NEW RESULTS ON ^{130}Te $0\nu\beta\beta$ DECAY & THE CUORE PROJECT

OLIVIERO CREMONESI
I.N.F.N. – MILANO

A. ALESSANDRELLO, C. BROFFERIO, D.V. CAMIN, O. CREMONESI, E. FIORINI, A. GIULIANI, A. NUCCIOTTI, M. PAVAN, G. PESSINA, E. PREVITALI & L. ZANOTTI

- HISTORY
- PRESENT RESULTS
- CUORE

HISTORIC REMARKS

- **GOAL:**

DEVELOPMENT OF A LARGE MASS HIGH SENSITIVITY DETECTOR TO SEARCH FOR $0\nu\beta\beta$ DECAY OF ...

- **QUESTIONS**

⊗ WHY LTD's ?

⊗ WHY ^{130}Te ?

⊗ IS TELLURIUM A GOOD MATERIAL ?
... AND ITS COMPOUNDS ?

⊗ WHAT IS THE MAXIMUM MASS FOR A SINGLE DETECTOR ? $\{C = M \cdot C_m\}$

⊗ ... AND THE MAXIMUM MEASURE LENGTH (TIME) ?
{THERMAL INSTABILITIES}

⊗ ARE LARGE DETECTOR ARRAYS FEASIBLE ?
{REPRODUCIBILITY}

⊗ ARE LOW ACTIVITY ENVIRONMENTS POSSIBLE ?
{COMPLEX DETECTOR & CRYOSTAT STRUCT.}

∴ HOW FAR CAN WE GO ?

DOUBLE BETA DECAY : LTD's

- SOURCE ≡ DETECTOR APPROACH

PIONEERED BY E. FIORINI (1967) FOR ^{76}Ge

- HIGH SENSITIVITY TO 0ν $\beta\beta$ DECAY:

$$S = \ln 2 \, \eta \frac{M}{A} N_A \frac{t}{\sqrt{B \cdot FWHM \cdot t \cdot (M)}}$$

$$= \ln 2 \, \frac{\eta N_A}{A} \sqrt{\frac{t \cdot M}{B \cdot FWHM}}$$

LTD's : (E. FIORINI & T. NIINIKOSKY 1984)

- GOOD ENERGY RESOLUTION
- POSSIBILITY TO SELECT DIFFERENT ISOTOPES
- POSSIBILITY TO BUILD LARGE MASS DETECTORS (ARRAYS)
- ISOTOPICALLY ENRICHED MATERIALS
- × LOW BACKGROUND ENVIRONMENTS

OTHER RESULTS:

- INTRINSIC RADIOACTIVITY OF MATERIALS
- × DARK MATTER CANDIDATES INTERACTION DETECTION (SIGNAL DISCRIMINATION USUALLY NEEDED)
  - WIMPS
  - AXIONS
- HIGH EFFICIENCY (Z) γ SPECTROSCOPY

NEUTRINOLESS DOUBLE BETA DECAY SENSITIVITY

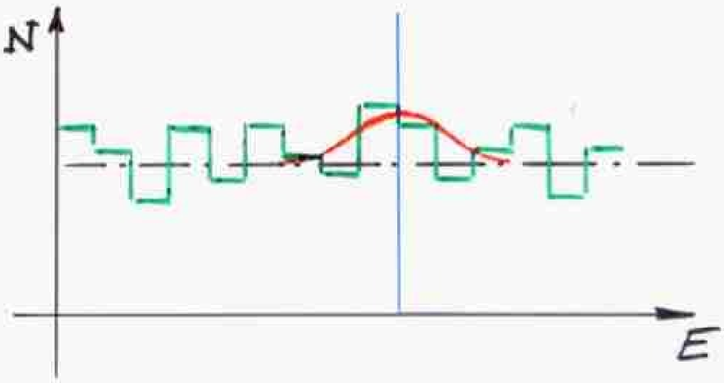
BY DEFINITION: MAXIMUM SIGNAL COMPATIBLE WITH BACKGROUND FLUCTUATIONS

$$\tau_{1/2} = \varepsilon N_{\beta\beta} \frac{t}{N_S} \ln 2 = \ln 2 \cdot \varepsilon \cdot \frac{M}{A} N_A \cdot \eta \cdot \frac{t}{N_S}$$

- BACKGROUND FLUCTUATION CAN HINDER A SIGNAL

$$N_S^{(M)} = \sqrt{N_B}$$

$$= \sqrt{B \cdot M \cdot t \cdot \Delta E}$$



$$B = \frac{d^3N}{dM\,dE\,dt} \equiv \text{BACKGROUND RATE}$$

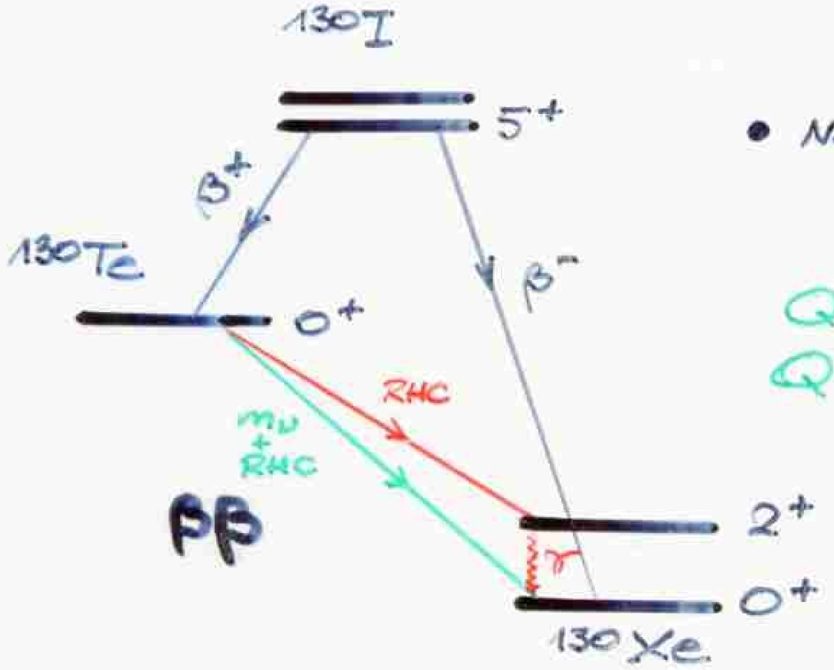
- $$S = \ln 2 \, \varepsilon \, \eta \, \frac{N_A}{A} \sqrt{\frac{t \cdot M}{B \cdot \Delta E}} = \tau_{1/2}^{(\text{BACKGR. FLUCT.})}$$

USUALLY: $\Delta E = \text{FWHM}$

$\beta\beta$: ^{130}Te

EXPERIMENTAL APPROACHES:

- GEOCHEMICAL ⇝ $\Gamma_{TOT} = \Gamma_{0\nu} + \Gamma_{2\nu}$
- DIRECT ⇝ HOMOGENEOUS (SOURCE = DETECTOR)



- NATURAL ABUNDANCE 33.87 %

$Q(0^+ \to 0^+) = 2528.8$ keV
$Q(0^+ \to 2^+) = 864$ keV

PRESENT RESULTS: (NO LTD)

- GEOCHEMICAL EXP.'s : $\tau_{1/2}^{TOT} \simeq 0.8 \times 10^{21}$ yrs (2.7×10^{21} yrs)
- DIRECT EXP.'s :
  - CdTe [Fisher & Mitchell] : $\tau_{1/2}^{0\nu} \gtrsim 2.8 \times 10^{18}$ yrs
  - Plastic scintillator [Zdesenko]

