DOUBLE BETA DECAY

E. Fiorini - Venice Febr. 23, 1999

$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$ two neutrino

$(A,Z) \rightarrow (A,Z+2) + 2e^- + X$ majoron

$(A,Z) \rightarrow (A,Z+2) + 2e^-$ neutrinoless

M. GOEPPERT MAYER (1935)

J. SUHONEN and O. CIVITARESE
PHYS. REP. 300 (1998) 124

A. MORALES - REVIEW AT "NEUTRINO 98"

TO EXPLORE:

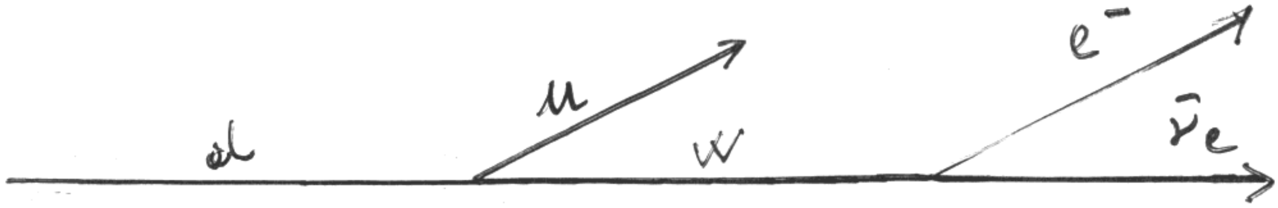
$\nu \not\equiv \bar{\nu}$

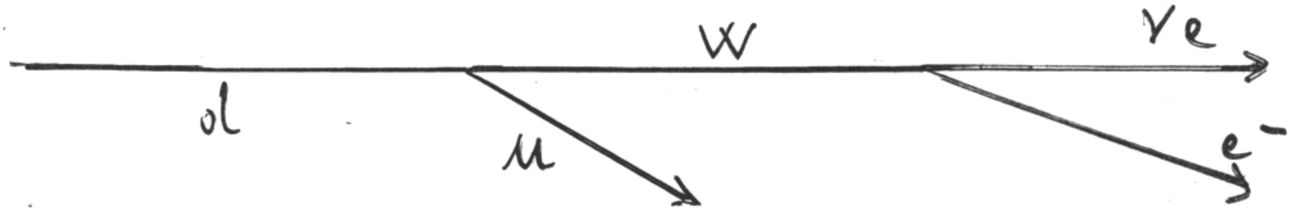
$\Delta L = 2$

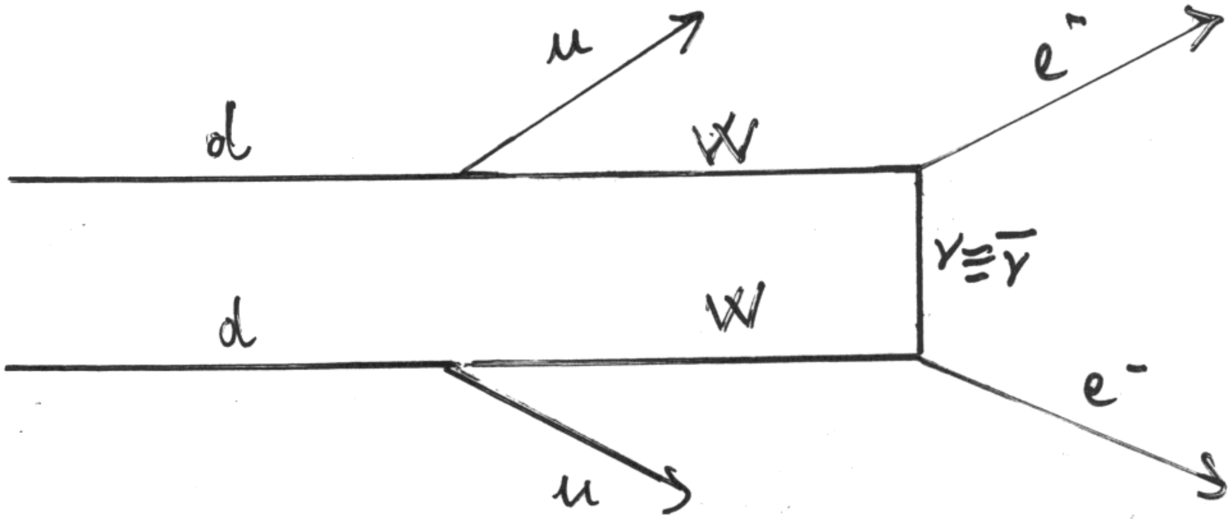
RIGHT HANDED CURRENTS

"AVERAGE" NEUTRINO MASS

$$\frac{1}{\tau_{1/2}} \quad \begin{matrix} \nearrow \propto E^5 & 0\nu \\ \searrow \propto E^{11} & 2\nu \end{matrix}$$







WITH $2\bar{\nu}$: $$\frac{1}{\tau_{2\nu}} = G_{2\nu}(Q,Z)\, M^2_{2\nu}$$

WITH MAJORON $$\frac{1}{\tau_{0\nu\chi}} = G_{0\nu\chi}(Q,Z)\left|M_{0\nu\chi}\right|^2 \langle g_\nu \chi\rangle^{2m}$$

FIRST MODEL IN COMPATIBLE WITH Z_0 WIDTH

VARIOUS NEW MODELS : TWO OR MORE MAJORONS

$m = 1$ → SINGLE MAJORON

$m = 2$ → TWO MAJORONS

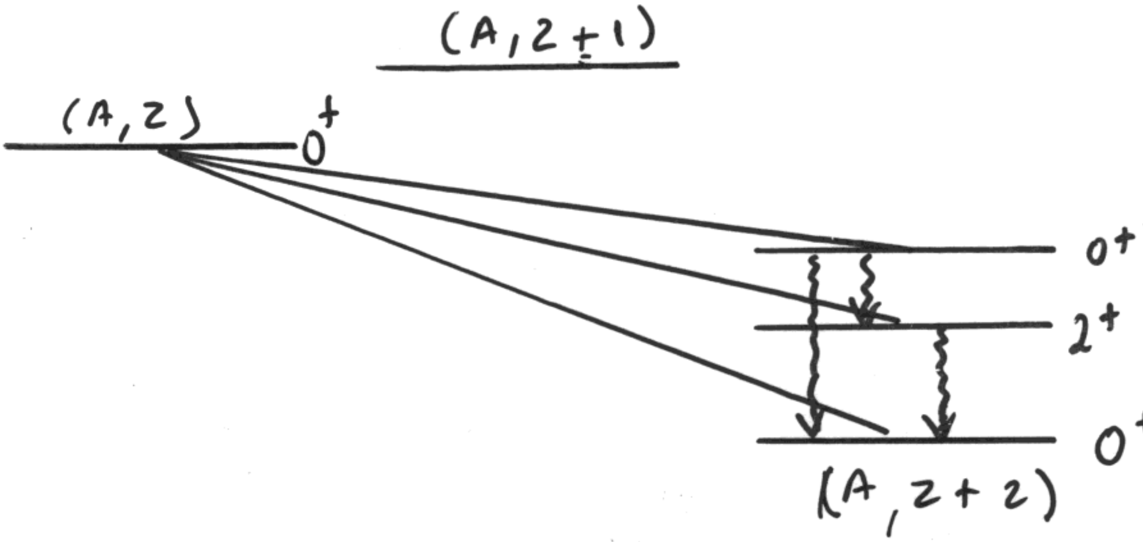
NEUTRINOLESS $\beta\beta$ DECAY

$m_\nu \neq 0$ and / or RIGHT HANDED CURRENTS

$$\frac{1}{\tau_{0\nu}} = C_{mm}\left(\frac{\langle m_\nu\rangle}{m_e}\right)^2 + C_{\eta\eta}\langle\eta\rangle^2 + C_{\lambda\lambda}\langle\lambda\rangle^2 +$$

$$+ C_{m\eta}\frac{\langle m_\nu\rangle}{m_e}\langle\eta\rangle + C_{m\lambda}\frac{\langle m_\nu\rangle}{m_e}\langle\lambda\rangle + C_{\eta\lambda}\langle\eta\rangle\langle\lambda\rangle$$

