 cm^3 (750 g)**
  - **750 kg TeO_2 granular calorimeter**
  - **600 kg Te = 203 kg ^{130}Te**
- **$\beta\beta$-0ν, Cold Dark Matter, Axions searches**

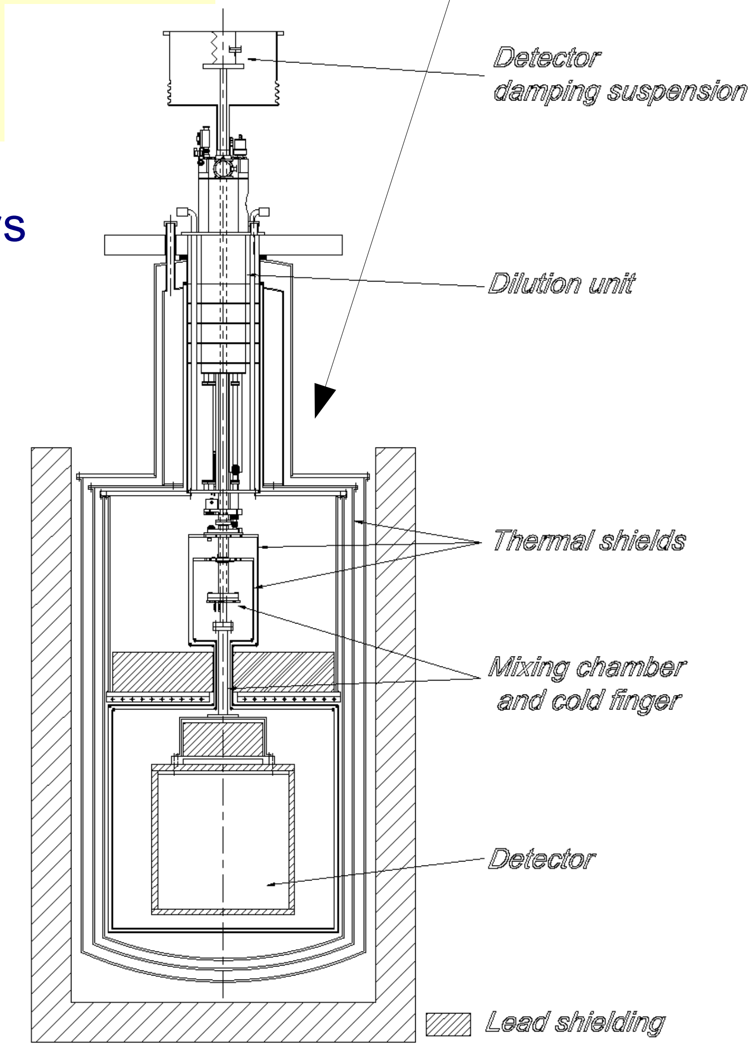
single dilution refrigerator (~ 10 mK)

Crystals grouped in a 5x5 matrix of 25 towers





Single tower: ten (4 crystal) modules

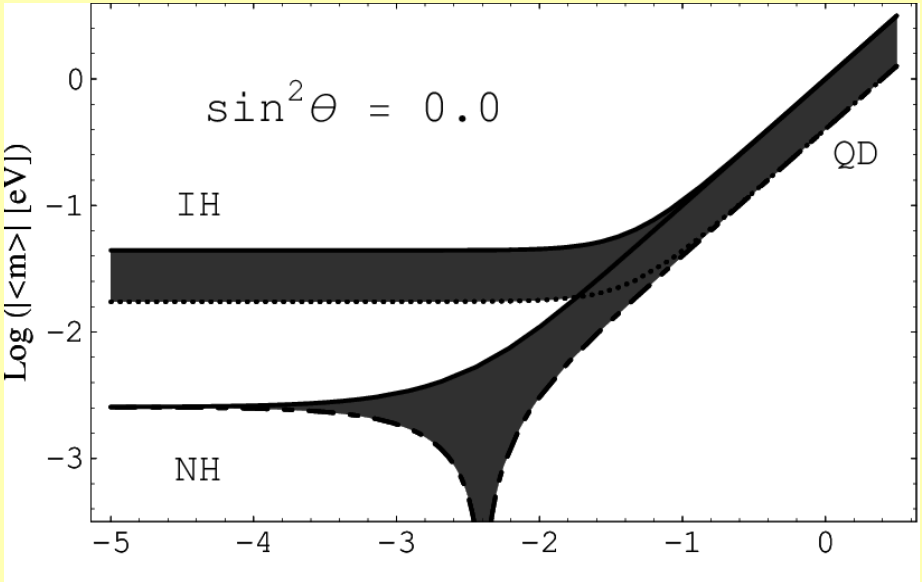


CUORE expected sensitivity

CUORE $\beta\beta(0\nu)$ sensitivity will depend strongly on the background level and detector performance. In five years:

B(counts/keV/kg/y)	Δ(keV)	$T_{1/2}$(y)	$\lvert\langle m_\nu \rangle\rvert$ (meV)
0.01	10	1.5×10^{26}	23–118
0.01	5	2.1×10^{26}	19–100
0.001	10	4.6×10^{26}	13–67
0.001	5	6.5×10^{26}	11-57

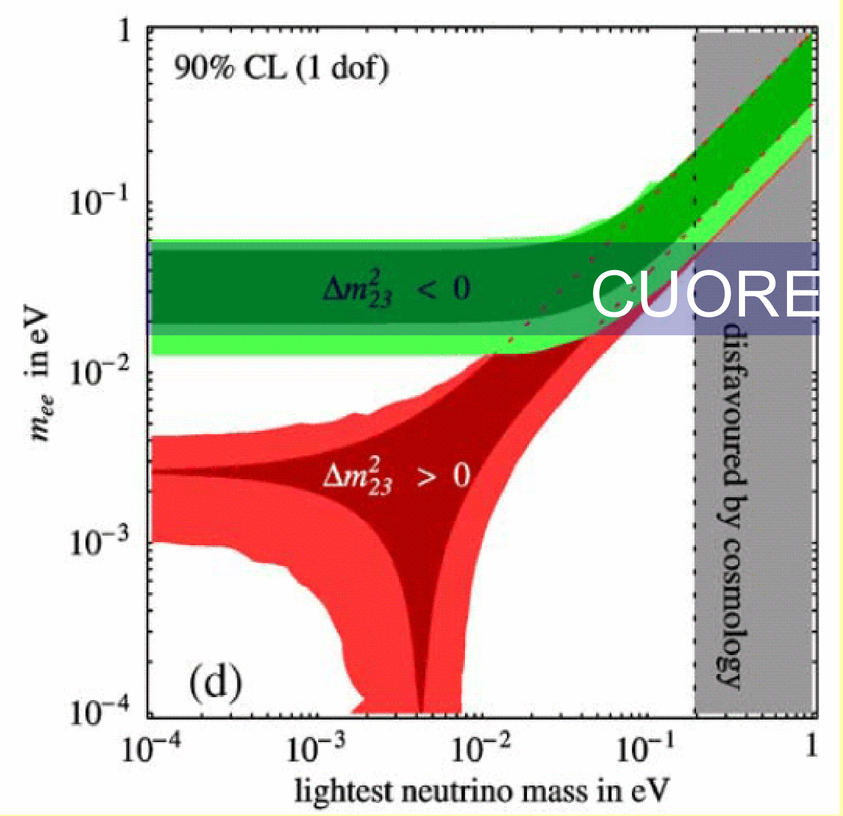
Pascoli and Petcov.: hep-ph/0310003



2003 LMA update

(SNO+salt, atmospheric,CHOOZ, KamLAND

Feruglio et al.: Nucl. Phys. B659 (2003) 359



Spread in $\langle m_\nu \rangle$ from nuclear matrix element uncertainty

CUORICINO

Slightly modified single **CUORE** *tower*

test:

- large mass TeO_2 detectors
- *tower*-like structure of **CUORE** sub-elements
- background origin and reduction techniques

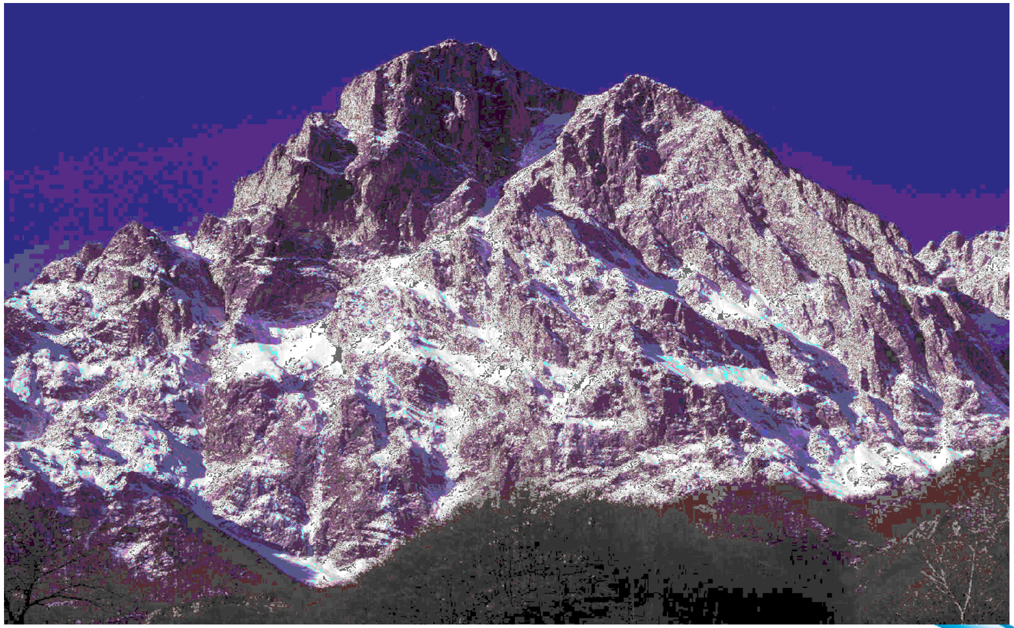
independent experiment:

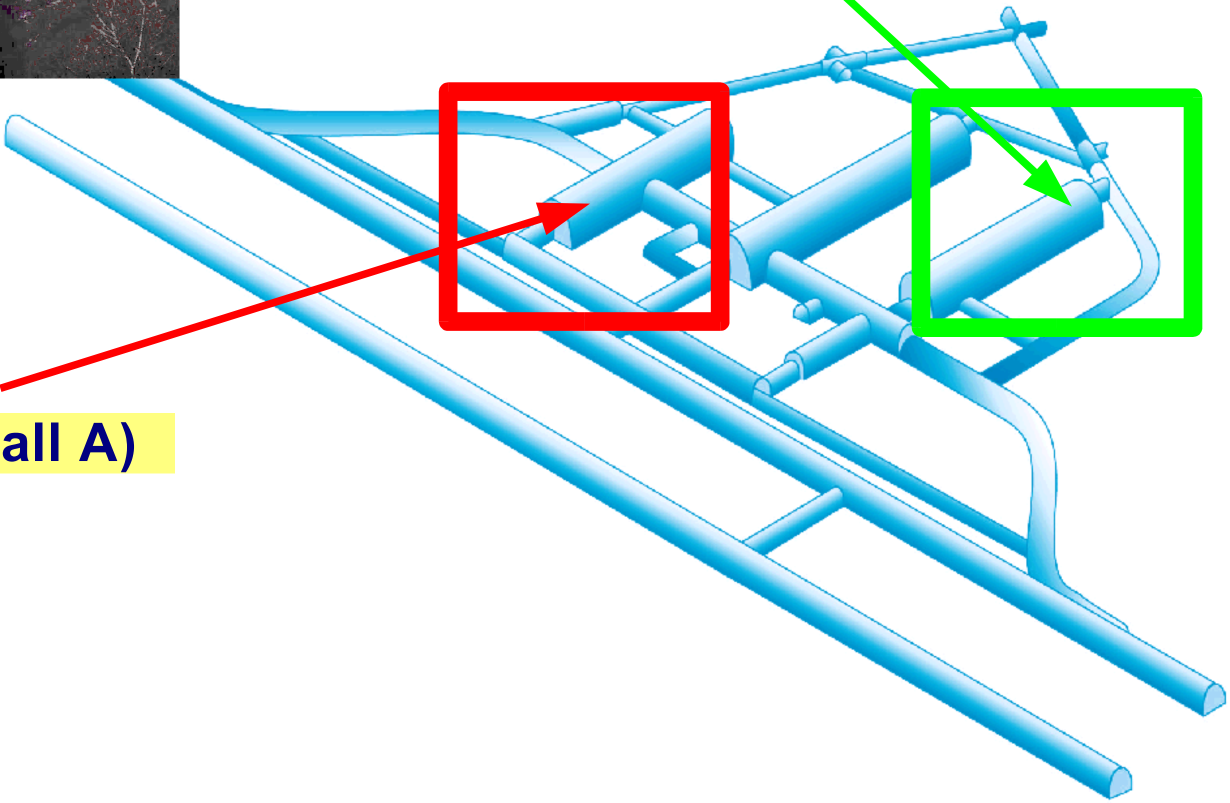
- important results on
  - ^{130}Te Neutrinoless Double Beta Decay
  - WIMP Dark Matter

Laboratori Nazionali del Gran Sasso, Hall A

same cryostat which hosted Mi-DBD 20 crystal array

LNGS LTD Underground Facilities



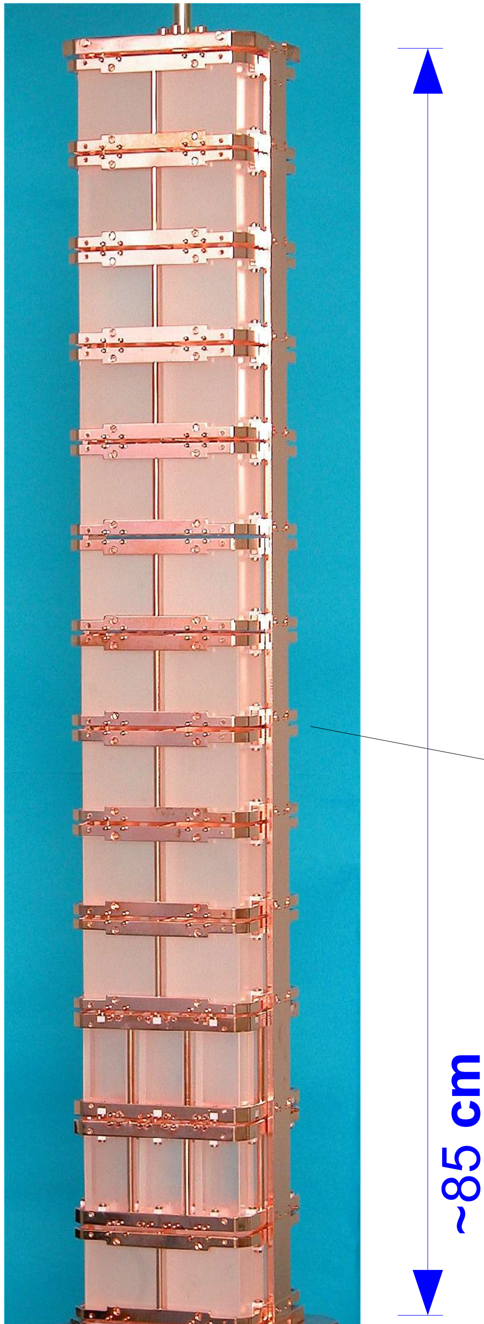


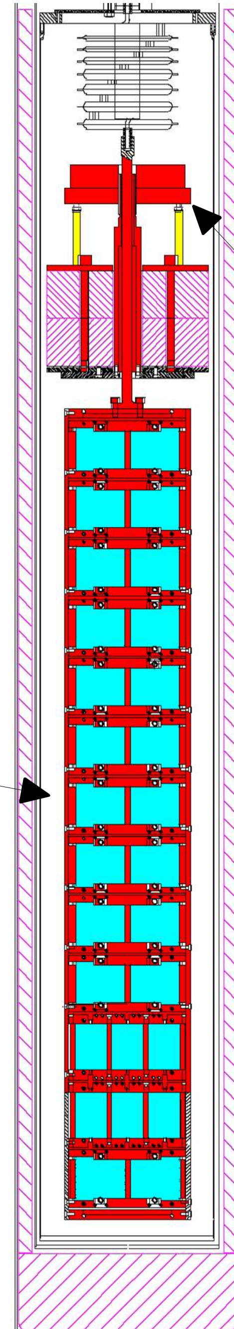
CUORE R&D (Hall C)

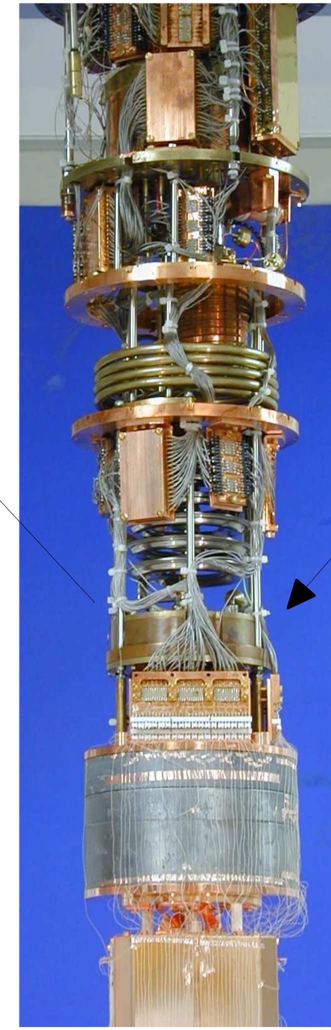
CUORICINO (Hall A)