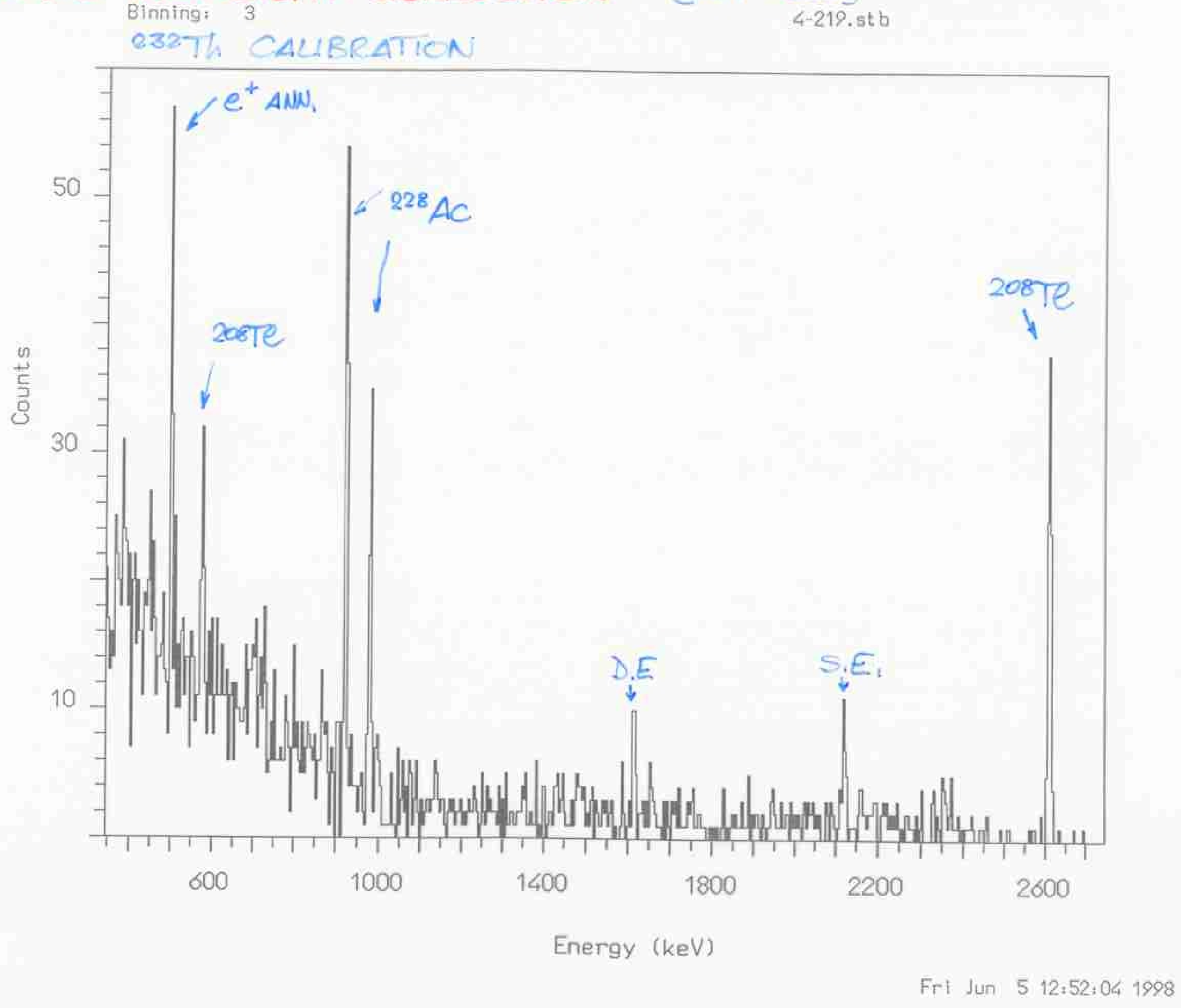
⇝ **BOLOMETERS**

TELLURIUM DETECTORS @ LNGS

- METALLIC TELLURIUM : NO
- TeO_2 ← THE RIGHT ANSWER! → NTD Ge
  - 73 g
  - 340 g
    - 10500 h LIVE TIME MEASUREMENT
      ⇒ LONG TERM "STABILITY" IS POSSIBLE (^{210}Po α's ... HEATER)
    - ⇝ FIRST ^{130}Te $0\nu\beta\beta$ RESULTS
    - SATISFACTORY BACKGROUND
  - 4 × 340 g
    - ONLY 2 DETECTORS WORK WELL
      ⇝ REPRODUCIBILITY COULD BE A PROBLEM
    - IMPROVED $\beta\beta$ RESULTS
    - PRELIMINARY DARK MATTER & Q_F RESULTS
    - TESTS OF THE COINCIDENCE TECHNIQUE
    - ^{123}Te EC MEASUREMENT
  - (2 × 73 g)
    - SPECIFIC MEASURE FOR NUCLEAR RECOILS Q_F
  - 20 × 340 g PRESENT DETECTOR
    - REPRODUCIBILITY PROBLEM SOLVED
    - BACKGROUND CAN BE IMPROVED

NEXT 1000 × 750 g

THERMAL INSTABILITY CORRECTION (NIM 1998)



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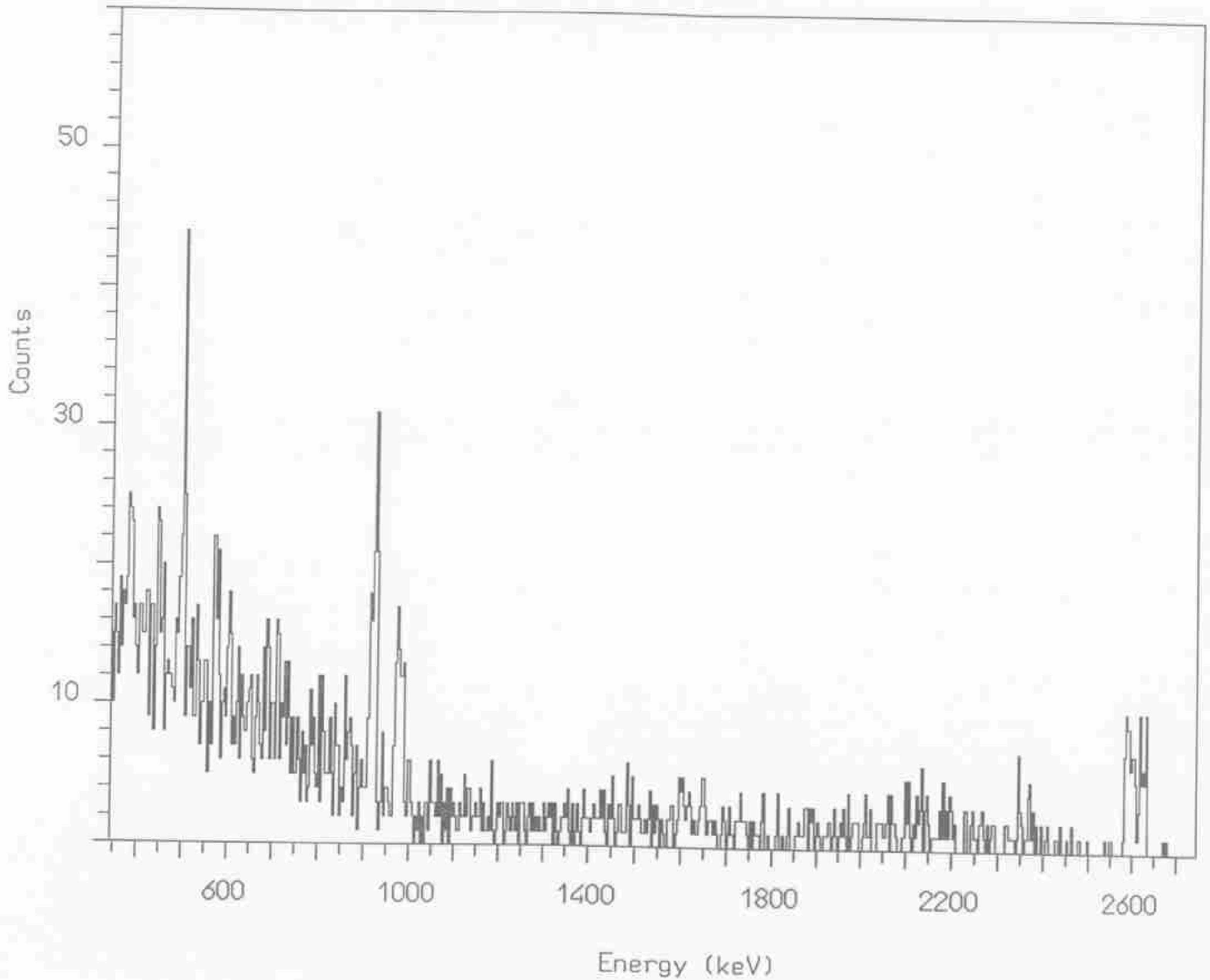