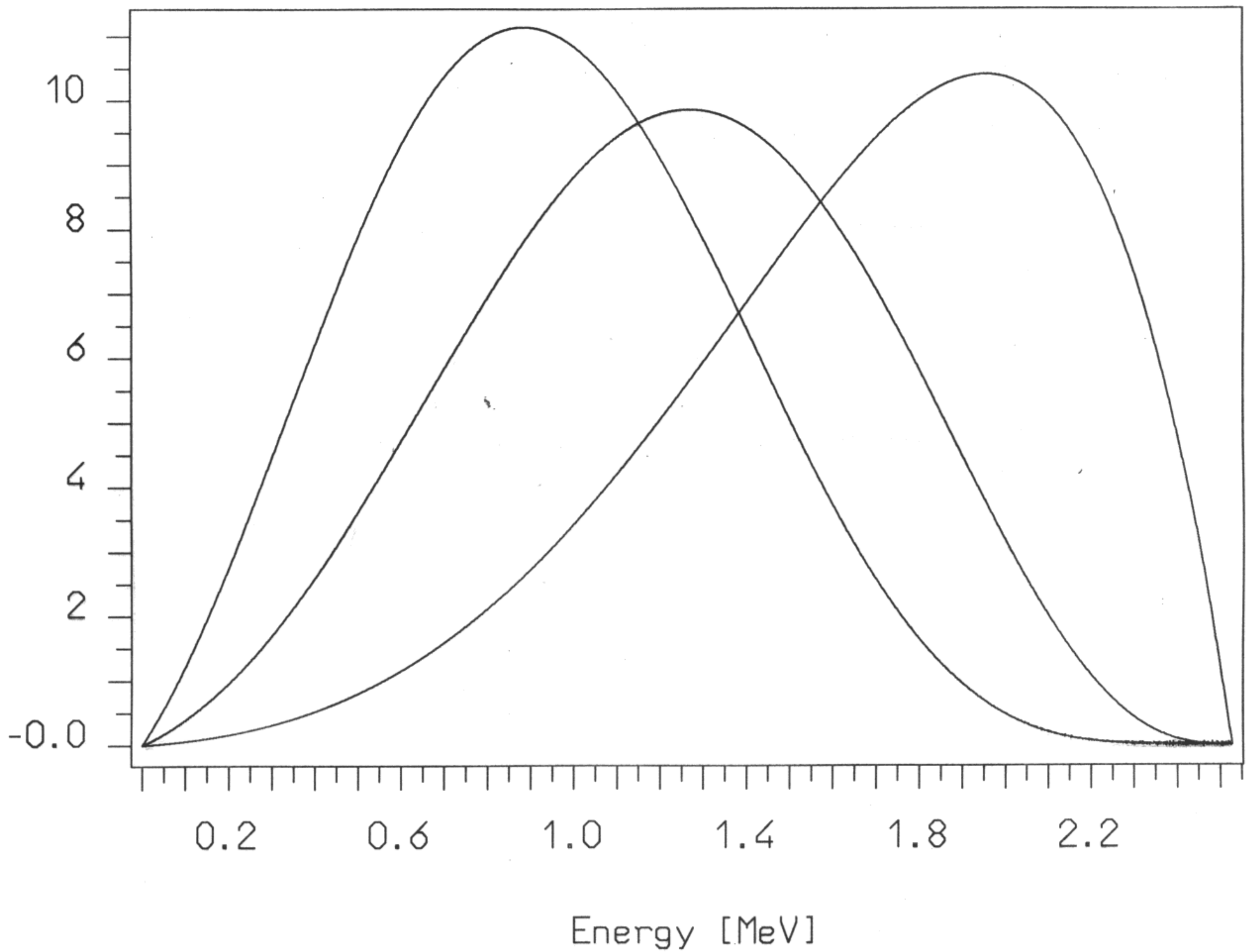
ALSO DECAYS TO EXITED LEVELS



DIFFICULTY → NUCLEAR MATRIX ELEMENTS

PRIMAKOFF AND ROSEN

$|M_{0\nu}| = |M_{2\nu}| \simeq 0.1$ for all nuclei


10
8
6
4
2
-0.0
0.2
0.6
1.0
1.4
1.8
2.2
Energy [MeV]

CALCULATIONS WITH SHELL MODEL → OK FOR ^{48}Ca → OVERESTIMATED THE RATES FOR LARGER A

Quasi Particles Random Phase Approximation

Particle - particle interaction g_{pp}

GREAT UNCERTAINTIES IN $\tau(2\nu)$

LESS IN $\tau(0\nu)$

MEDEX -

RECENT DISCUSSIONS WITH

G. PANTIS, O. CIVITARESE, J. VERGADOS, P. HESS
A. BARABASH

IMPORTANT ROLE PLAYED BY THE INTERMEDIATE 1^+ STATE
(A. MORALES)

· SIDE REACTIONS (EJIRI et al)

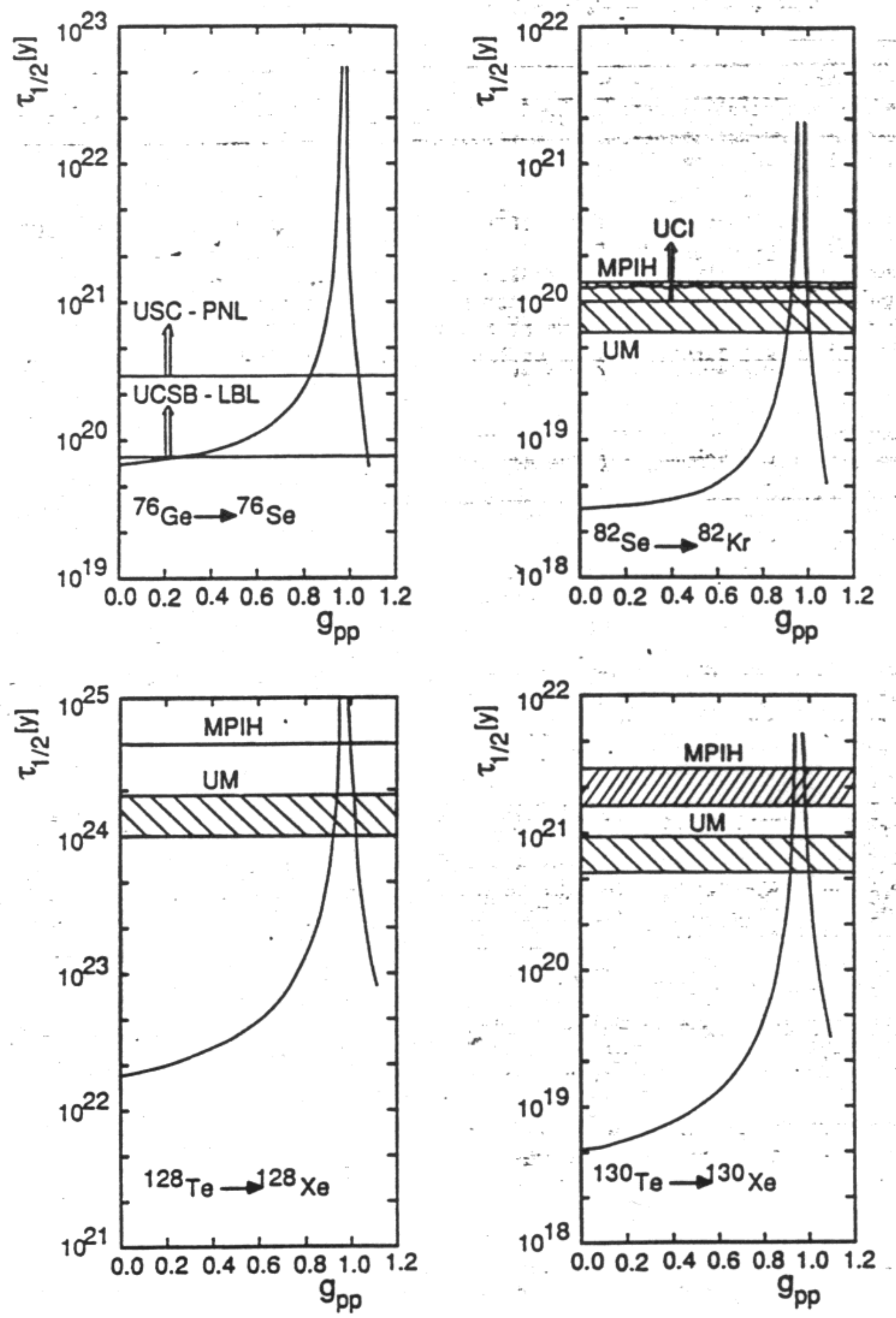


Fig. 6. Half-lives for the 2ν $\beta\beta$-decay of ^{76}Ge, ^{82}Se, ^{128}Te, and ^{130}Te calculated in the Quasiparticle Random Phase Approximation (Civ87). Also shown are experimental limits. The line marked UCI in the graph for ^{82}Se is a limit (10^{20} y) given prior to their recently published result (Ell87a).

EXPERIMENTS

- STORE $^{238}U \rightarrow {}^{238}Pu$

$\downarrow$

α in 87.7 y

MILKING OR RADIOCHEMICAL

- GEOCHEMICAL EXPERIMENTS

A ROCK CONTAINING

^{82}Se ^{96}Zr ^{128}Te ^{130}Te

$\downarrow$ $\downarrow$ $\downarrow$ $\downarrow$

^{82}Kr ^{96}Mo ^{128}Xe ^{130}Xe

MEASURES $\beta\beta 0\nu$, $\beta\beta 2\nu$, $\beta\beta 0\nu \chi$, $\beta\beta$ exited levels

RATIO $\frac{128}{130}Te$ DIFFERENT CROSS SECTION by C. R. (exp. in Berkeley)

GAS RETENTION IN THE ROCK

REASONABLE AGREEMENT FOR ^{82}Se (even with experiments directl.) DIFFICULTIES FOR

^{128}Te $(1.5 \pm .2) \times 10^{24}$ — $(7.7 \pm 0.4) \times 10^{24}$

^{130}Te $(7 \pm 2) \times 10^{20} \rightarrow (2.8 \pm 0.3) \times 10^{21}$

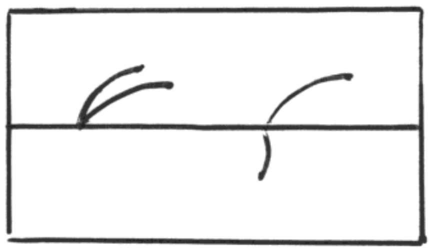
A PROVOCATIVE QUESTION

by A. Barabash DOES THE WEAK INTERACTION CONSTANT DEPEND ON TIME ?

→ AGE OF THE ROCK, COMPARISON WITH DIRECT EXPERIMENTS

DIRECT EXPERIMENTS

SOURCE = DETECTOR
(TRACKING DEVICES)



RECENTLY :

- DRIFT CH. + NaI + SOLID STATE — ELEGANTS
- PROP. COUNTERS + NAI — BAKSAN
- TPC — MOSCOW - IRVINE
- G.M. COUNTERS + SCINTILLATORS — NEMO
- ^{100}Mo in liquid Argon (LNGS)
- SOLID STATE — MOUNT HOLYHOKE

ALL UNDERGROUND
EXCELLENT FOR 2ν - LIMITED
RESOLUTION — AUTO ABSORPION

A PROVOCATIVE QUESTION

by A. Barabash DOES THE WEAK INTERACTION CONSTANT DEPEND ON TIME?