CUORICINO tower

Cuoricino *tower*: 62 TeO_2 crystals







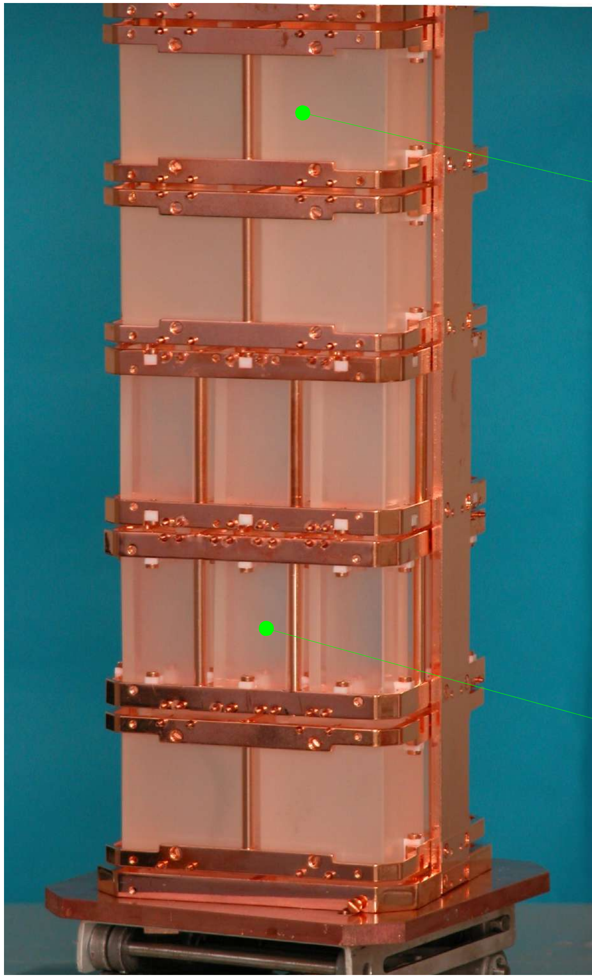
mixing chamber
***T* ≈ 6 mK**

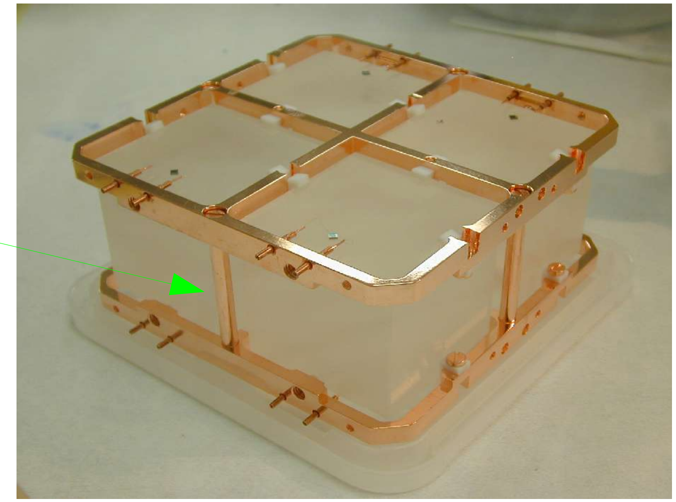
roman Pb shielding (1 cm lateral)

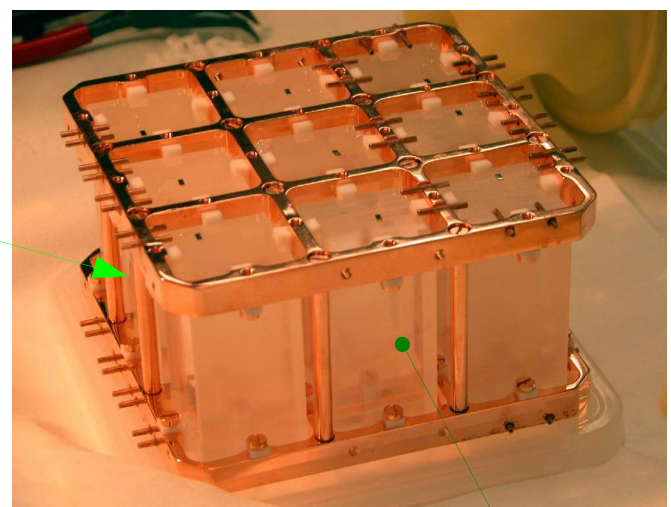
external shields:

- 10 cm Pb + 10 cm low act Pb
- neutron shield: B-polyethylene
- nitrogen flushed anti-radon box

CUORICINO tower (2)





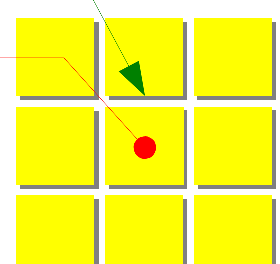


- **11 modules with 4 detectors**
  - 44 TeO_2 crystals
  - $5\times5\times5$ cm^3 ⇒ 790 g
  - **TeO_2 mass ⇒ 34.76 kg**

Total number of detectors: 62

- **2 modules with 9 detectors**
  - 18 TeO_2 crystals
  - $3\times3\times6$ cm^3 ⇒ 330 g
  - **TeO_2 mass ⇒ 5.94 kg**
- **4 crystals are enriched**
  - $2\times{}^{130}TeO_2 + 2\times{}^{128}TeO_2$

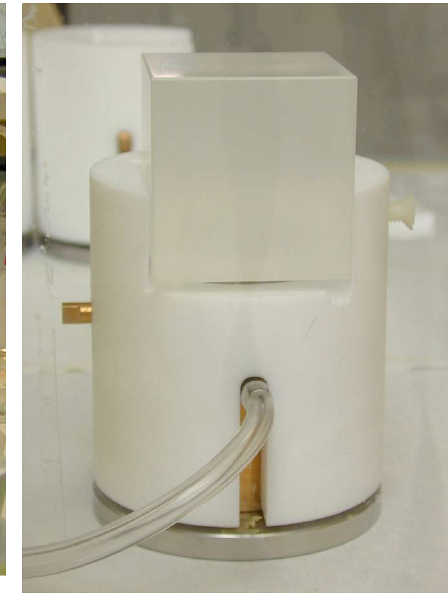
central crystal has a 4π *active shielding*
like in CUORE configuration
⇒ anti-coincidence for **background reduction**



- **total active mass**
  - **$TeO_2 \rightarrow 40.7$ kg**
  - **$^{130}Te \rightarrow 14.1$ kg**
  - **$^{128}Te \rightarrow 0.54$ kg**

CUORICINO assembly

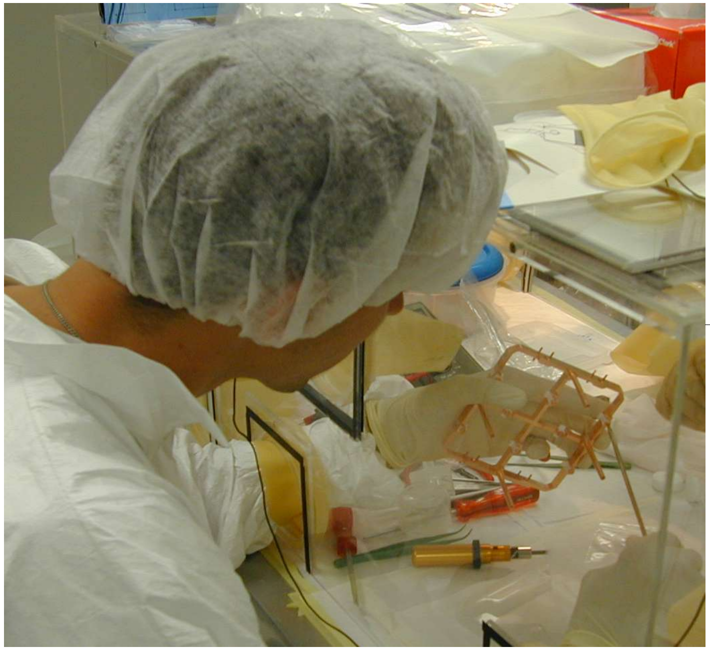
crystal surface cleaning



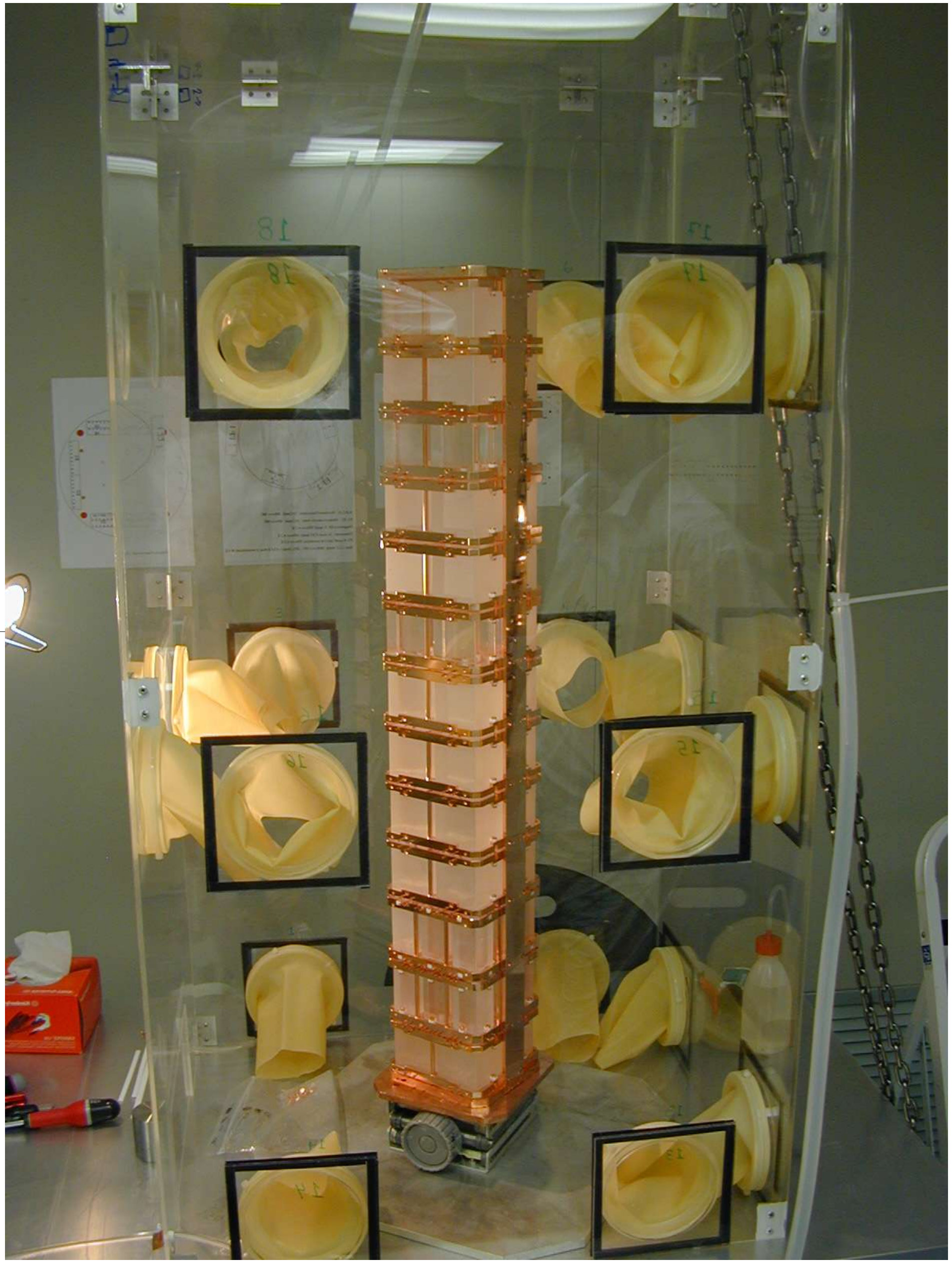
thermistor & heater gluing

- careful material selection
- careful cleaning of Cu and TeO_2 surfaces
- clean conditions for detector assembling
  - clean room
  - nitrogen atmosphere to avoid radon contaminations