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NOT CORRECTED

20 TeO_2 BOLOMETERS EXP.

- LOCATION:

  LABORATORI NAZIONALI DEL GRAN SASSO (HALL "A")

- SHIELDING:

  INNER
  ABOVE: 10 cm ROMAN LEAD
  AROUND: 1.5 " " "
  BENEATH: 5 " " "
  2 cm COPPER (ELECTROLYTIC: Thermal shields)

  OUTER
  10 cm SPECIAL LEAD (^{210}Pb: 16 ± 4 Bq/kg)
  10 cm COMMON LOW ACTIVITY LEAD

- FRAME:

  OFHC LOW ACTIVITY COPPER + PTFE SUPPORTS

- DETECTOR:

  (20 ×)
  - $3\times3\times6\ cm^3$ TeO_2 (m = 340 g, i.a. = 0.34)
  - NTD Ge THERMISTOR
  - HEATER (1 mm^3 Si CHIP DOPED OVER METAL/INSULATOR TRANSITION: 10-100 kΩ)

    ⇒ THERMAL INSTABILITY CORRECTION

  TOTAL MASS = 0.34 × 20 kg = 6.8 kg

- READ-OUT:
  - 60 μm ϕ CONSTANTAN WIRES
  - ROOM TEMPERATURE FRONT-END ELECTRONICS (DIFFERENTIAL CONFIGURATION)
  - VXI ACQUISITION SYSTEM

- PERFORMANCE:

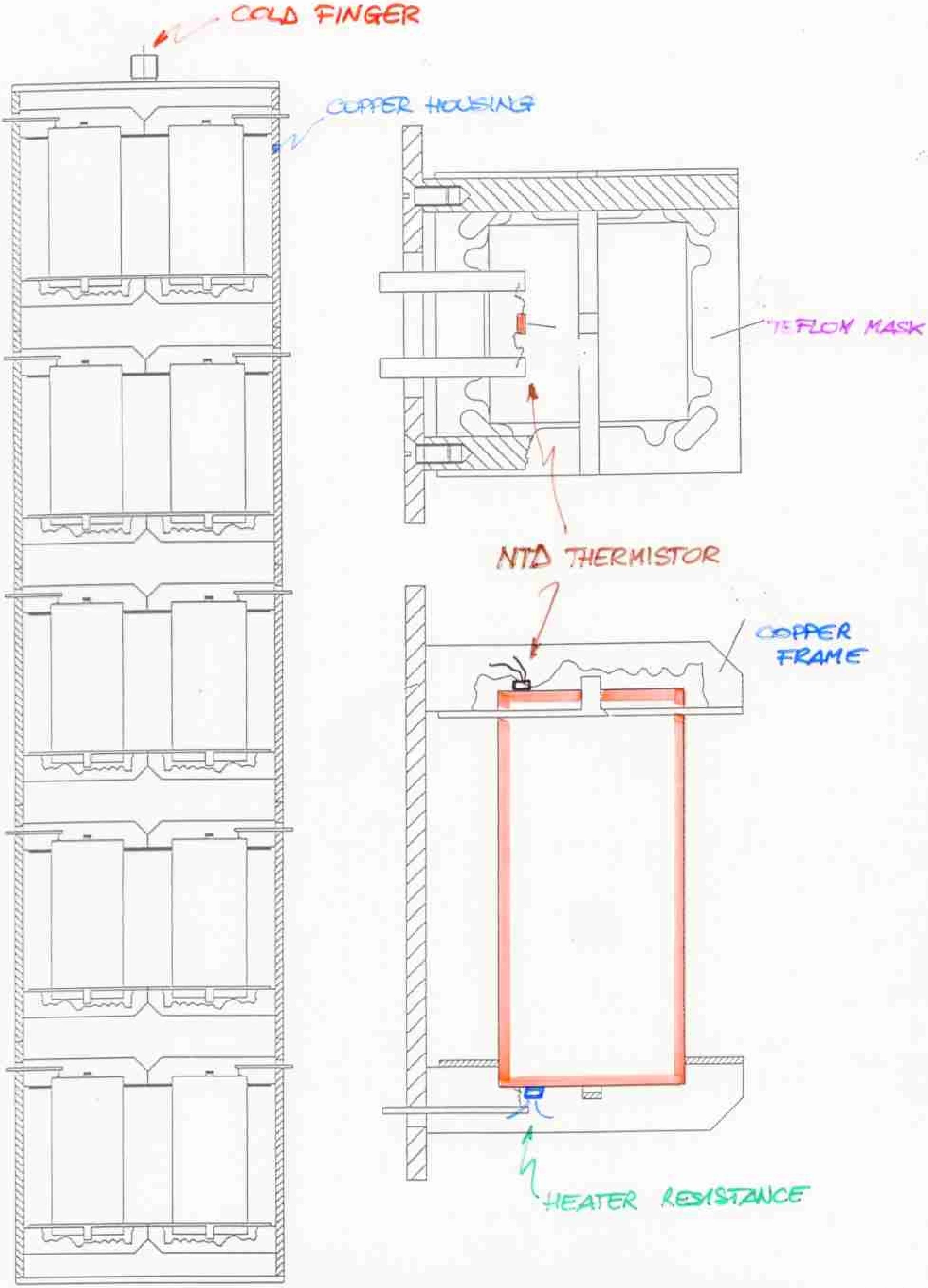
  $\langle G \rangle$ = 260 μV/MeV $S_{0\nu\beta\beta} = 9\times10^{23}$ yr (1 yr M.)

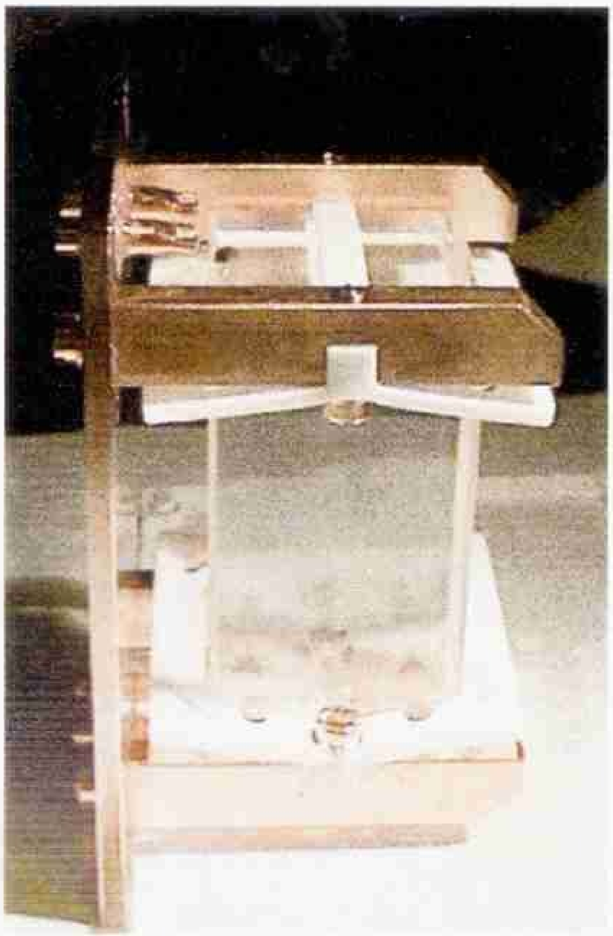
  $\langle T_{bol} \rangle$ = 12.5 mK $\langle R_{bol} \rangle$ = 110 MΩ