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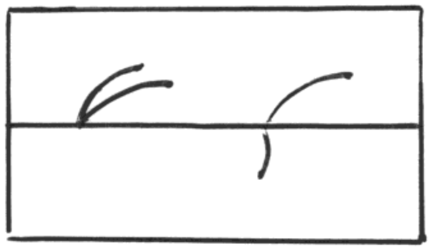

RECENTLY :

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- TPC — MOSCOW - IRVINE
- G.M. COUNTERS + SCINTILLATORS — NEMO
- ^{100}Mo in liquid Argon (LNGS)
- SOLID STATE — MOUNT HOLYOKE

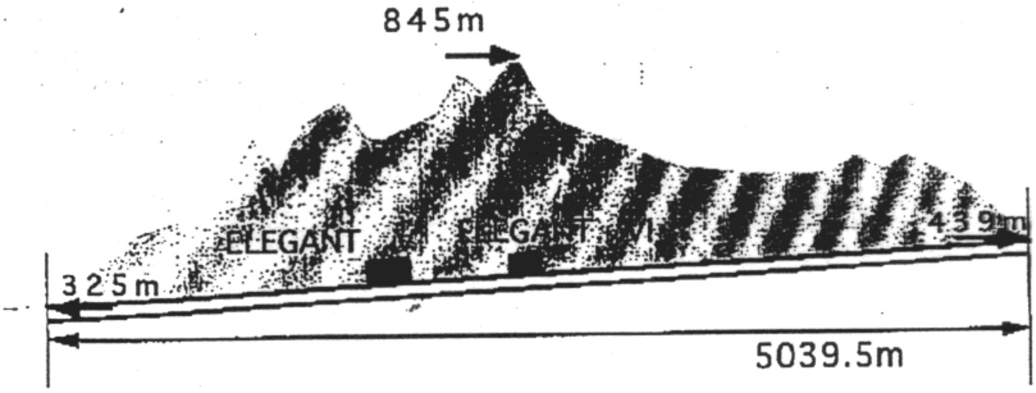
ALL UNDERGROUND

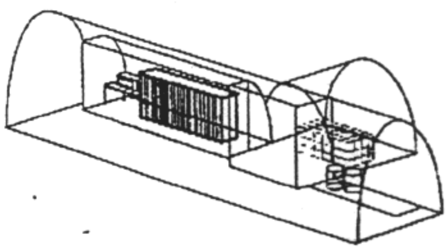
EXCELLENT FOR 2ν - LIMITED RESOLUTION — AUTO ABSORPION

Oto Cosmo Observatory

New Low BG Underground Lab. 100km South of Osaka

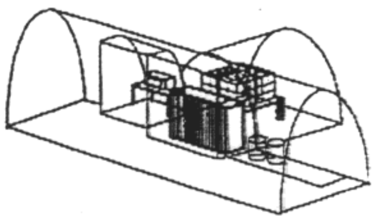
	Oto	Kamioka	Gran Sasso
Depth(m)	500	1000	1400
Distance(km)	100	350	10000
$\mu(/m^2/s)$	$4 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$3 \cdot 10^{-4}$
$Rn(Bq/m^3)$	10	10^3	>3





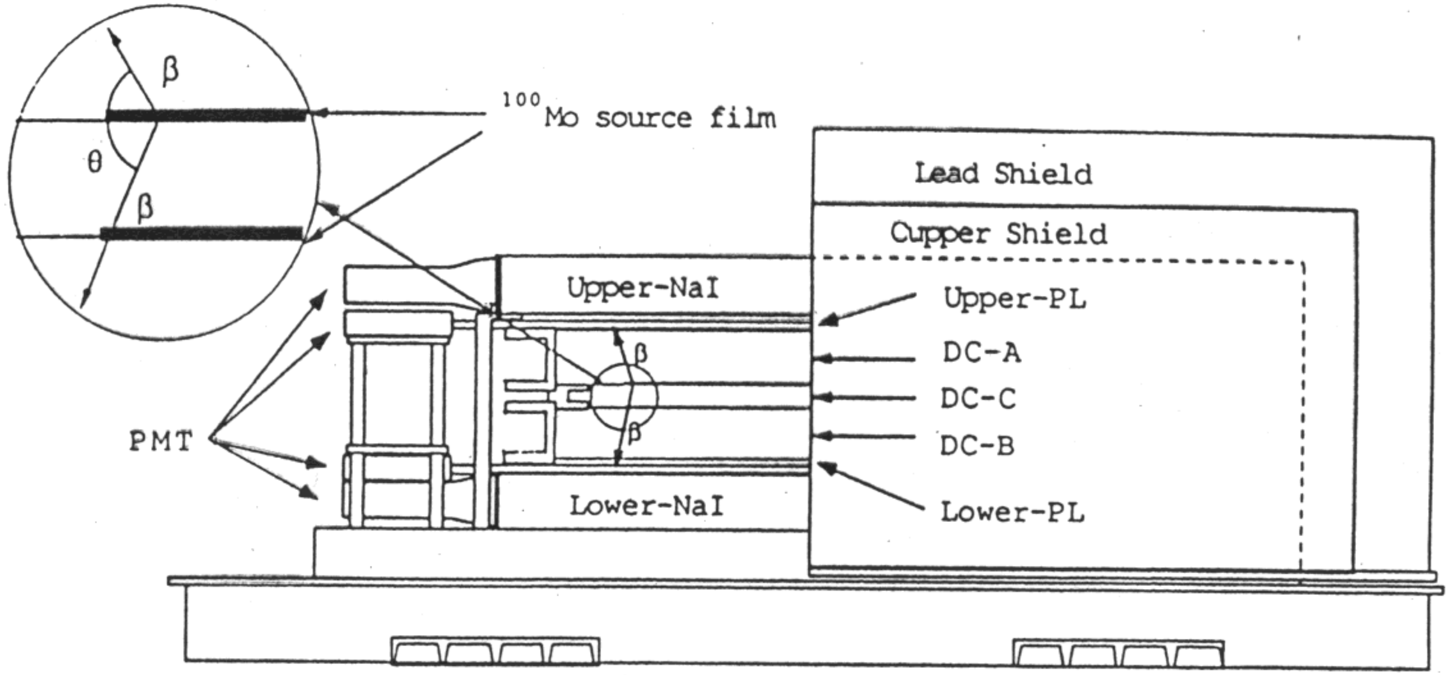
ELEGANT V

^{100}Mo, ^{116}Cd, ββ & NaI DM



ELEGANT VI

^{48}Ca ββ & ^{19}F DM


^{100}Mo source film
β
θ
β
Lead Shield
Cupper Shield
Upper-NaI
Upper-PL
DC-A
DC-C
DC-B
Lower-PL
Lower-NaI
PMT

ELEGANTS

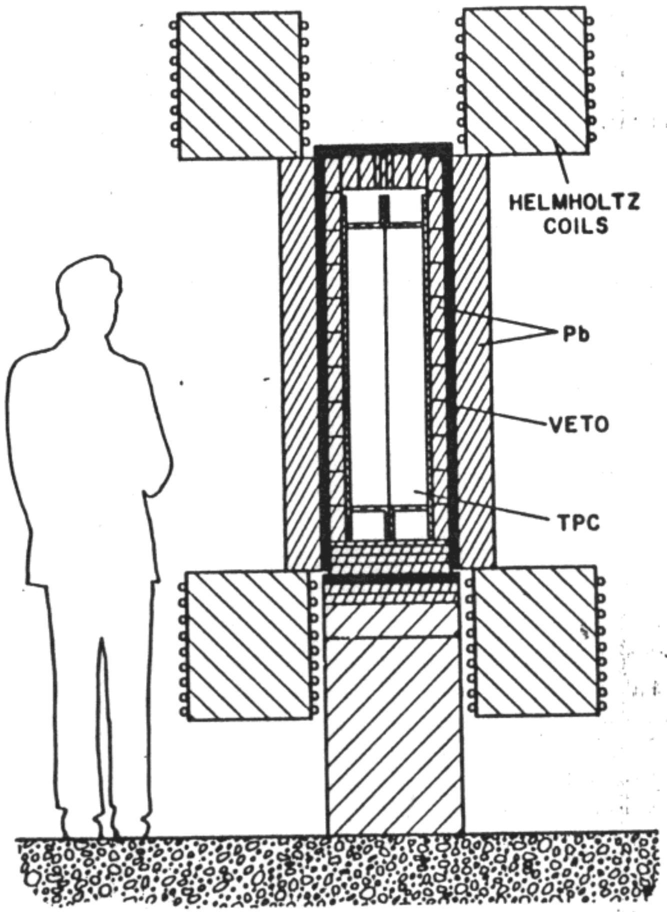


Fig. 7. University of California, Irvine TPC, showing a cross section of the chambers, wire detectors, and shielding.

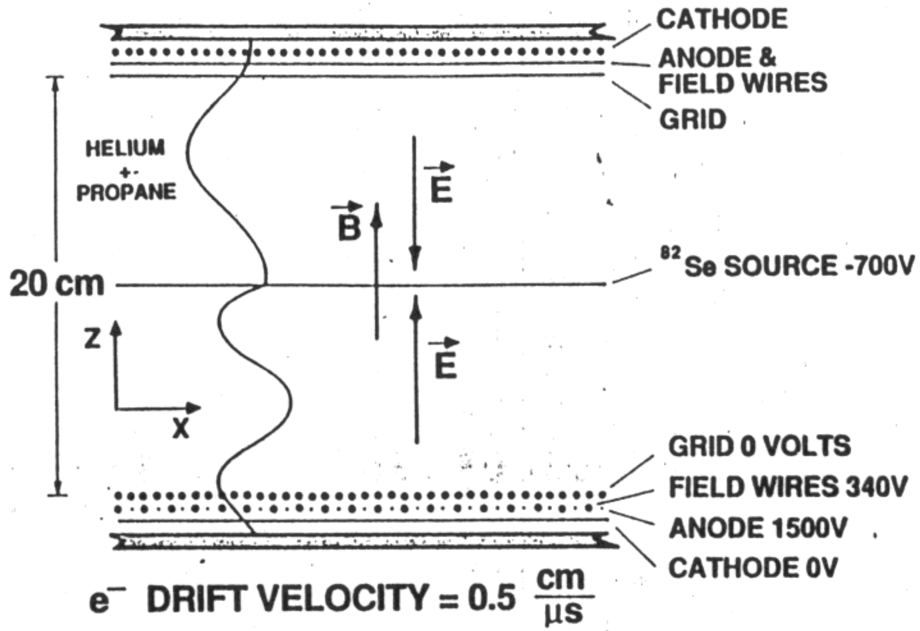


Fig. 8. Side view of the UCI TPC showing the source plane, $\vec{E}$ and $\vec{B}$ fields, and wire chambers.