CUORICINO assembly (2)



detector frame

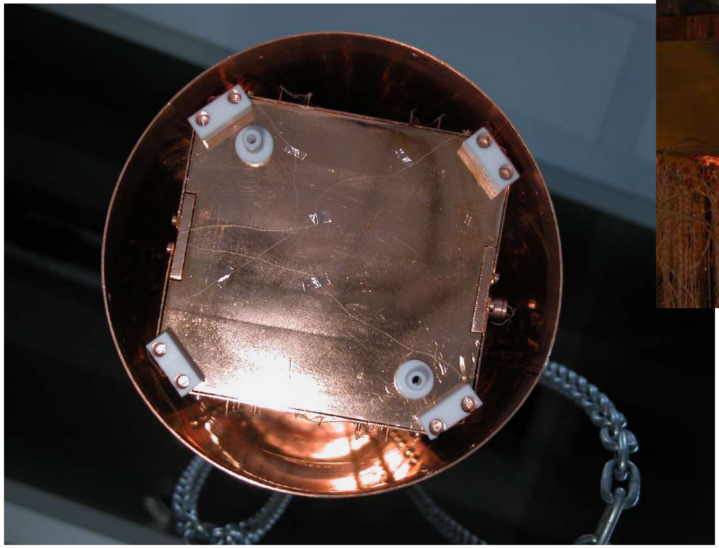


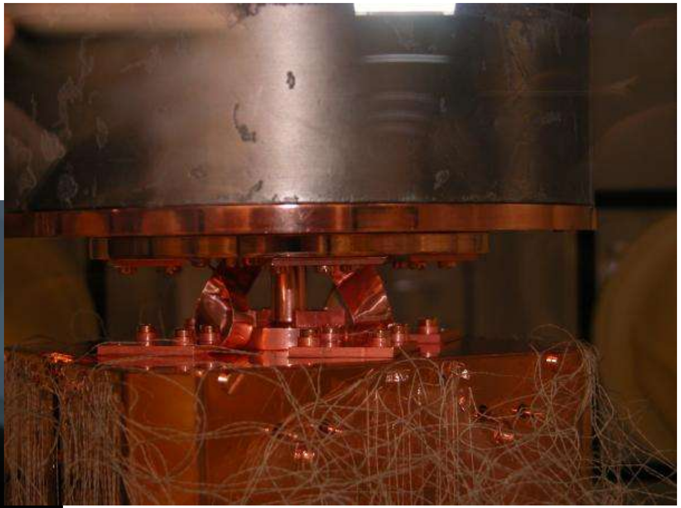
tower

4 detector module

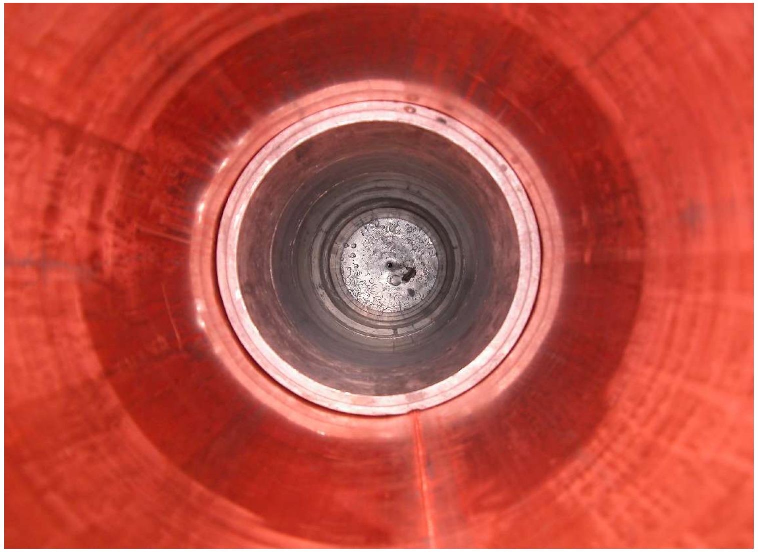
CUORICINO final assembly

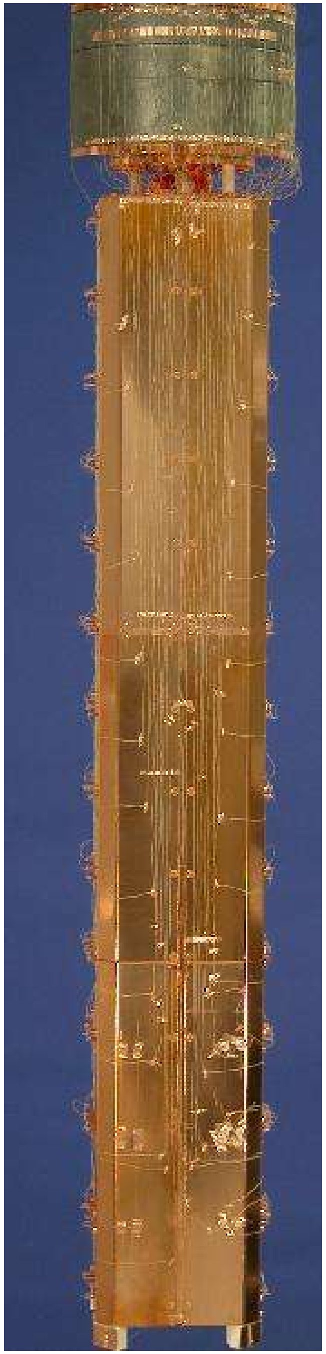
Tower positioning system





Roman lead shield and suspension





Detector performance

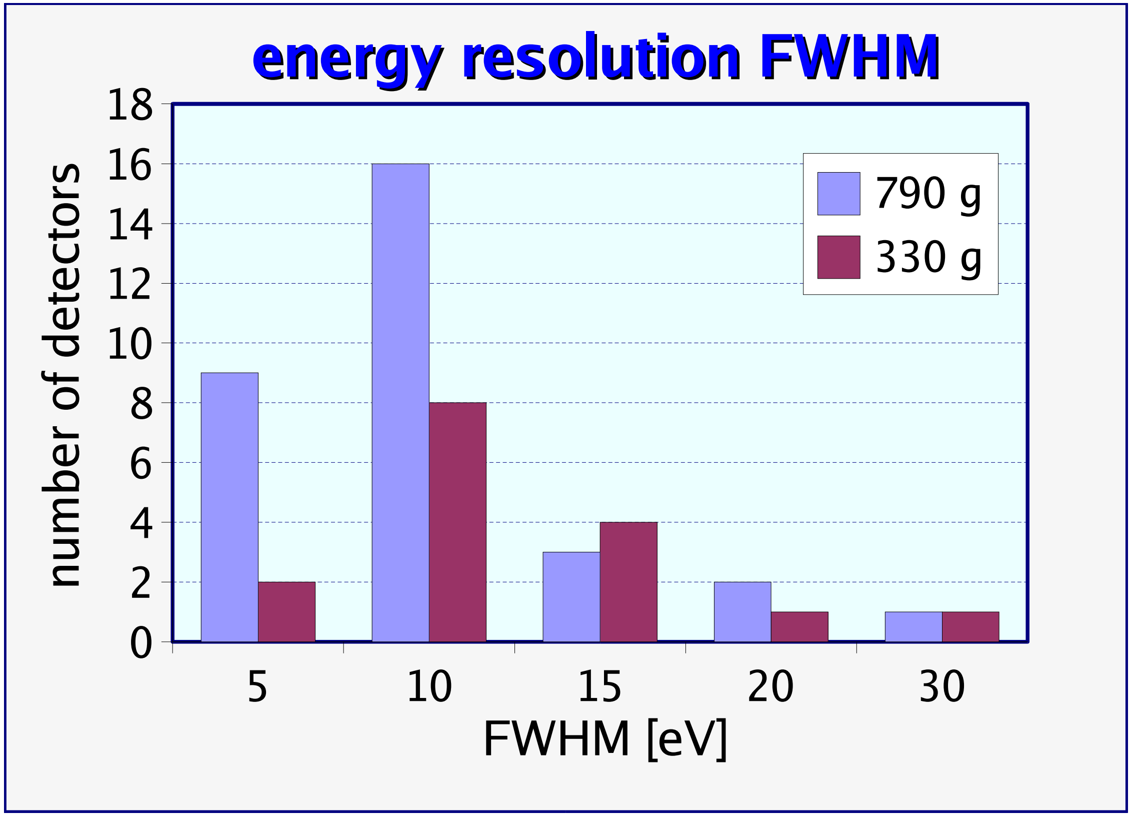
- **Wiring system failure during cooldown**
  - ⇒ few detectors disconnected
  - ► 330 g crystals: 16 working
    - ▸ 3.96 kg of TeO_2
  - ► 790 g crystals: 32 working
    - ▸ 25.28 kg of TeO_2

cool down: february 2003
start: april 19^{th}, 2003
stop I: june 23^{rd}, 2003 (LNGS temporary stop)
stop II: november 1^{st} 2003 (wiring repair)