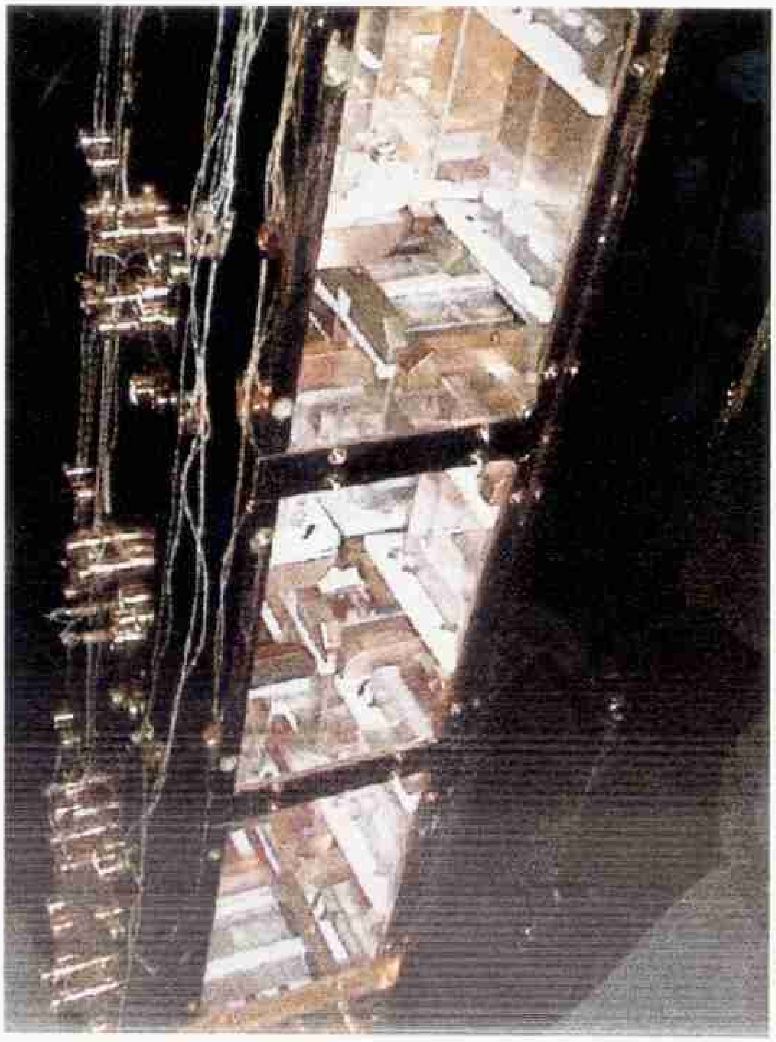
  $\langle FWHM \rangle$: 5 keV @ 511 keV   10 keV @ 2615 keV

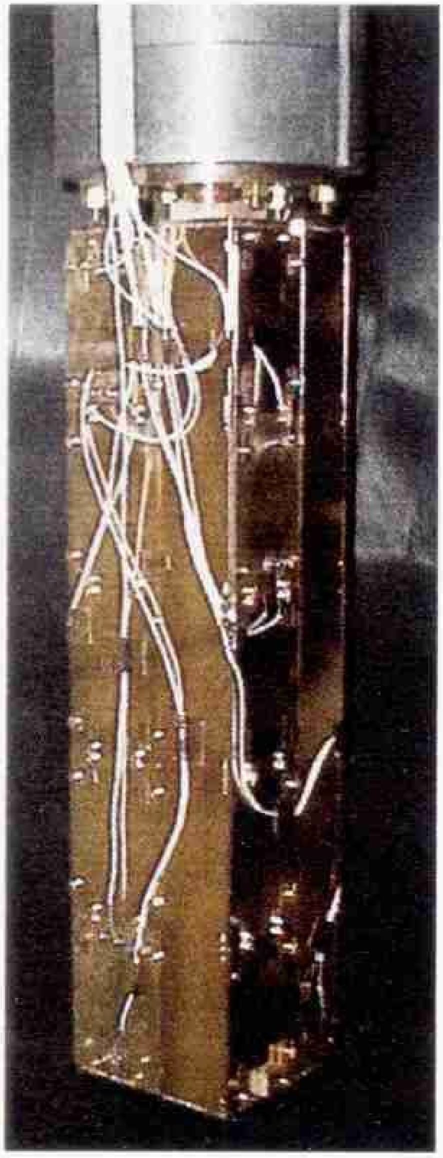
× **NEAR FUTURE:** TWO CRYSTALS ARE GOING TO BE SUBSTITUTED WITH 1 ^{130}Te AND 1 ^{128}Te ENRICHED CRYSTALS:
2ν ββ DECAY (SUBTRACTION)