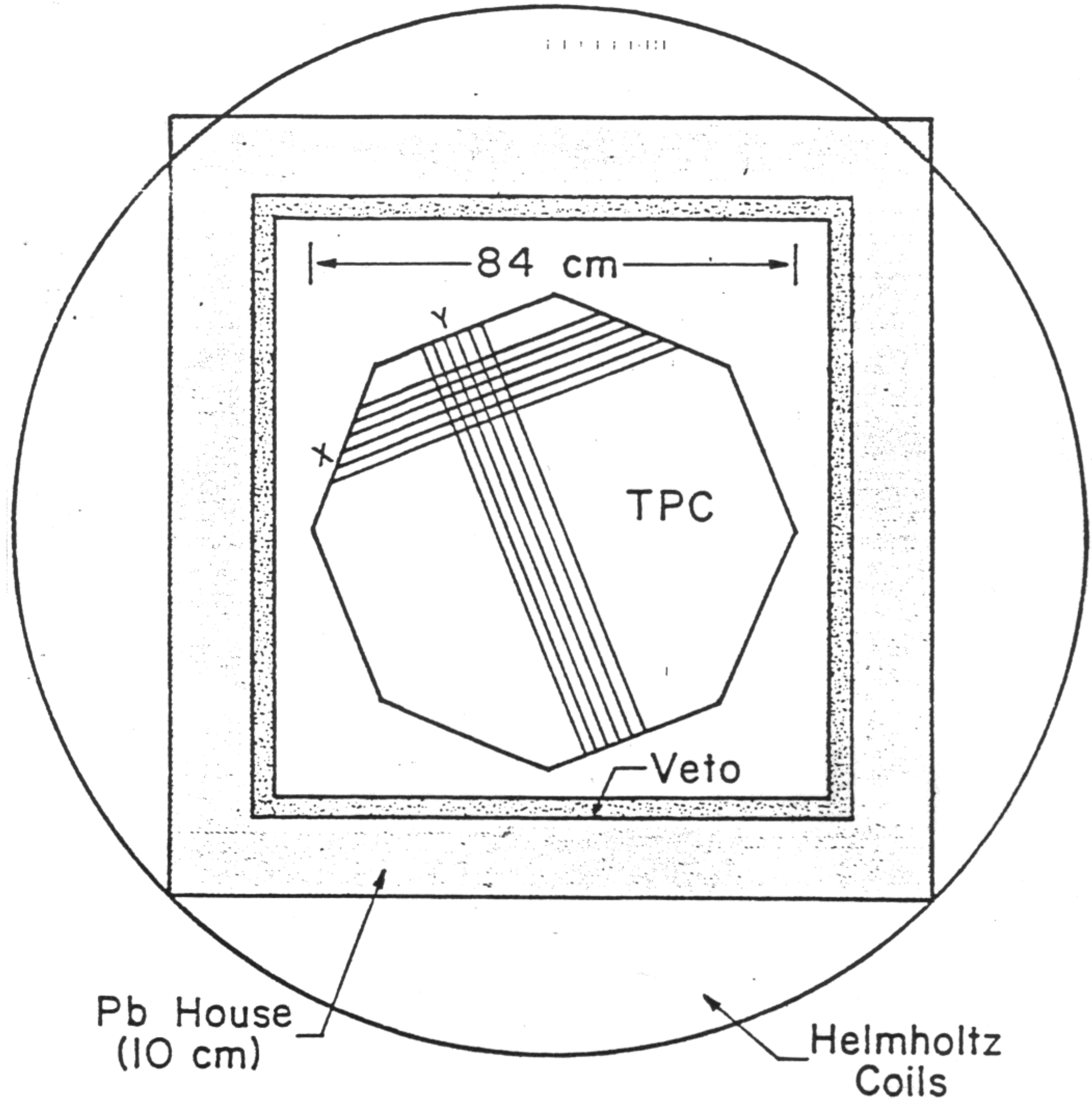


Fig. 2 Schematic axial view of TPC

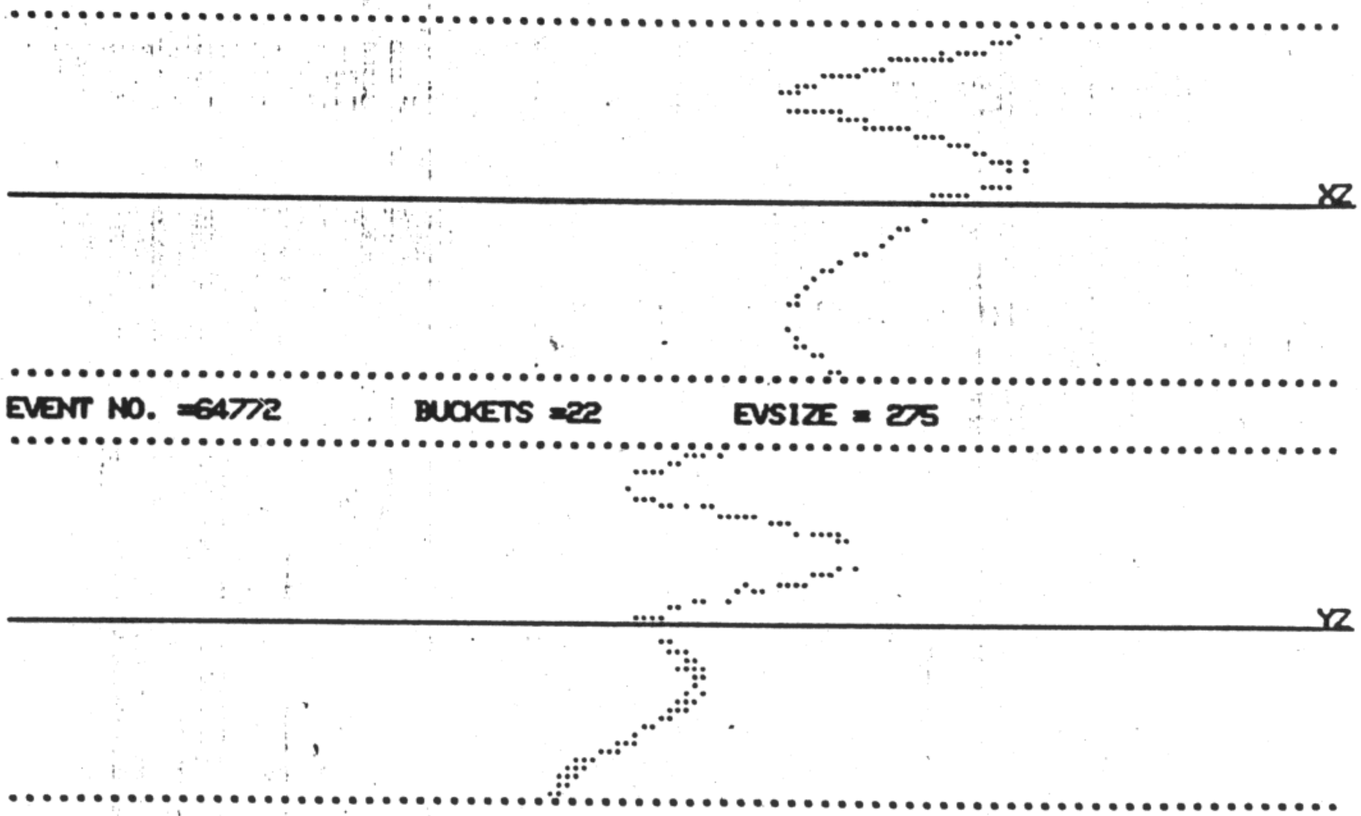


Fig. 9. An example of reconstructed ionization tracks from a $\beta\beta$-decay event in the UCI TPC.

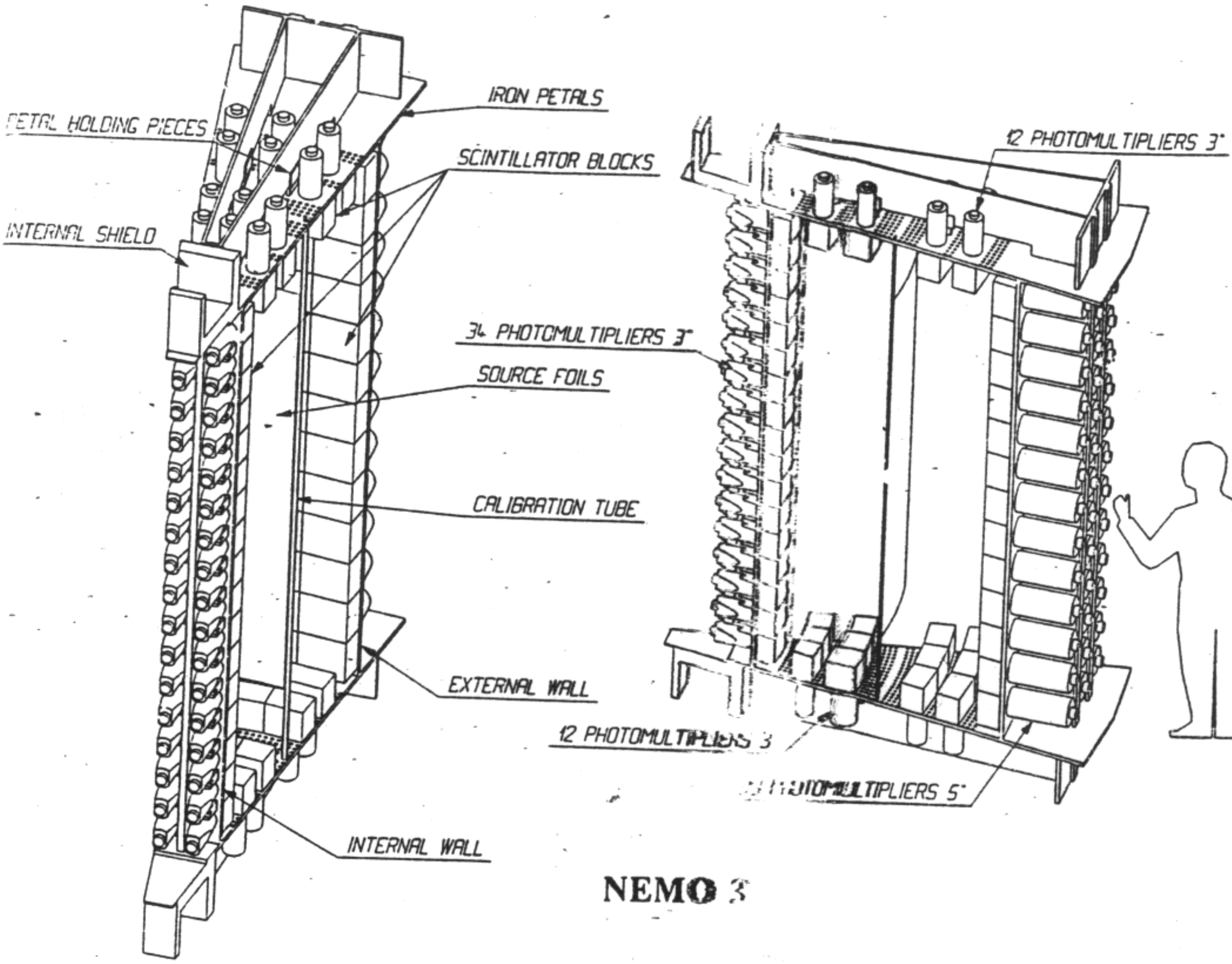


Figure 2: One sector of NEMO 3 with details on the ^{100}Mo source foil, scintillator blocks, photomultipliers. The Geiger cells are located between the internal and external walls.