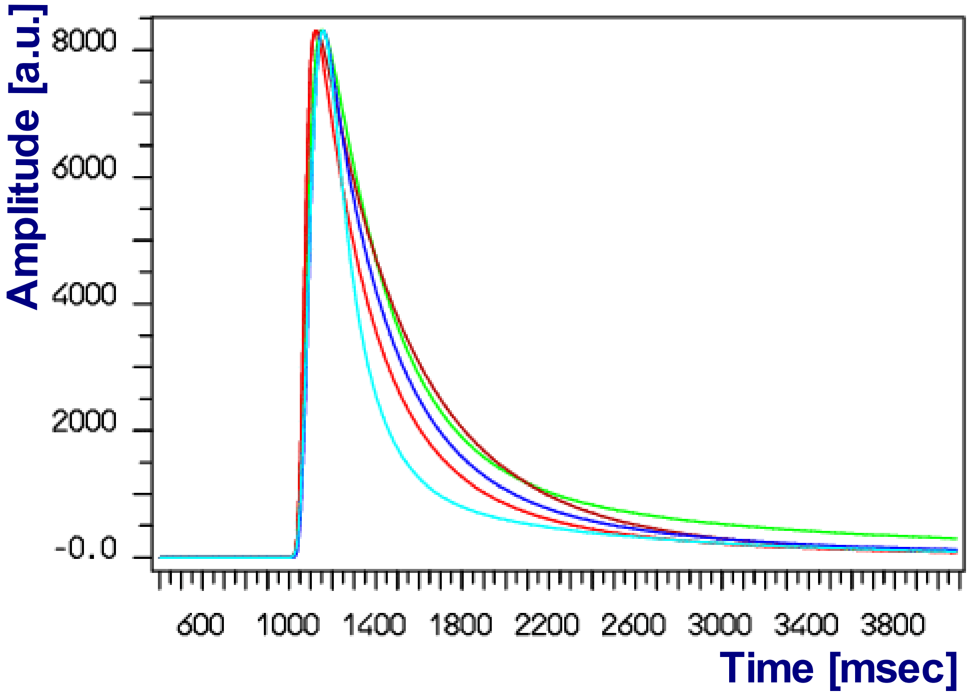
total working mass
- ▹ ^{130}Te: 10.4 kg
- ▹ ^{128}Te: 0.54 kg

average (FWHM) energy resolutions
- 790 g → $\langle \Delta E_{FWHM} \rangle \approx 7$ keV
- 330 g → $\langle \Delta E_{FWHM} \rangle \approx 9$ keV

2615 keV ^{208}Tl γ-line
- ▸ 3 days calibration
- ▸ external ^{232}Th source

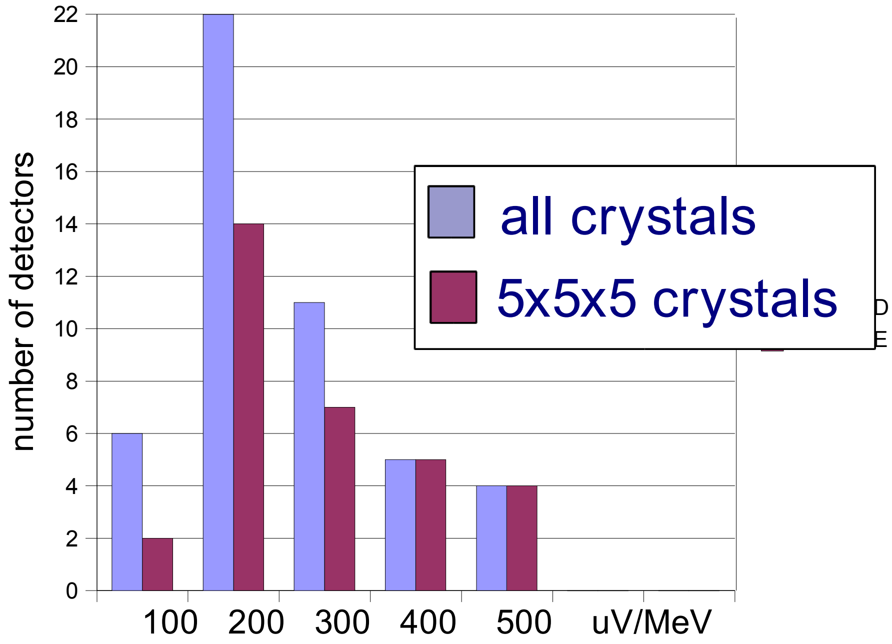


Detector response



Pulse shape
- raise time: tens msec
- decay time: hundreds msec

Pulse height (normalized to 1 kg of TeO2)

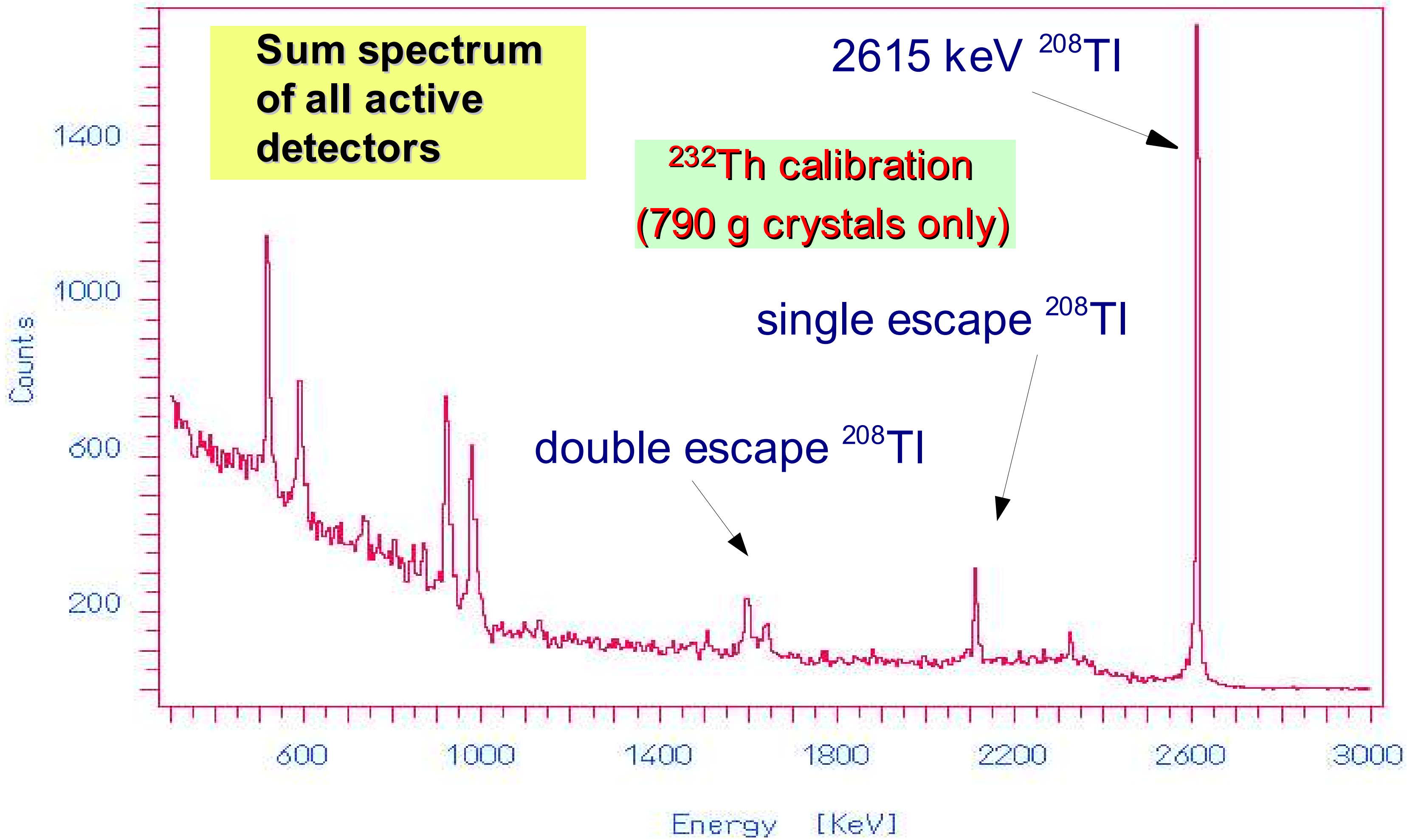


Average pulse height distribution
- 5x5x5 crystals: 340 μV/MeV
- 3x3x6 crystals: 440 μV/MeV