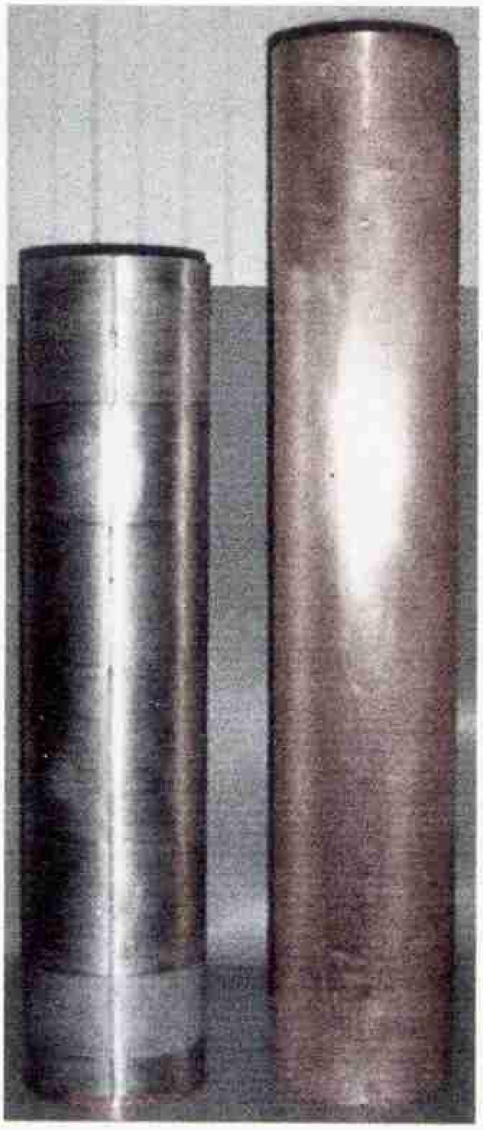
MILANO GROUP: 20 TeO_2 BOLOMETER ARRAY

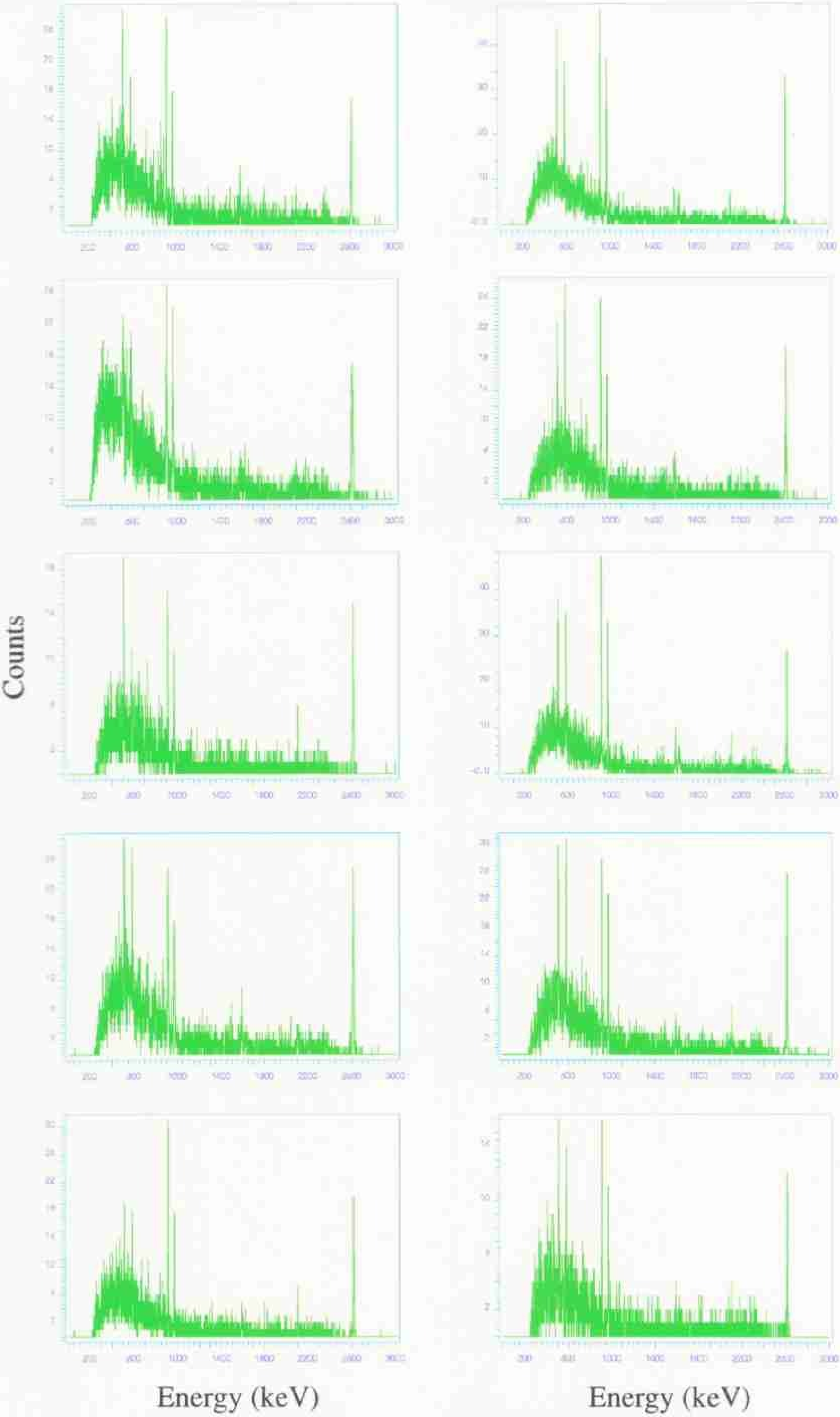






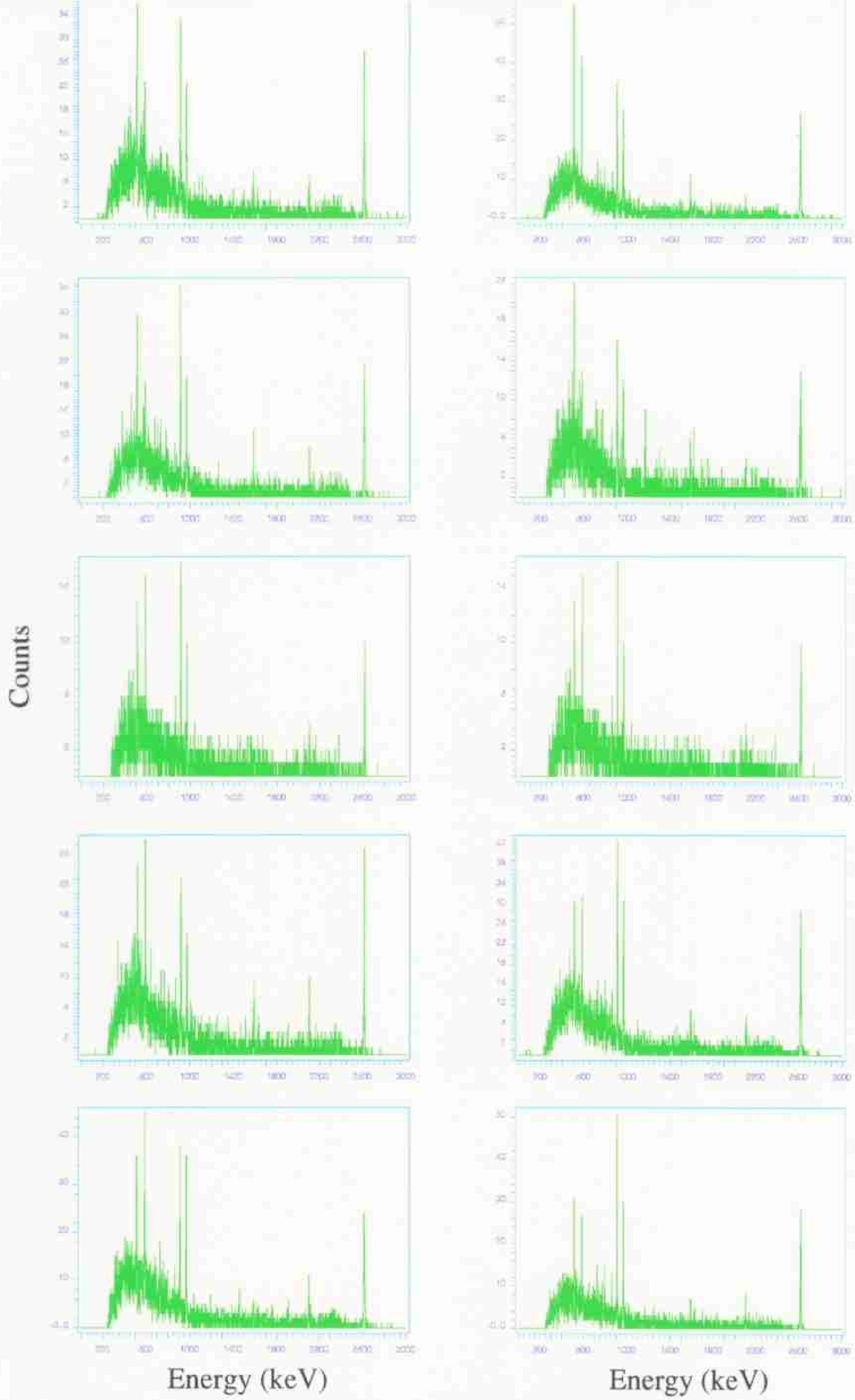






MILANO GROUP : 20 TeO_2 BOLOMETERS' ARRAY
Calibration spectra (^{232}Th) of detectors 1-10

AVERAGE ENERGY RESOLUTION : 5 keV @ 511 keV
10 keV @ 2615 keV



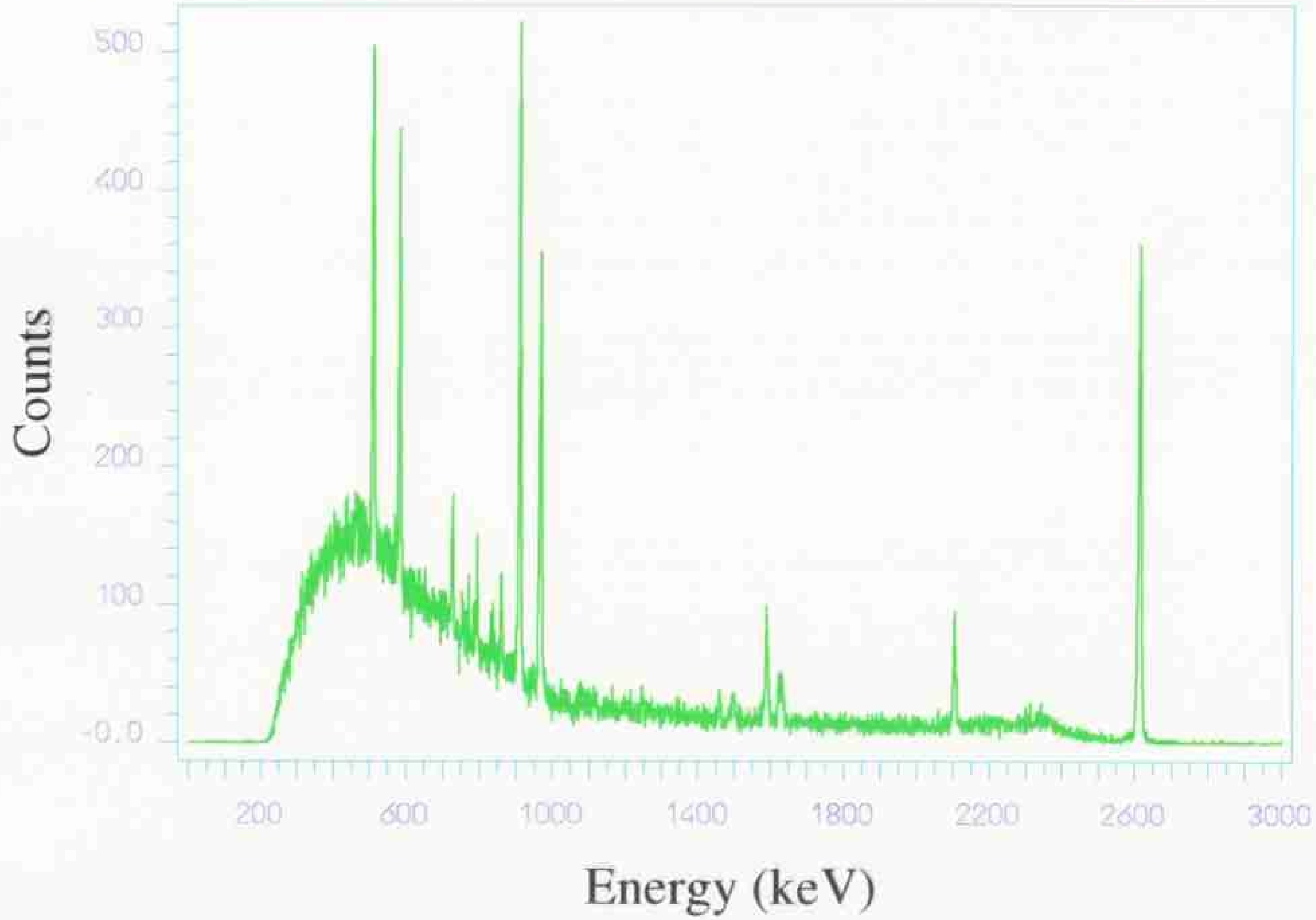
MILANO GROUP : 20 TeO_2 BOLOMETER ARRAY
Calibration spectra (^{232}Th) of detectors 11-20