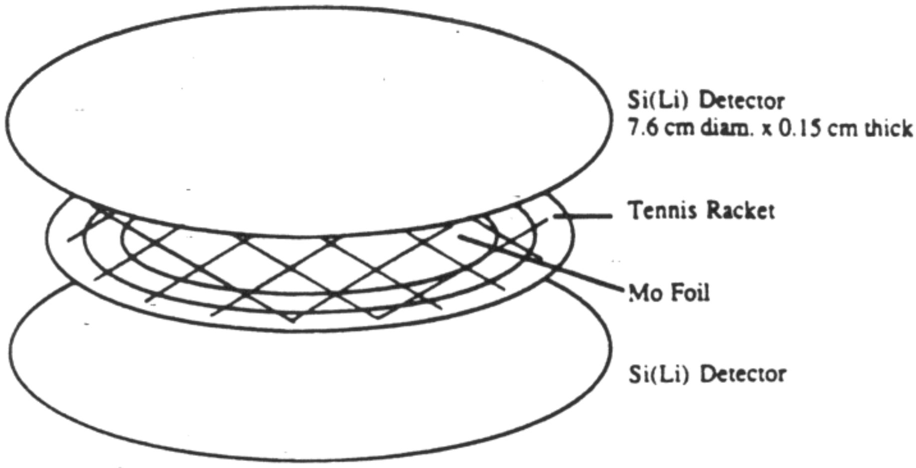


Fig. 1. Exploded view of part of the detector array. The gaps between detectors are 0.1 cm.

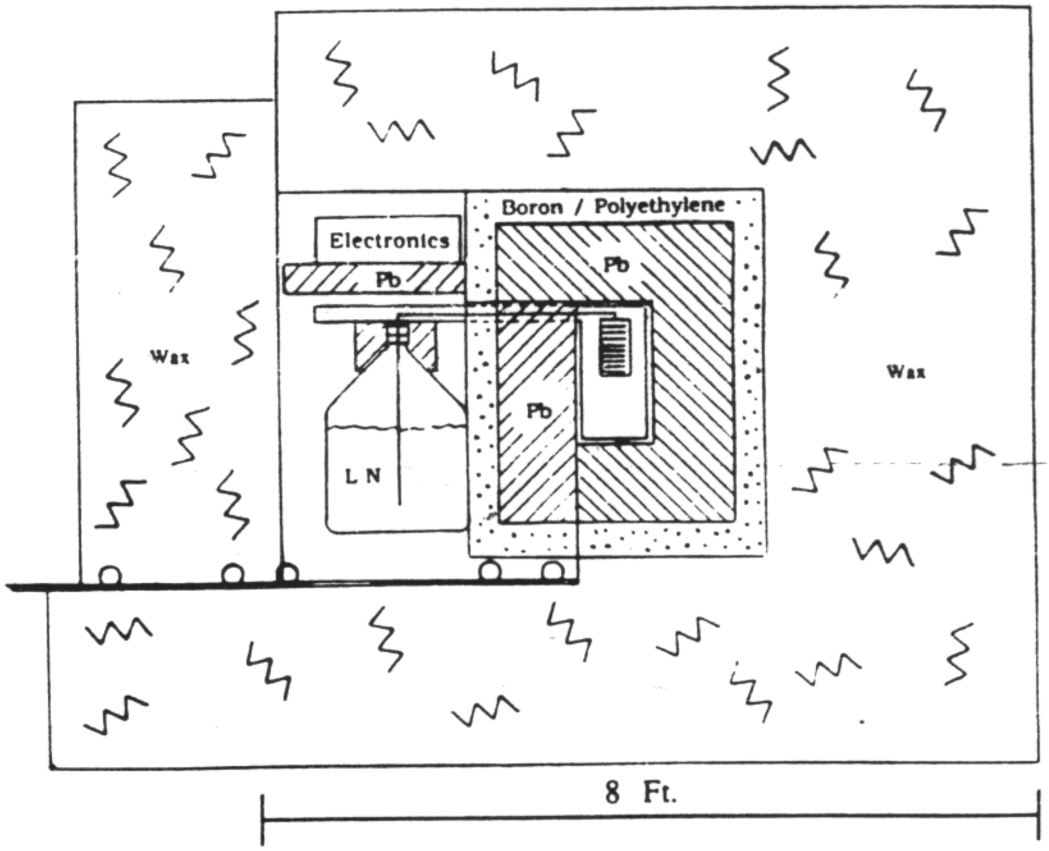


Fig. 2. Elevation of experiment.

SOURCE = DETECTOR

G.F. DELL' ANTONIO AND E.F.

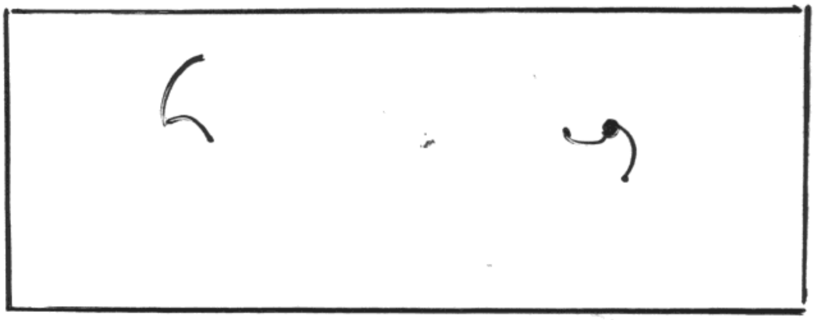
CaF_2 for ^{48}Ca - SCINTILLATORS

$CdWO_4$ for ^{116}Cd "