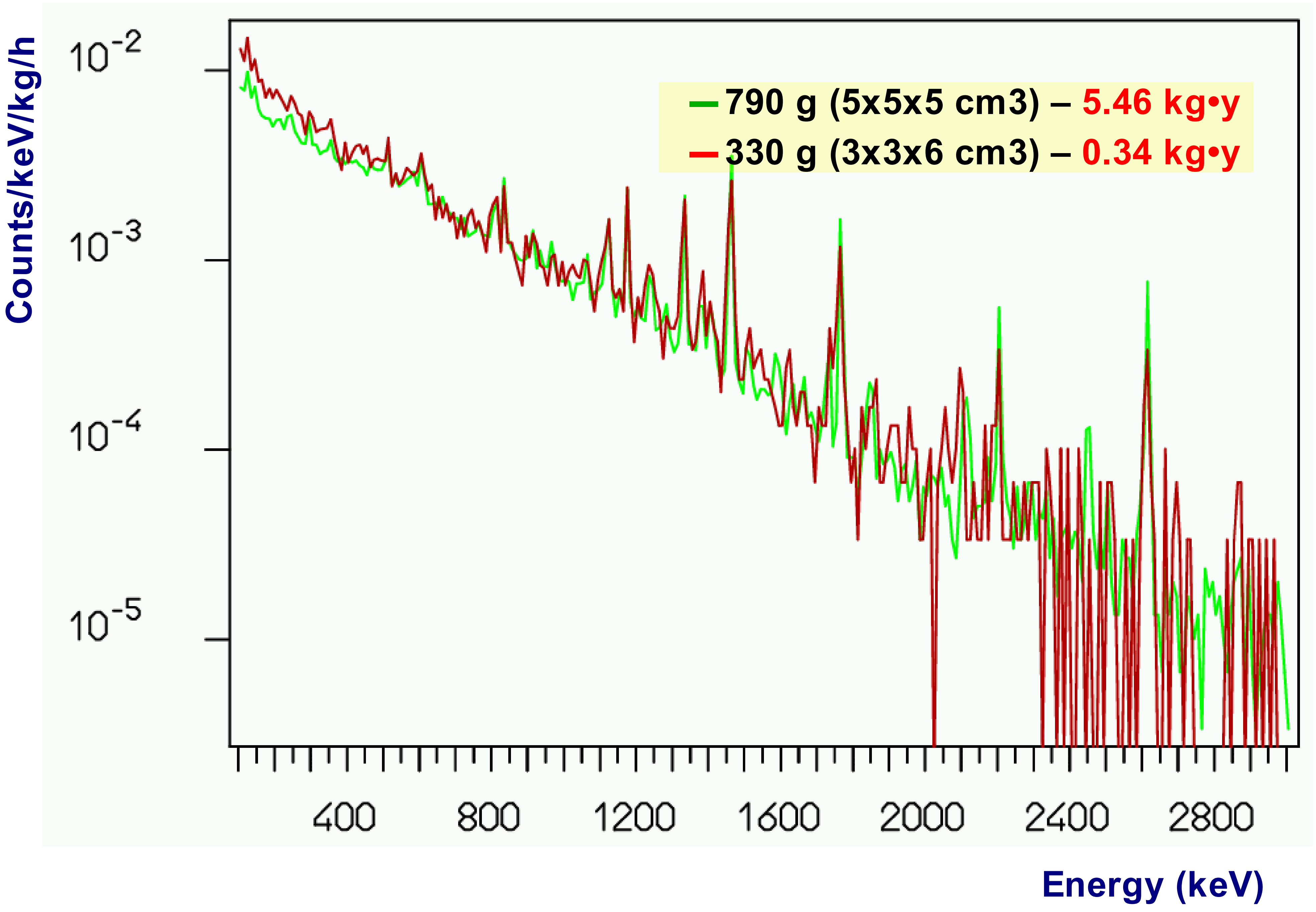
Detector performance: γ-source calibrations

^{232}Th (and ^{238}U) γ-sources
- **External to the cryostat in contact with OVC**

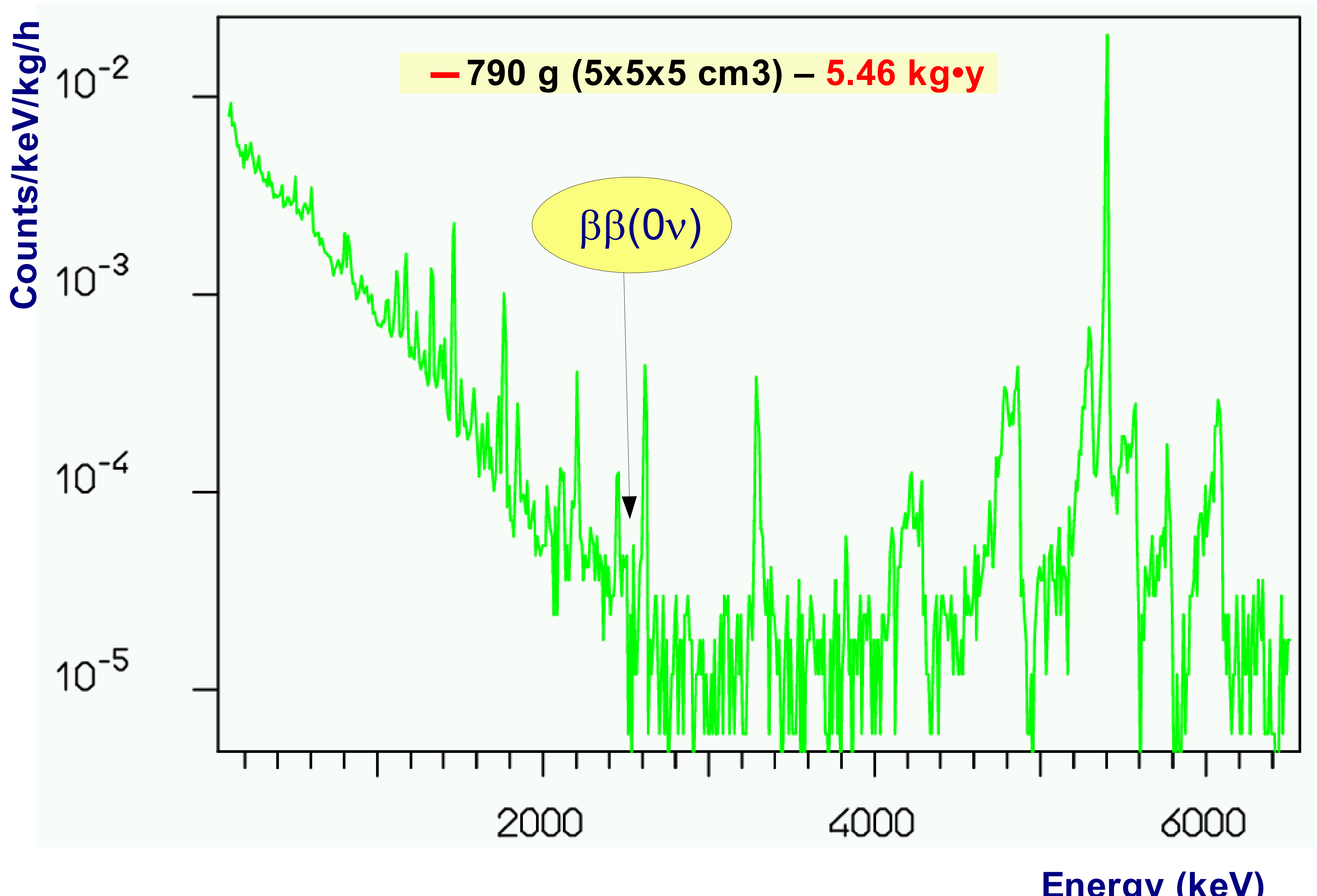
$\langle \Delta E \rangle$ = 7 keV @ 2615 keV