MILANO GROUP : 20 TeO_2 BOLOMETER ARRAY

SUM OF THE 20 SINGLE DETECTOR CALIBRATION SPECTRA (^{232}Th)

ENERGY RESOLUTION : SAME AS FOR THE SINGLE DETECTORS

⇒ GOOD EQUALIZATION ⇒ ~ SINGLE 6.8 kg SEGMENTED DETECTOR



MILANO GROUP: TeO_2 BOLOMETERS

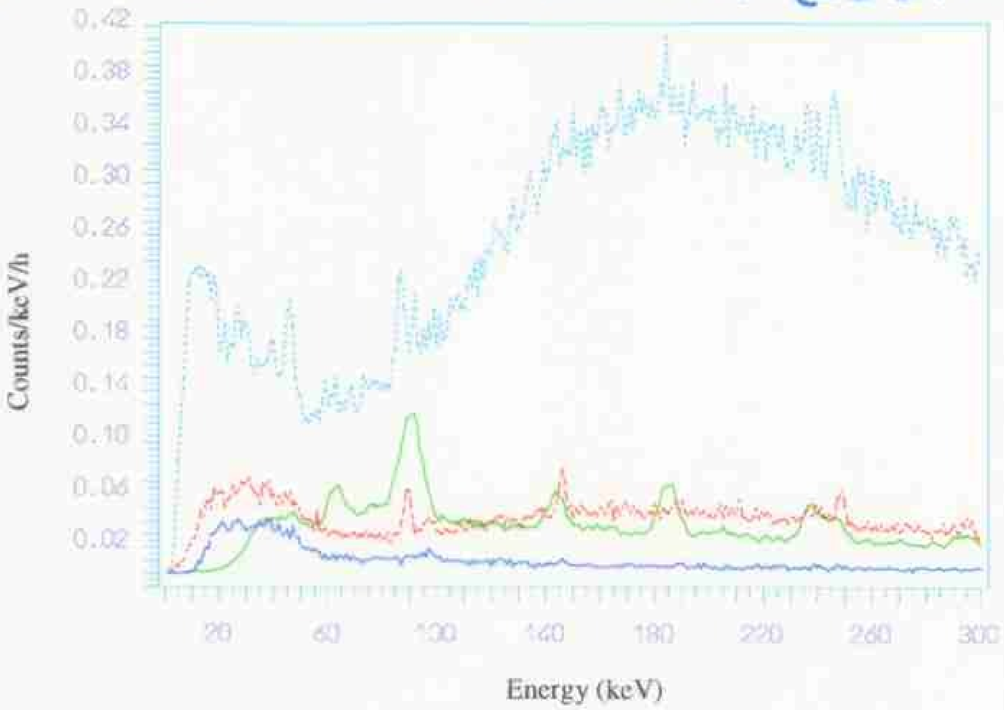
BACKGROUND SPECTRA AT LOW ENERGY

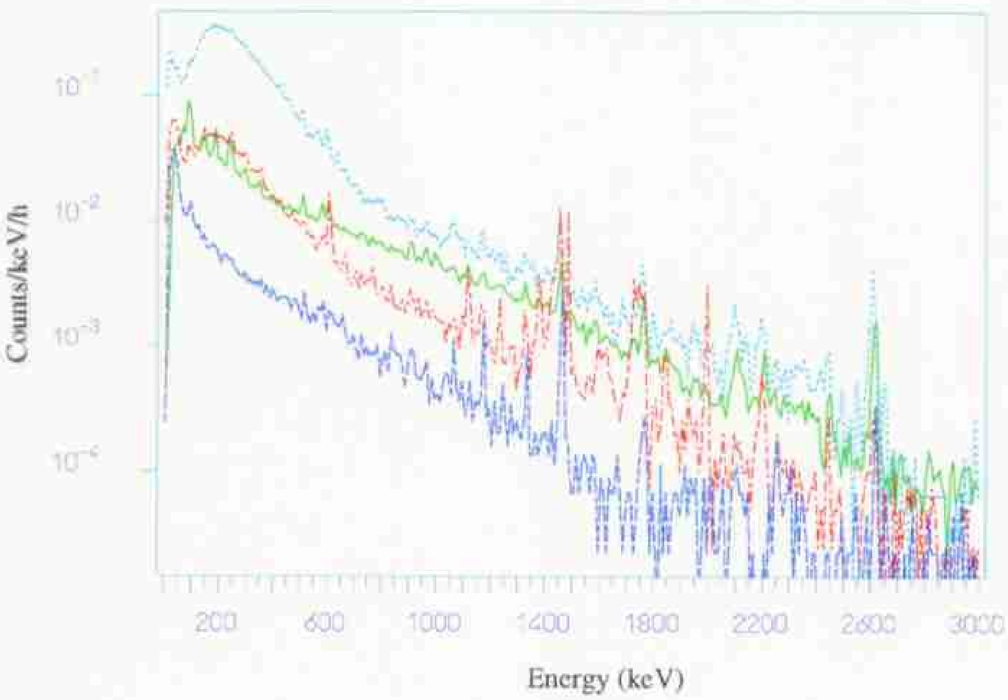
— 340 g SINGLE CRYSTAL (INNER ROMAN LEAD)

···· DETECTOR # 4 OF THE FOUR BOLOMETER ARRAY

— SUM SPECTRUM OF 8 DETECTORS OF THE 20 B. ARRAY (I)

— SUM SPECTRUM OF THE 20 DETECTORS (20 B. ARRAY, ROMAN LEAD)