Xe ionization, proportional, TPC, SCINTILL. for ^{136}Xe

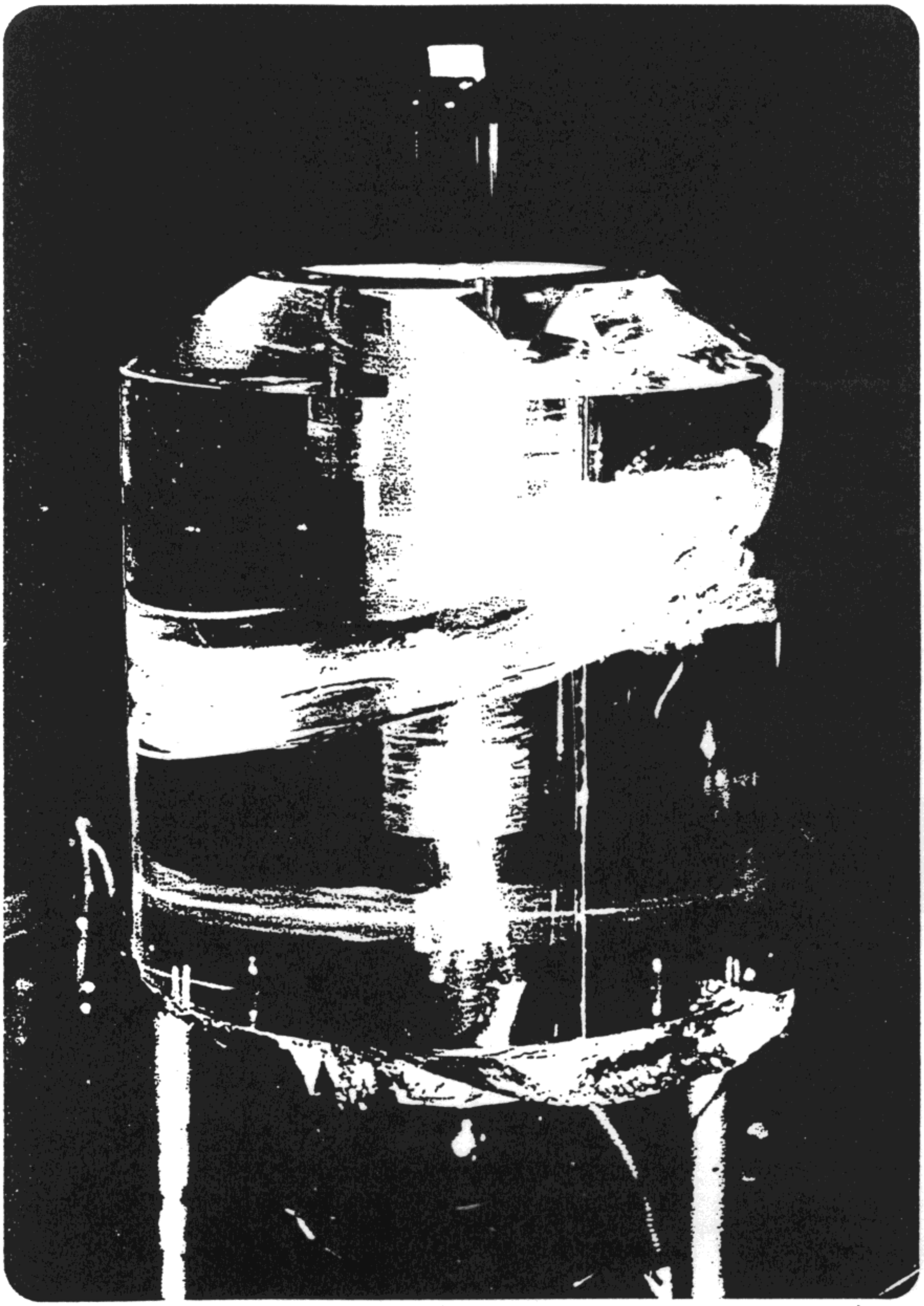
Ge diodes for ^{76}Ge

MILANO → HEIDELBERG-MOSCOW, IGEX

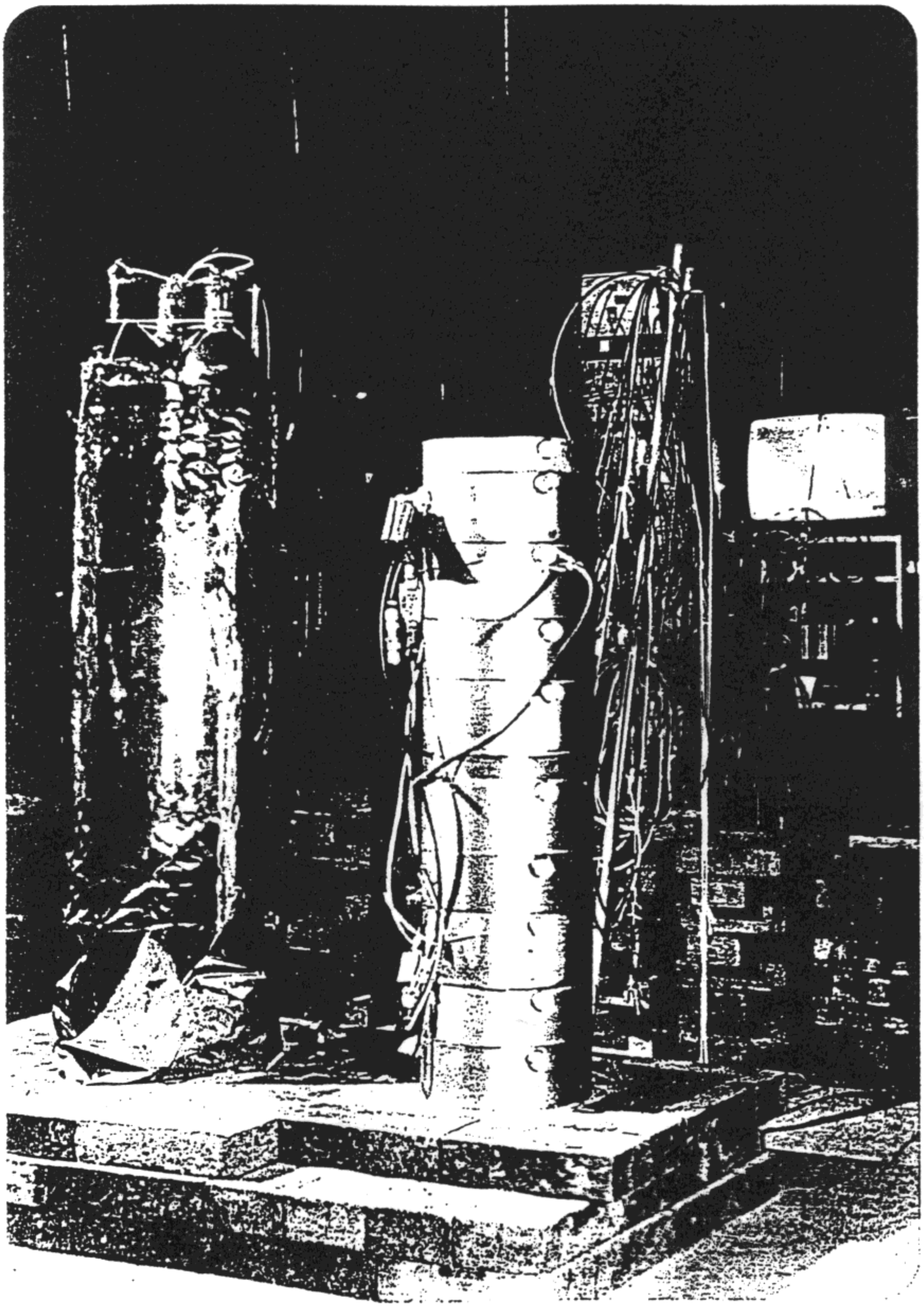


GOOD FOR NEUTRINOLESS $\beta\beta$ decay

DIFFICULTY - LIMITED CHOICE OF CANDIDATES

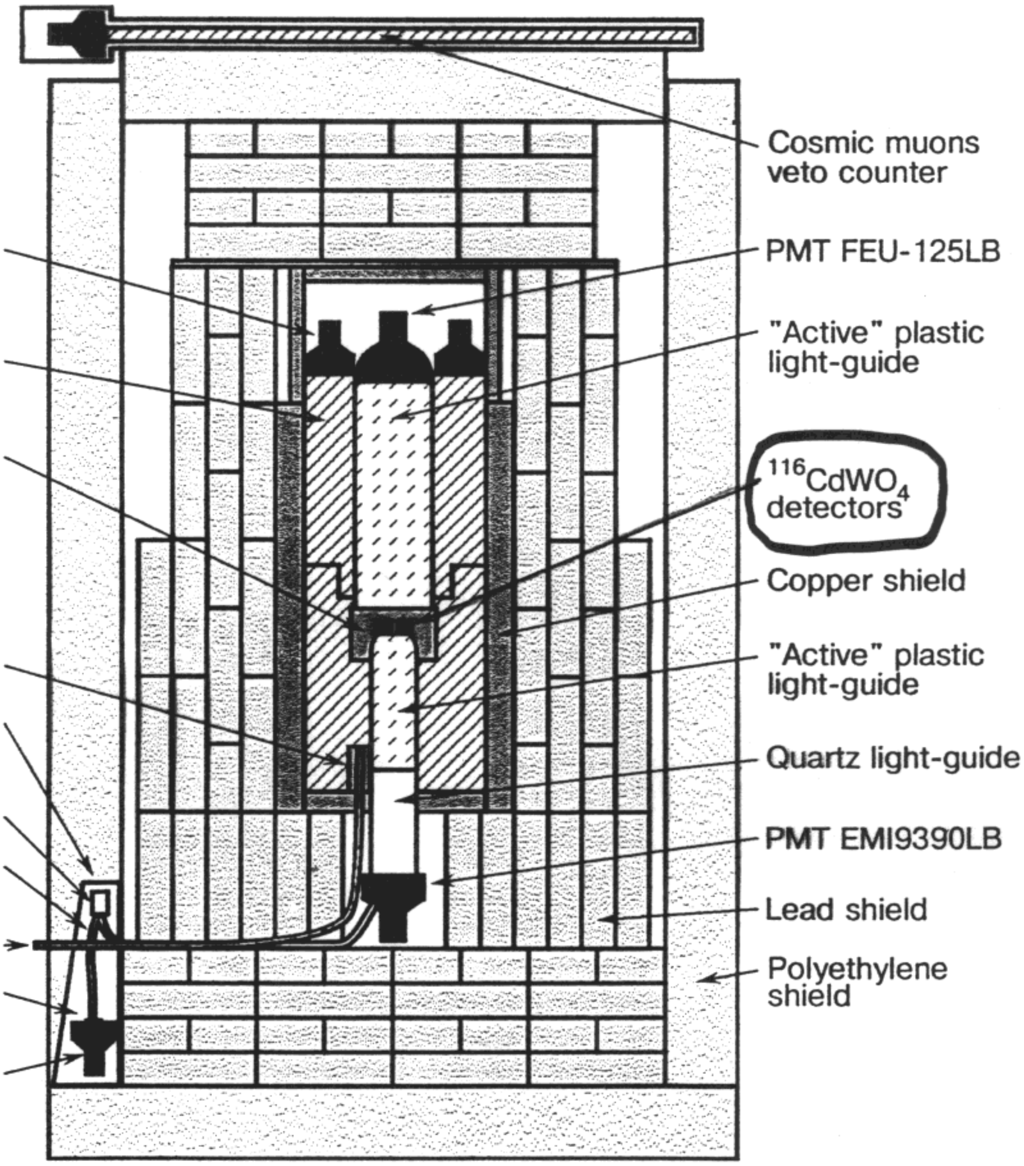


Open set up with $^{116}CdWO_4$ crystal



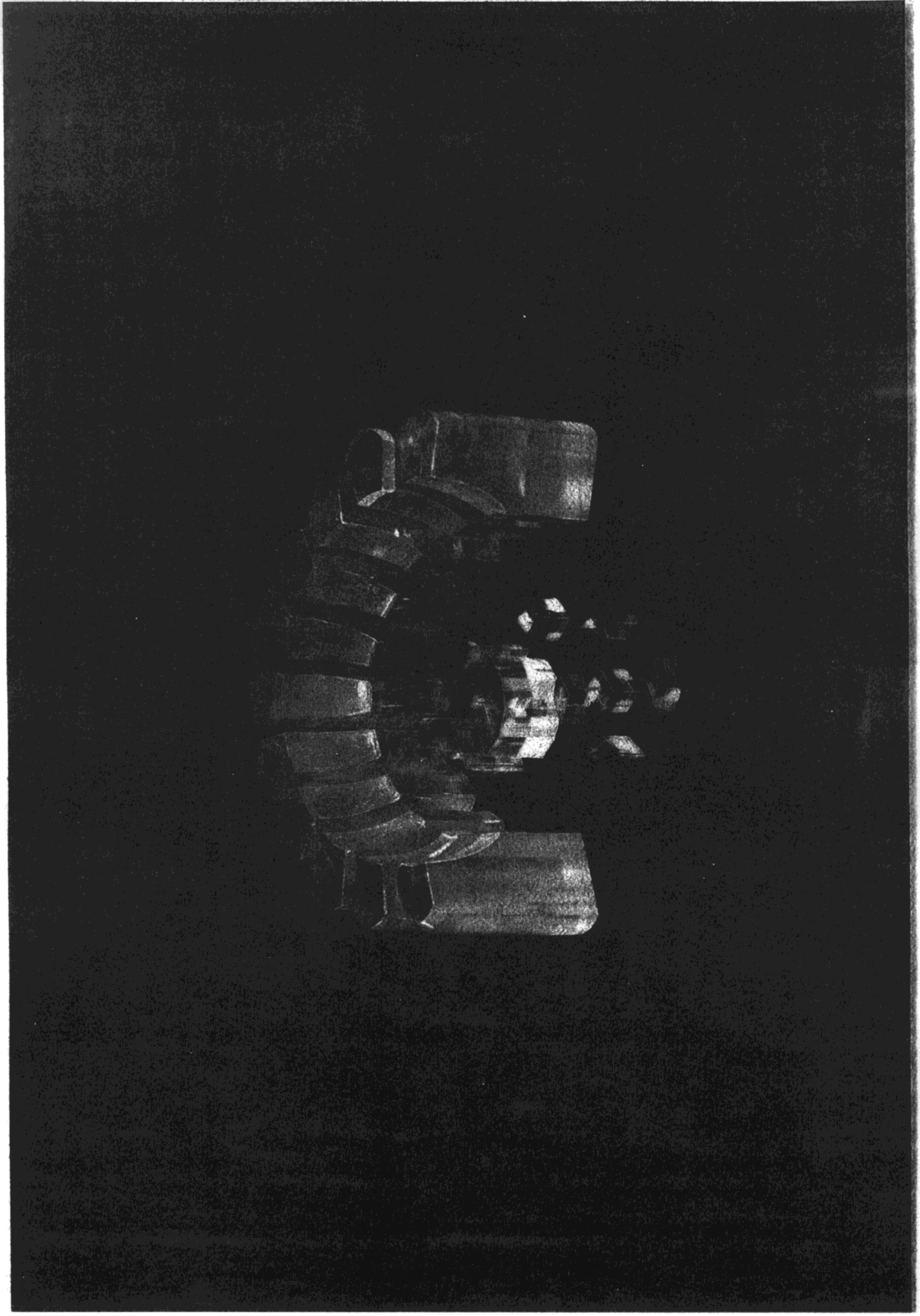