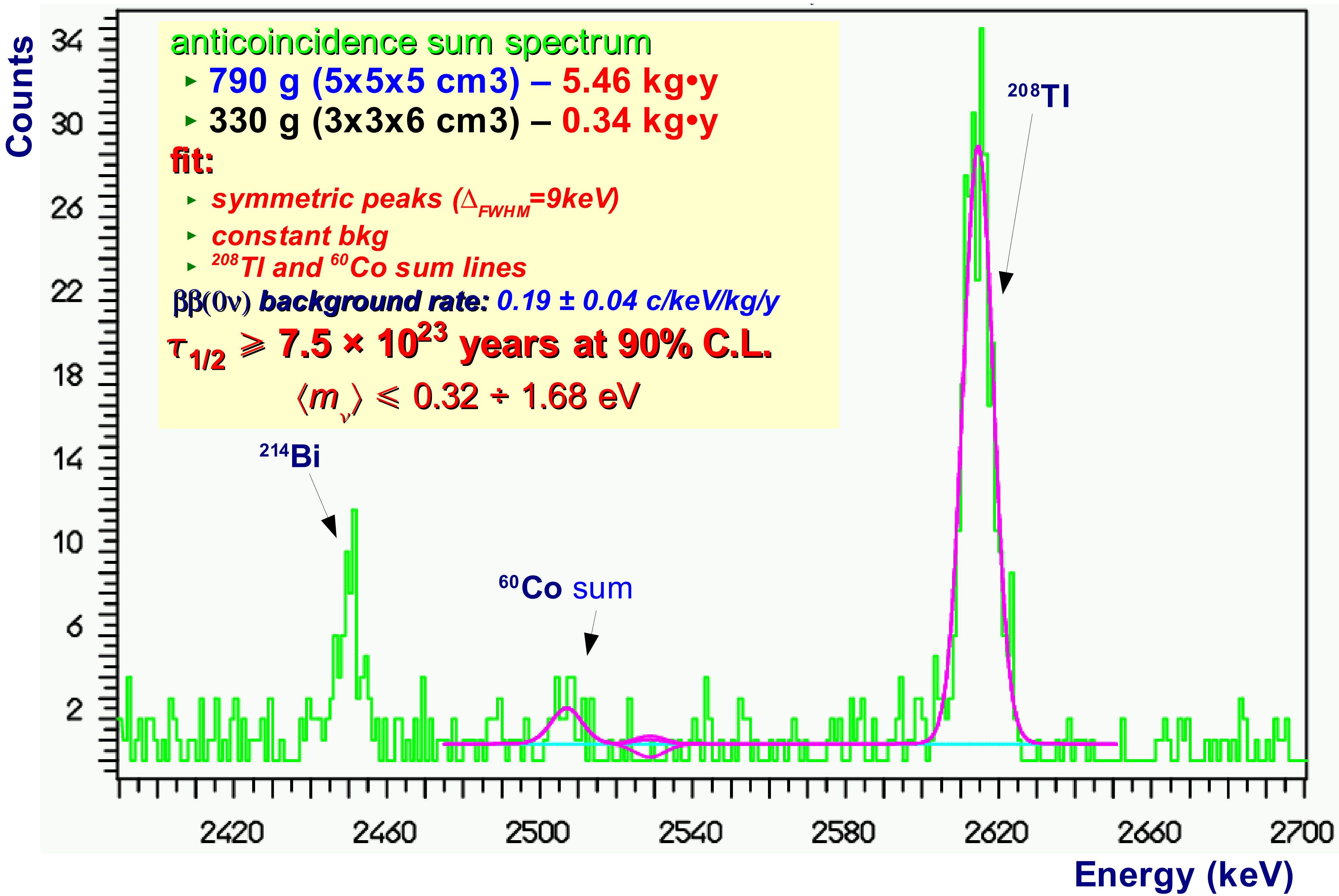
Background measurements: γ-region



Background measurements: α-region



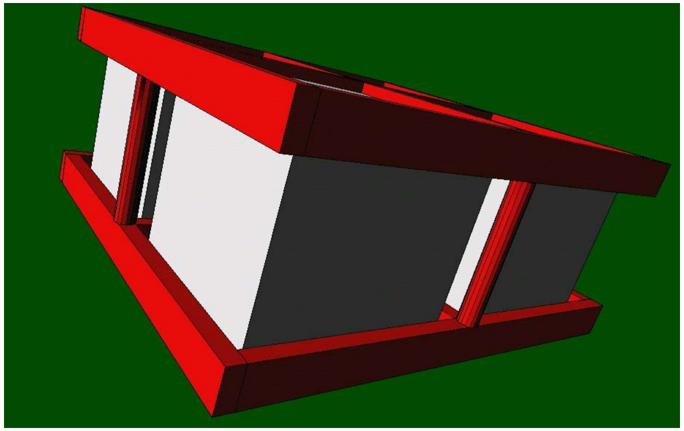
Updated ββ(0ν) results



Background model

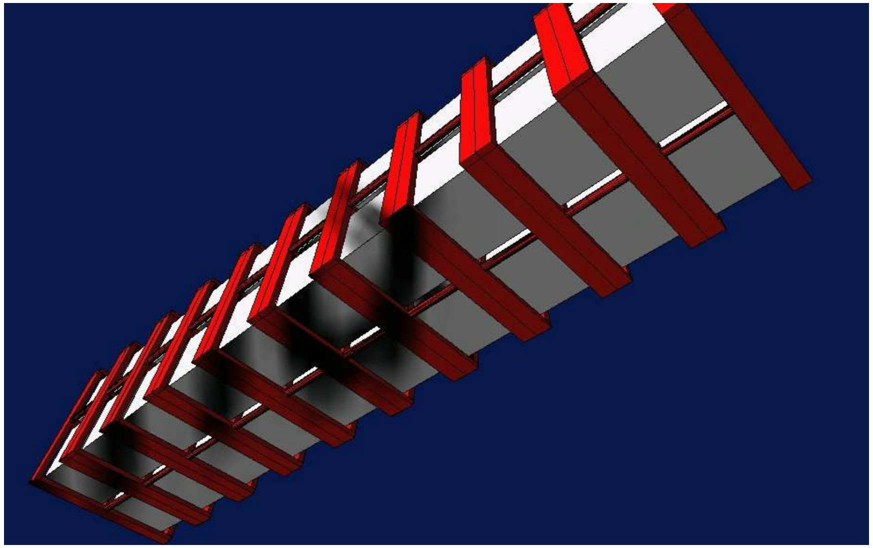
Background sources

- bulk contaminations of setup materials
- cosmic rays
- Neutrons
- surface contaminations ($e^{-\lambda x}$) of detector elements



Experimental measurements

- MiDBD I+II
- CUORICINO



Monte Carlo simulations

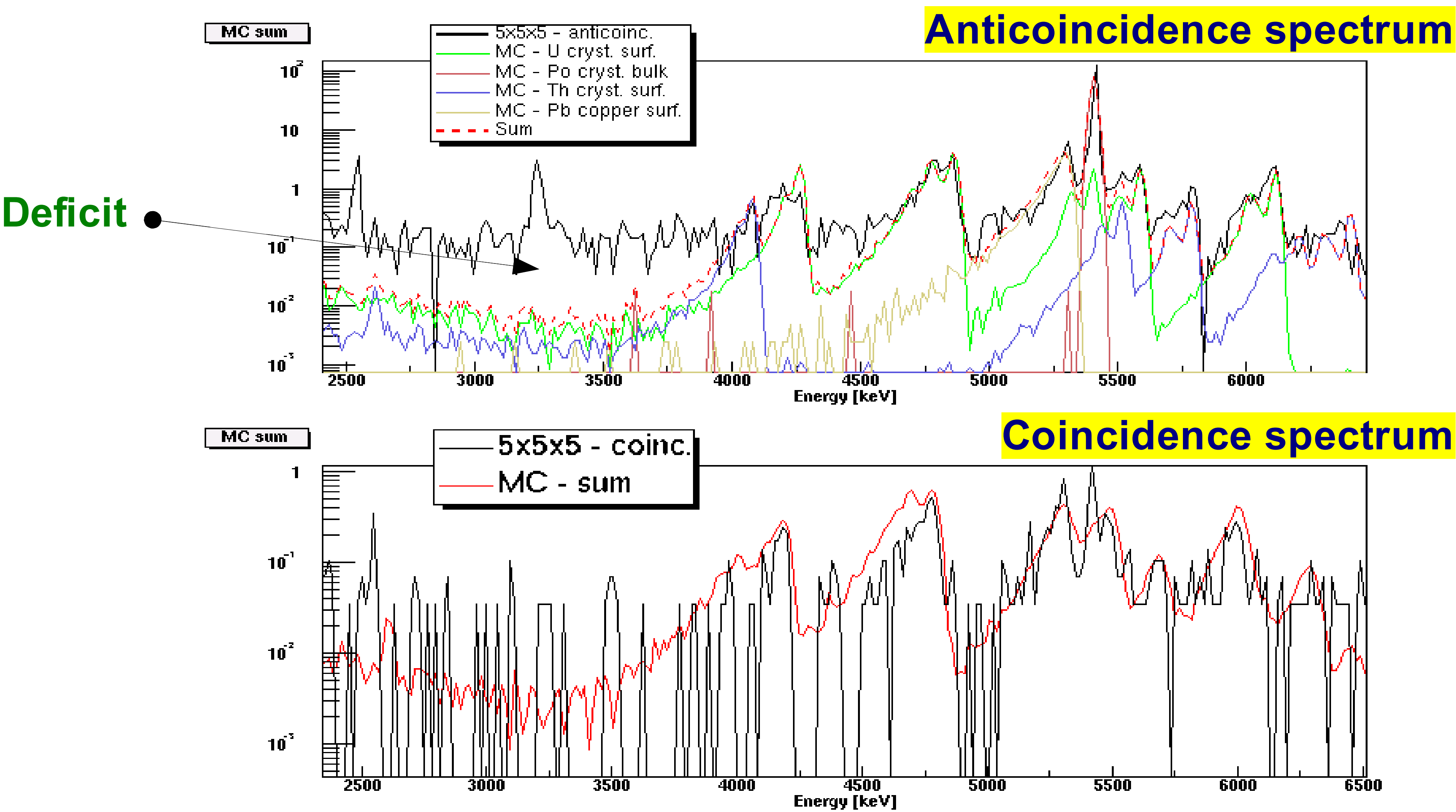
- GEANT4 (+decay chains generator)
- FLUKA
- COSMO