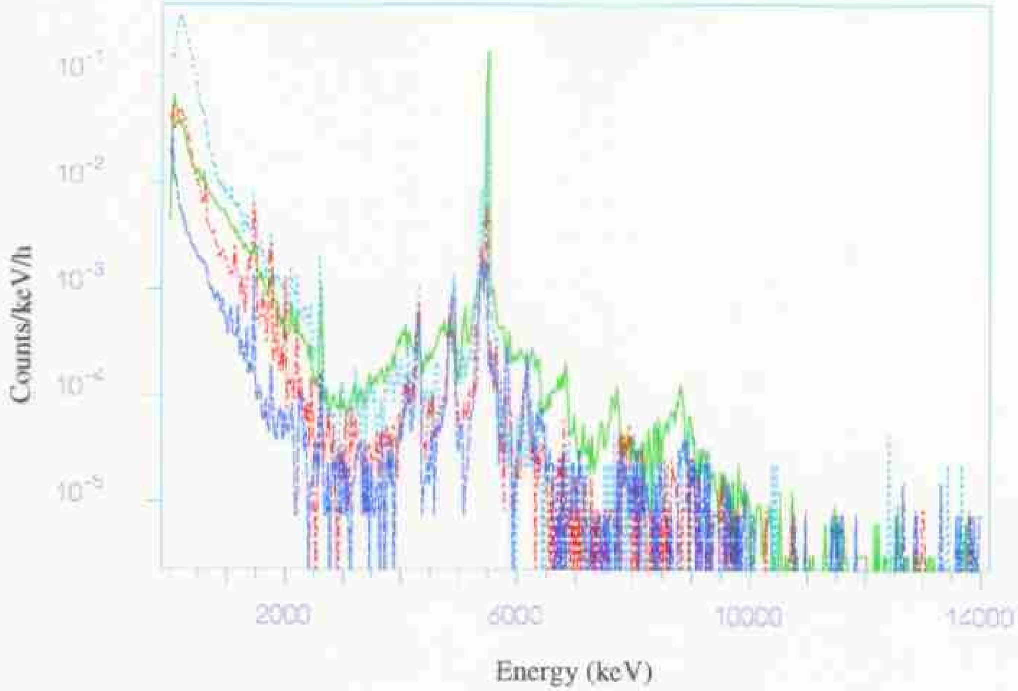




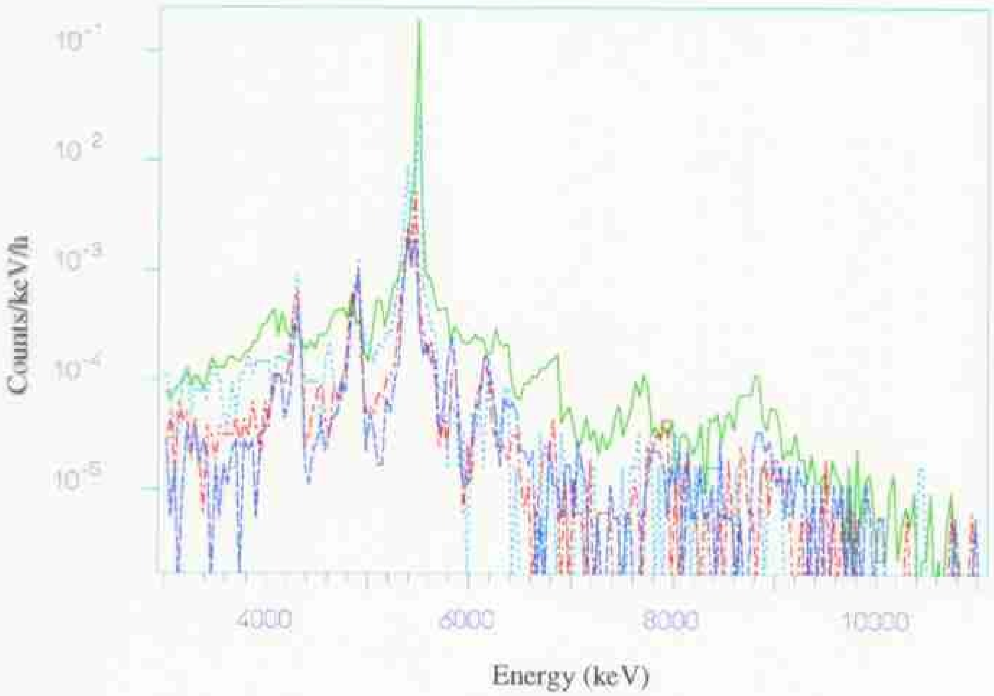
MILANO GROUP : TeO_2 BOLOMETERS

BACKGROUND SPECTRA COMPARISON :

TOTAL



α REGION

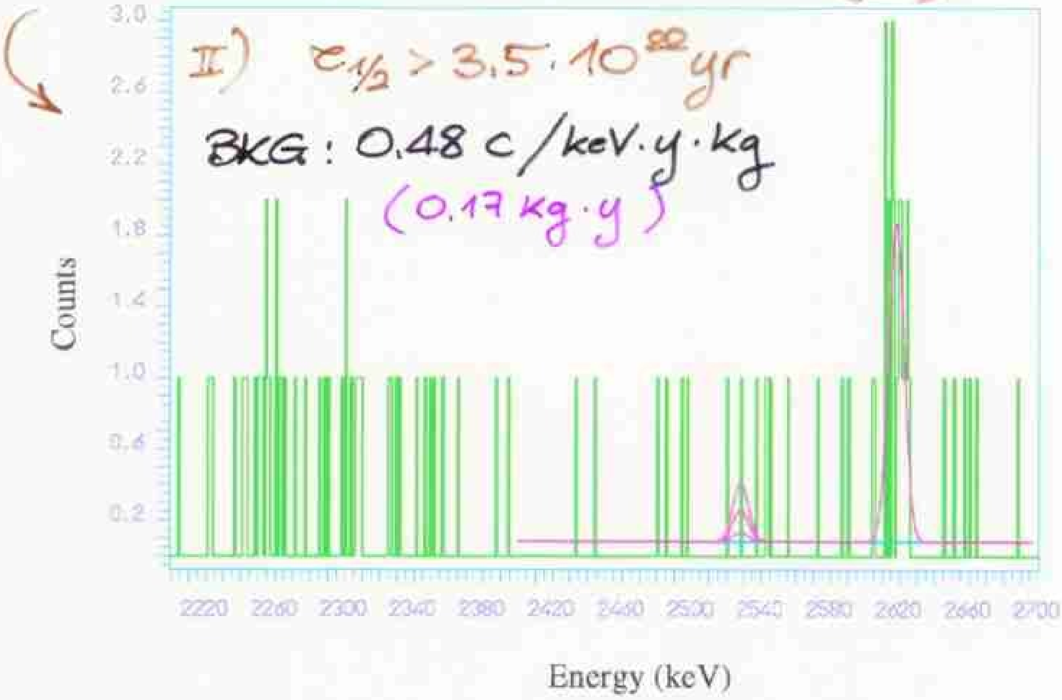


MILANO GROUP : 20 TeO_2 BOLOMETER ARRAY

0ν ββ DECAY REGION FOR ^{130}Te

SUM SPECTRUM OF THE 20 CRYSTALS (II)

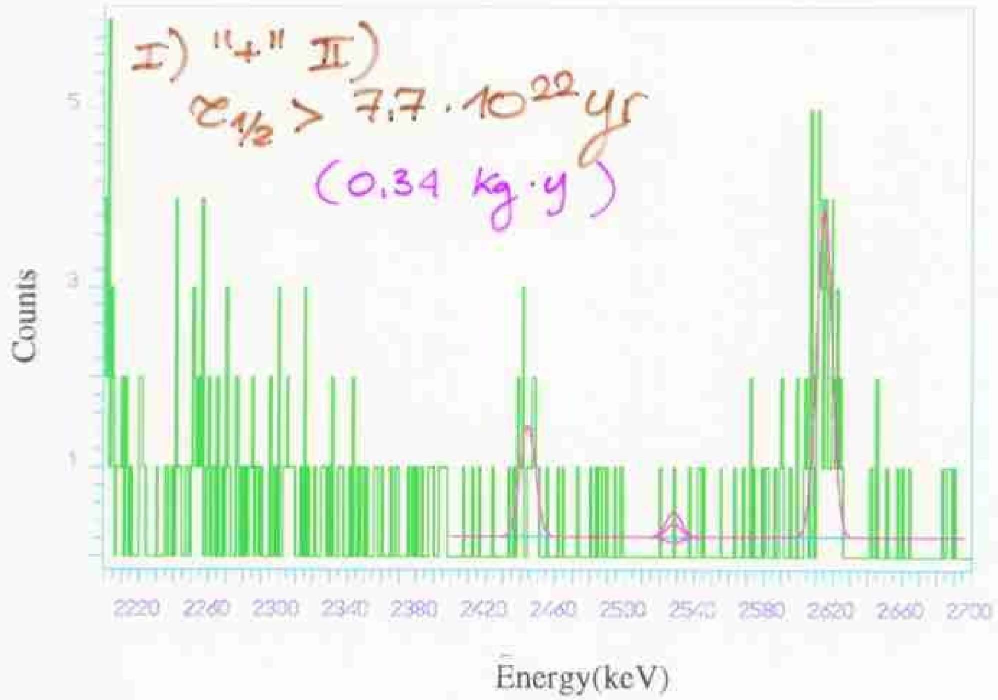
PRELIMINARY



TWO RUNS :