Two set ups for ^{116}Cd study

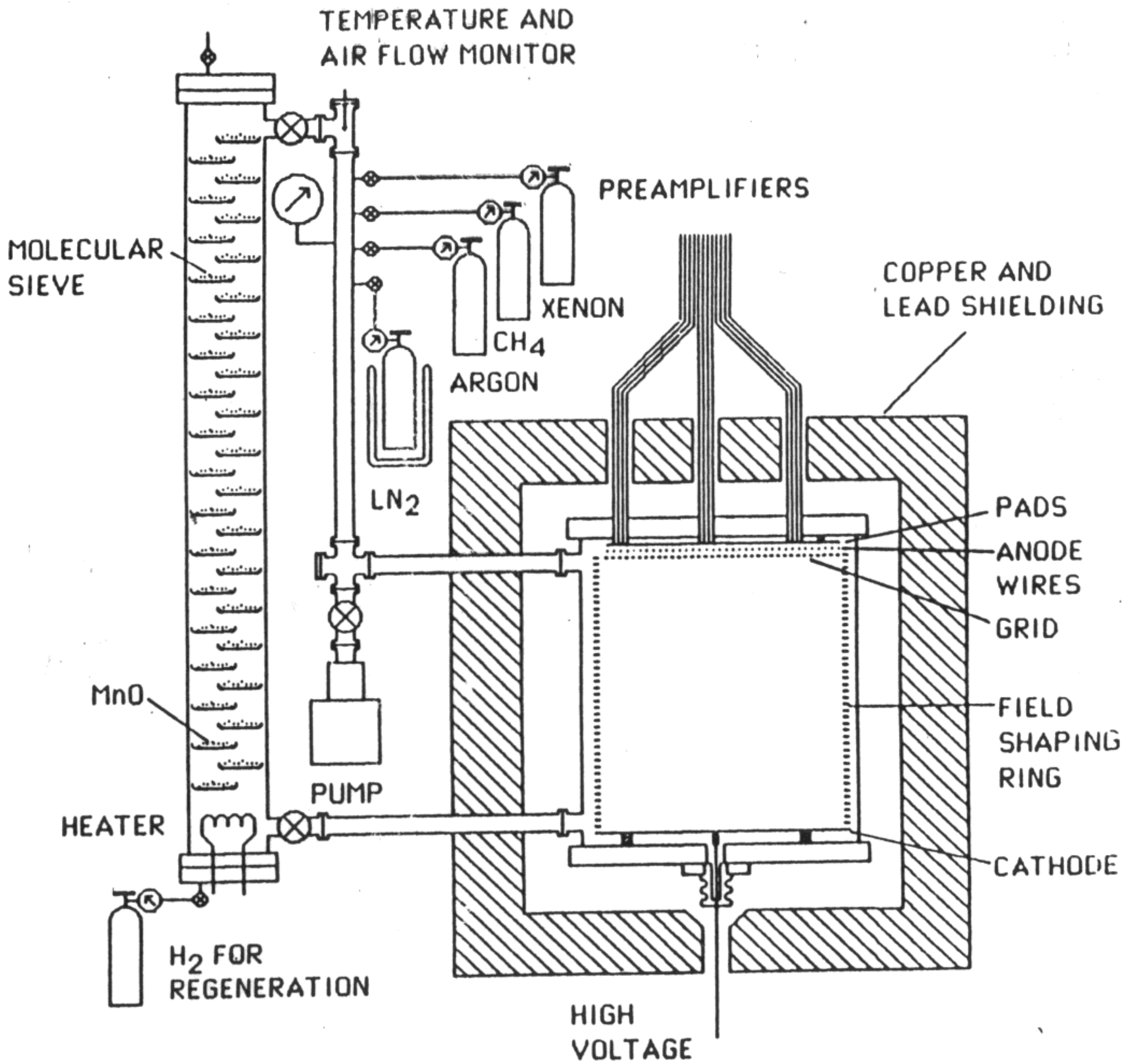
Kiev-Firenze ^{116}Cd 2β experiment

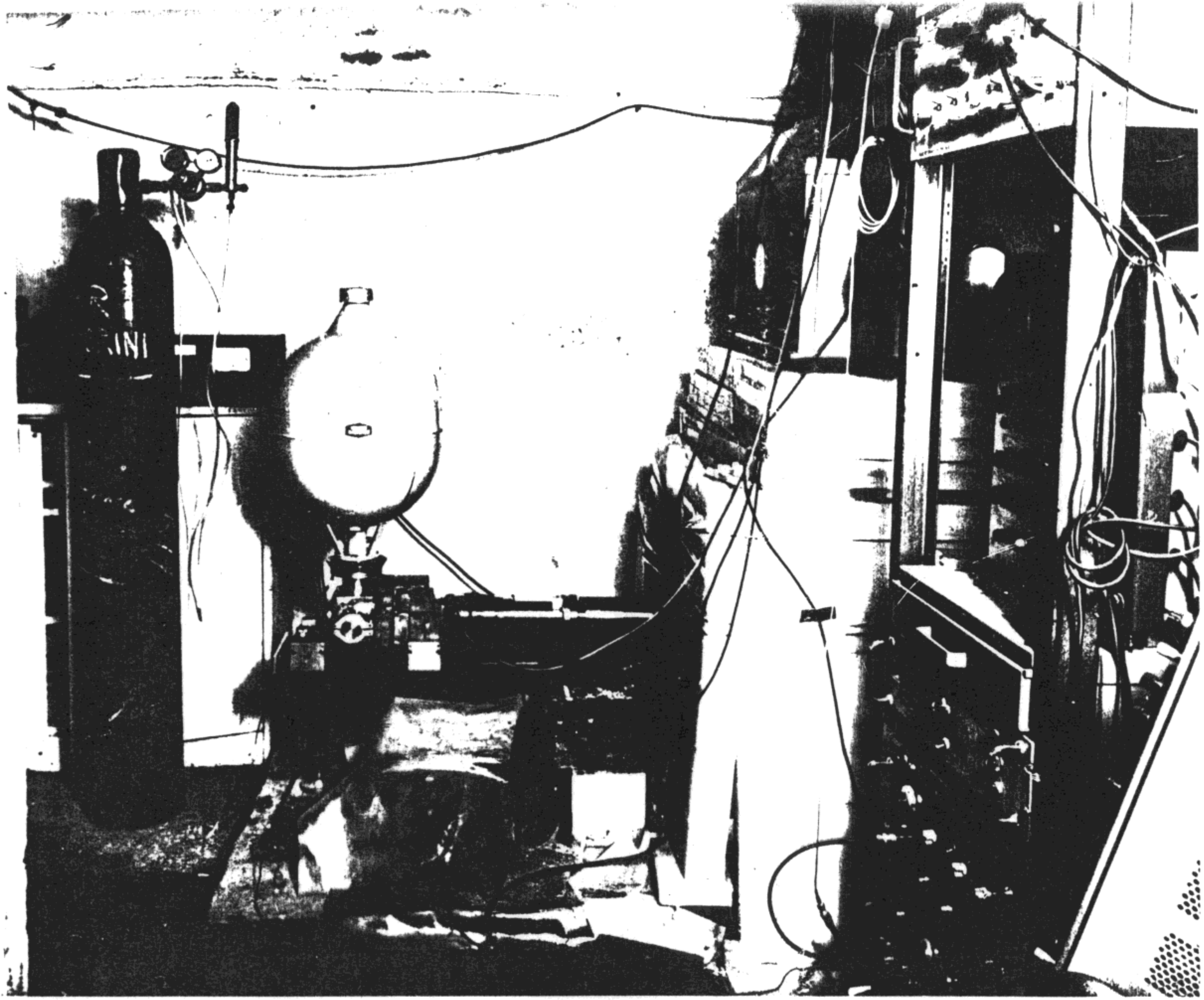


New set up

in Solotvina Underground Laboratory




TEMPERATURE AND
AIR FLOW MONITOR
PREAMPLIFIERS
MOLECULAR
SIEVE
XENON
CH_4
ARGON
COPPER AND
LEAD SHIELDING
LN_2
PADS
ANODE
WIRES
GRID
MnO
FIELD
SHAPING
RING
PUMP
HEATER
CATHODE
H_2 FOR
REGENERATION
HIGH
VOLTAGE