detailed description of

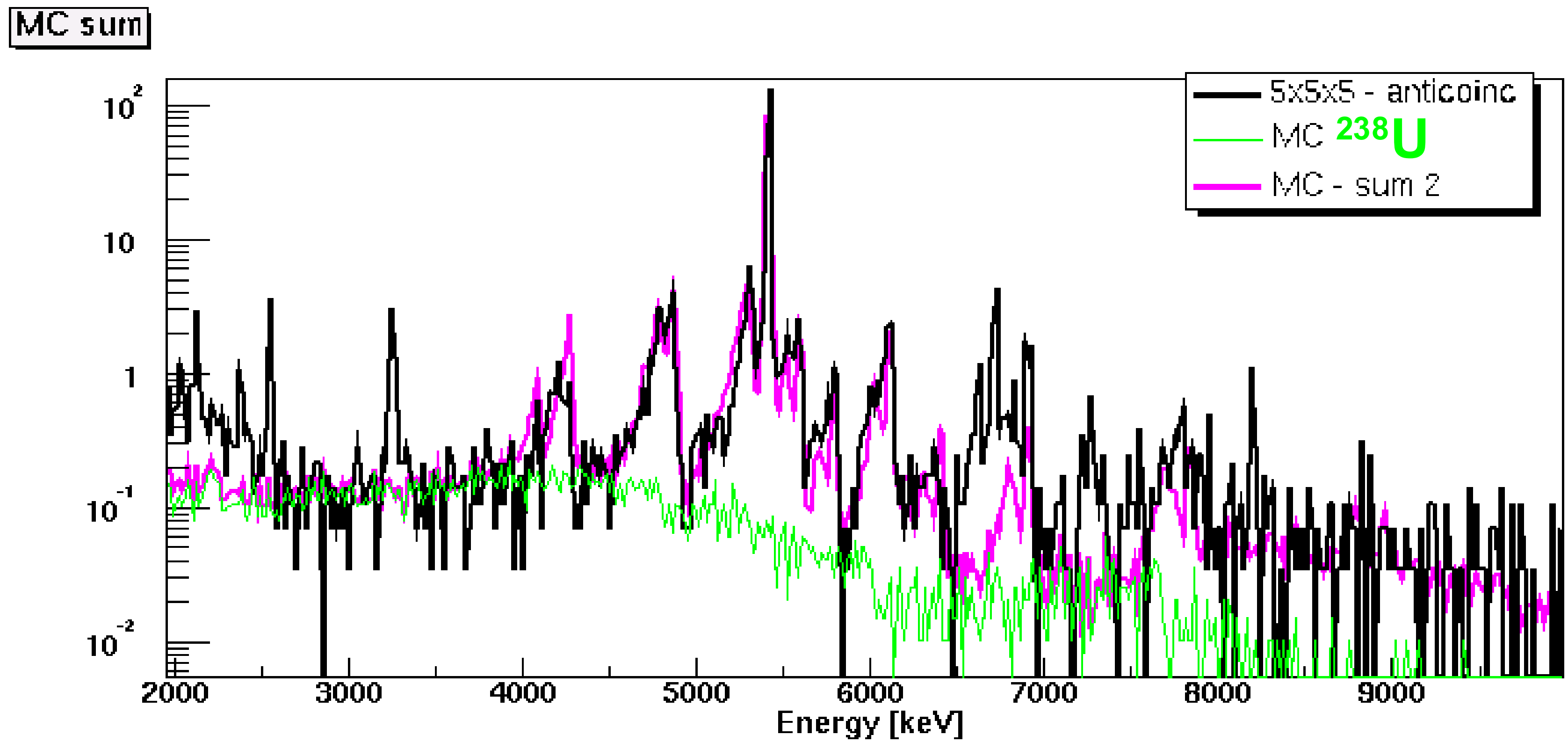
- Detector
- Cryogenic setup
- Radiatiopn shields

Background model: α peaks

U & Th (s.e.) **crystal** surface contaminations (λ~0.2-1 μm)
^{210}**Po crystal** bulk contamination (*5.4 MeV peak)*
^{210}**Pb copper** surface contamination (λ< 0.1 μm) (*5.3 MeV peak)*



Background model: continuum



U & Th (s.e.) **crystal** surface contaminations (λ~0.2-1 μm)
^{210}**Po crystal** bulk contamination (*5.4 MeV peak)*
^{210}**Pb copper** surface contamination (λ< 0.1 μm) (*5.3 MeV peak)*

+

U or Th or ^{210}Pb copper ("deep") surface contaminations (λ~10 μm)

Background results and CUORE perspectives

CUORICINO

γ-region

- bulk contaminations of detector and cryogenic setup materials
  - required contamination levels in agreement with Ge detector measurements

α-region

- surface contaminations of detector materials (crystal & mounting structure)
  - exponential density profile ($e^{-\lambda x}$: λ=0.1-10 μm)
  - required contamination levels (when considered as distributed over a thin surface layer) are 2-3 orders of magnitude larger than the bulk values of the corresponding materials
- **preliminary** HR ICPMS measurements of CUORICINO copper samples seem to confirm both contamination levels and density profiles
- **Surface cleaning procedure can be improved**

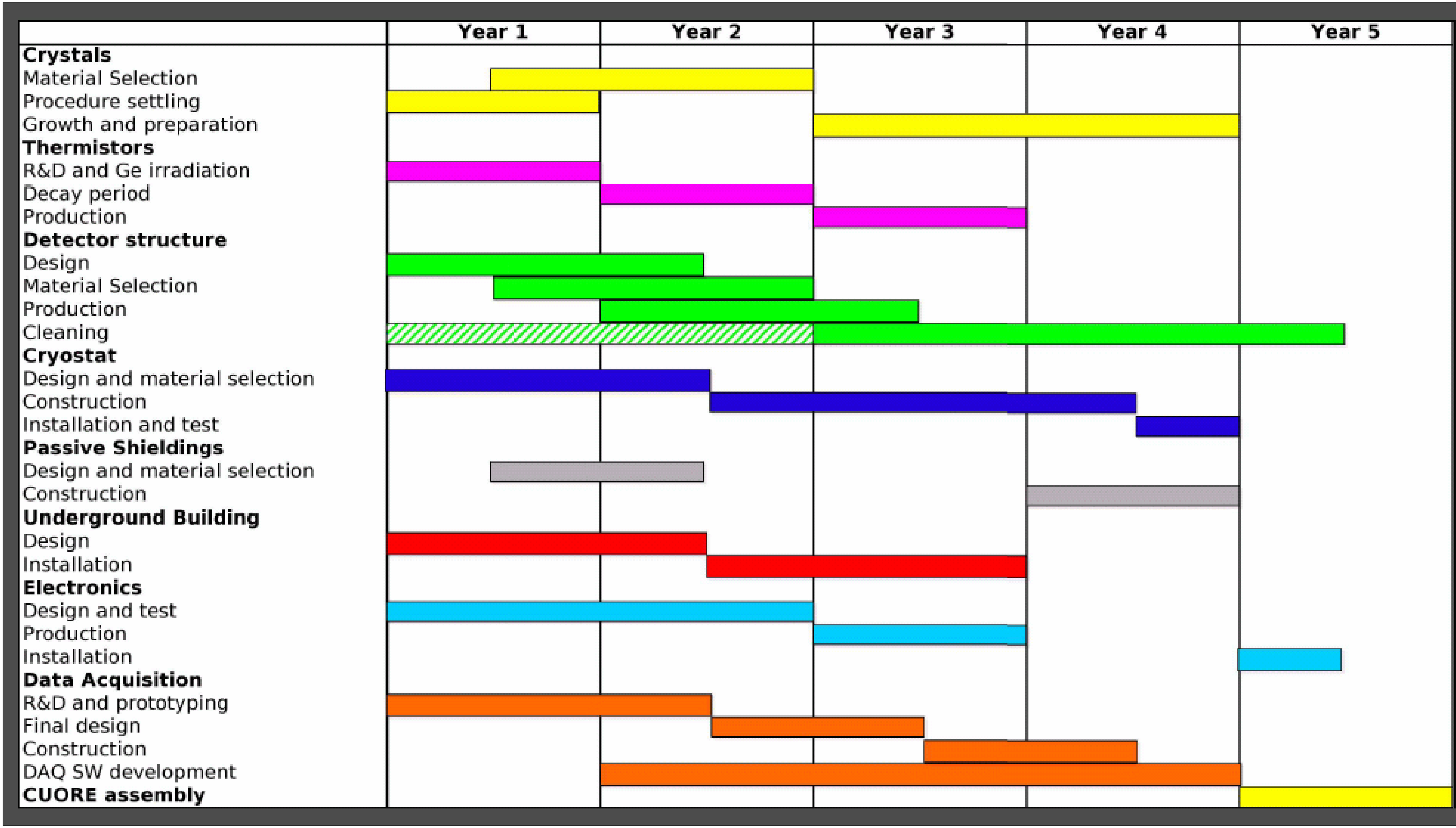
CUORE

$\beta\beta(0\nu)$ Monte Carlo evaluations based of CUORICINO background results and available bulk contamination limits from Ge measurements:

bulk	3.8×10^{-3}	couns/keV/kg/y
surface (TeO2)	2×10^{-2}	couns/keV/kg/y
surface (Copper)	5×10^{-2}	couns/keV/kg/y

CUORE sensitivity goal can be reached

CUORE time schedule



Summary

CUORICINO: **19st April 2003 →**

- successfully operating independent experiment on ^{130}Te $\beta\beta(0\nu)$
  - ► **40.7 kg of TeO_2, $B_{\beta\beta(0\nu)}$ = 0.19 ± 0.04 c/keV/kg/y, ΔE = 8keV**
  - ► **$\tau_{1/2} \geqslant 7.5 \times 10^{23}$ years at 90% C.L.** ($\langle m_\nu \rangle \leqslant 0.32 \div 1.68$ eV)
  - ► $S^{1\sigma}_{3\ years}$ **$\geqslant 6 \times 10^{24}$ years** - $\langle m_\nu \rangle \leqslant 0.11 \div 0.60$ eV
- good technical performance
  - ▲ **reproducibility, stability, energy resolution**
  - ▲ **problems with wiring system now repaired**
- good knowledge of the background contributions

- good control of the surface cleaning procedures
- tower-like large mass LTD's (CUORE) are feasible

  - CUORE proposal: http://crio.mib.infn.it/wig/Cuorepage/proposal-040119.pdf