I) 8 OUT OF 20 DETECTORS ACQUIRED (I) AT THE BEGINNING OF 1997 (567 h × 8)

$\tau_{1/2}(^{130}Te) > 5.6 \cdot 10^{22}$ y (Phys. Lett. B 1998)



II) PRELIMINARY : Last week measurement

20 DETECTORS (340 g) WITH INNER ROMAN LEAD SHIELD (222 h × 20)

♥ CUORE PROJECT

ITALIAN TRANSLATION FOR HEART

CRYOGENIC UNDERGROUND OBSERVATORY FOR RARE EVENTS

- 1000 TeO_2 DETECTORS ($5\times5\times5\ cm^3$: 750 g EACH) :
  - 750 kg NATURAL TeO_2
  - 204 kg ^{130}Te
- LOCATION : LNGS
- NEW CRYOGENIC SYSTEM :
  - → MICROPHONICS
  - → RADIOACTIVE BACKGROUND
  - → LONG TERM STABILITY

- GOALS :
  - 5 keV FWHM @ 2.5 MeV
  - 0.2 c/keV·y·kg

$$\Rightarrow S_{0\nu\beta\beta} = 2\cdot10^{25}\ yr$$ (1 yr MEASUREMENT)

- FURTHER BACKGROUND SUPPRESSION : ANTICOINCIDENCE

OTHER RESULTS :

- SOLAR AXIONS (COHERENT PRIMAKOFF CONVERSION)
- DARK MATTER
- (· NEUTRINO MAGNETIC MOMENT (ARTIFICIAL $\bar{\nu}$ SOURCE))

- PRELIMINARY TESTS :
  - DETECTOR REPRODUCIBILITY (← 20 BOLOMETER ARRAY)
  - TEST OF A $5\times5\times5\ cm^3$ BOLOMETER (IN PREPARATION)

▶ TWO CRYSTALS ARE CURRENTLY RUNNING (HALL C) :

$T_b = 10.5\ mK$ $\langle G\rangle \simeq 150\ \mu V/MeV$ FWHM 6.6 @ 911 keV, 9.1 @ 2615 keV

- INTERMEDIATE STEP : CUORICINO (100 TeO_2 CRYSTALS)

$0\nu\beta\beta$ DECAY & NEUTRINO MASS

$$\Gamma_{0\nu} \equiv \tau^{-1} = C \langle m_\nu \rangle^2$$

$C \equiv$ kinematic & Nuclear factor

$$\left.\begin{aligned} \langle m_\nu \rangle &= \sum_k U_{ek}^2 \, m_k \\ &\overset{\text{CP Conserv.}}{=} \sum_k \lambda_k |U_{ek}|^2 m_k \end{aligned}\right\} \text{EFFECTIVE } \nu \text{ MASS}$$

- IF $0\nu\beta\beta$ DECAY IS OBSERVED:

  ① ν IS A MAJORANA PARTICLE

  ② ν IS A MASSIVE PARTICLE ...
  ... AND THERE EXISTS AT LEAST ONE MASS EIGENSTATE ν_k SUCH THAT

$$\boxed{m_{\nu_k} > \langle m_\nu \rangle}$$

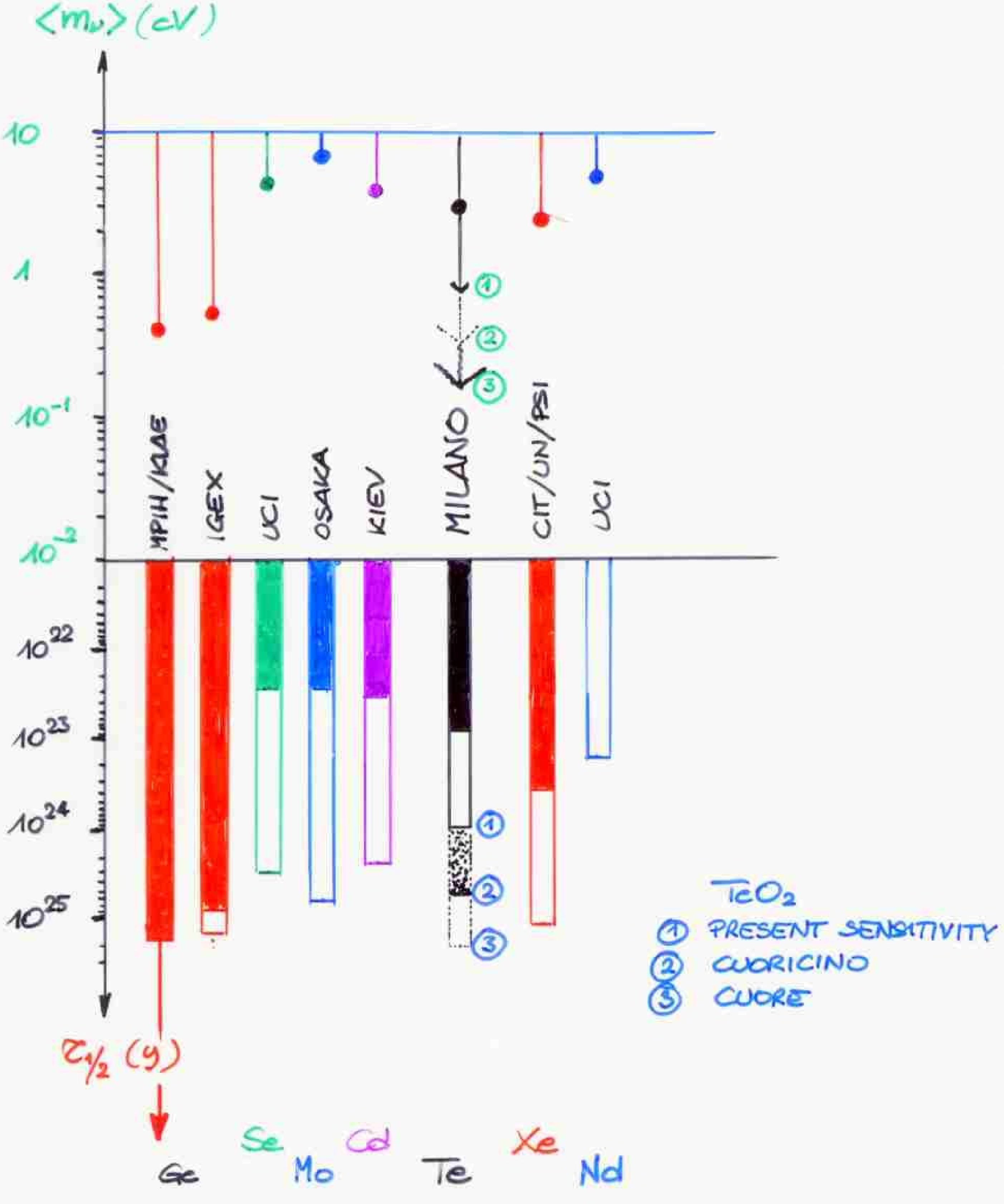
- IF $0\nu\beta\beta$ DECAY IS NOT OBSERVED:

SIMPLY

$$\langle m_\nu \rangle < \sqrt{\frac{1}{C\tau}}$$

TeO_2 SENSITIVITY COMPARED TO PRESENT $0\nu\beta\beta$ EXPERIMENT RESULTS

- $\langle m_\nu \rangle \Rightarrow$ STAUDT et al. Europh. Lett. 1990
- □ $\tau_{1/2}$ MEAS. TO BE REACHED TO MATCH CURRENT $\langle m_\nu \rangle_{Ge}$



CONCLUSIONS

- LARGE MASS BOLOMETRIC ARRAYS ARE FEASIBLE
- REPRODUCIBILITY, LONG TERM STABILITY, LOW BACKGROUND, GOOD ENERGY RESOLUTION HAVE ALREADY BEEN OBTAINED : THEY MUST BE IMPROVED!
- TIME SCHEDULE FOR CUORE

1998 • TEST OF THE $5\times5\times5\ cm^3$ CRYSTALS

1998/99 • DESIGN OF A NEW CRYOGENIC SYST.
• CUORICINO CONSTRUCTION

2000 • CUORICINO DATA TAKING

2000-2002 • CUORE CONSTRUCTION

- OTHER ISOTOPES ?