c.a. 1968

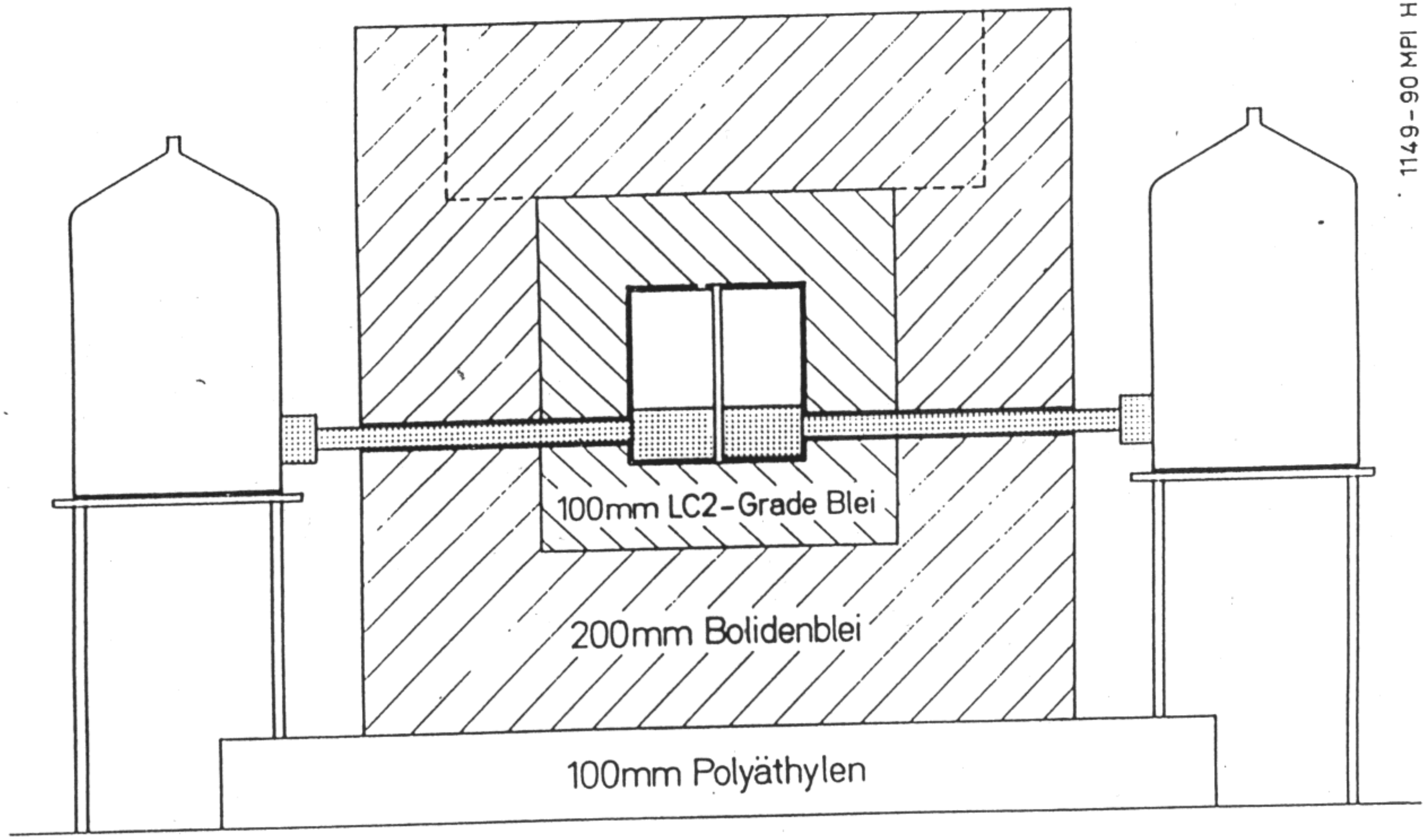
$\tau > 5 \times 10^{21}$

↓

1986 4×10^{23}

↓

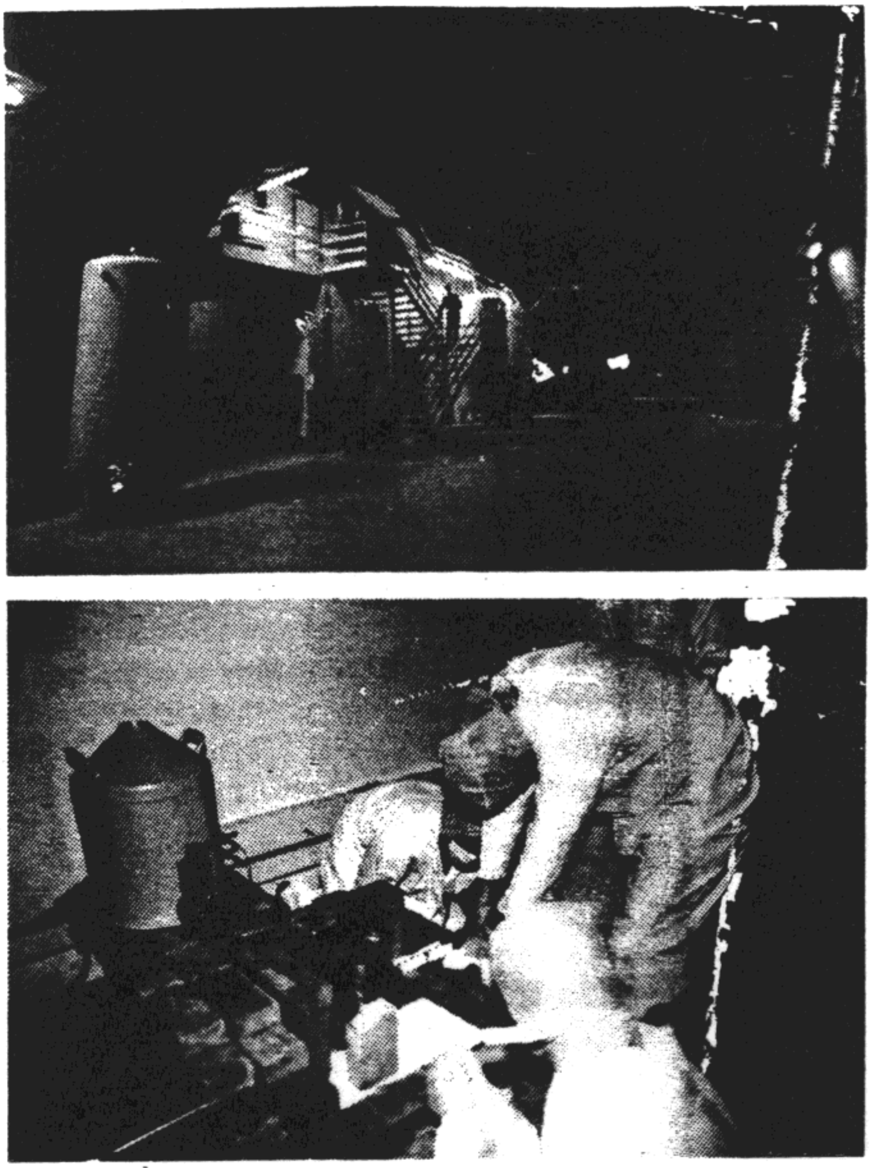
1.1×10^{25} !



M 1:2,5

1149-90 MPI H

PS9



$\tau > 5 \times 10^{24}$

Fig. 12: The ββ laboratory of the HEIDELBERG-MOSCOW experiment in the GRAN SASSO near Rome (a) Mounting of the enriched detectors under low-level conditions (b)

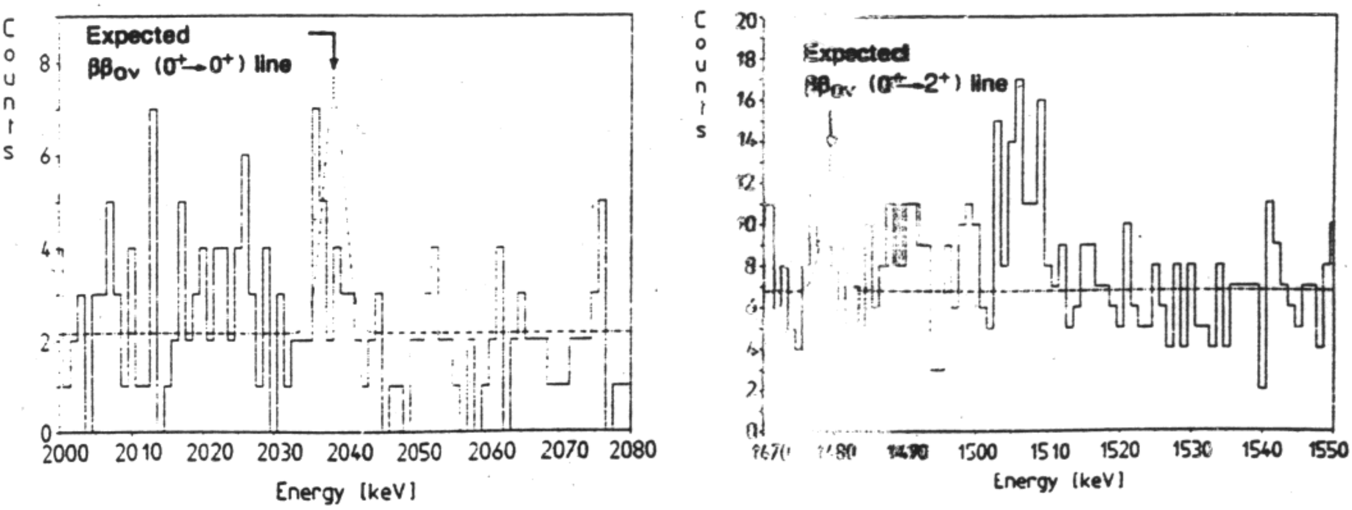
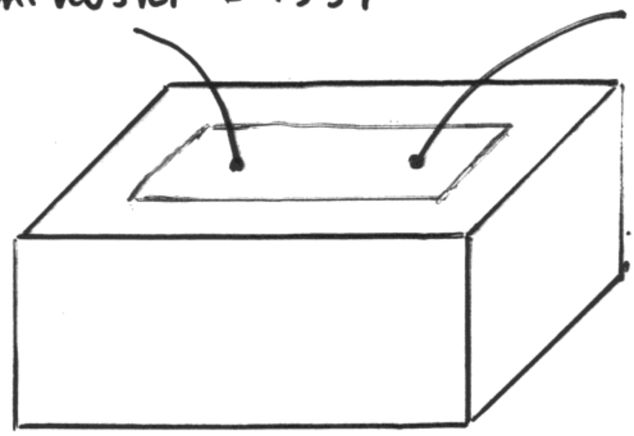


Fig. 13: Details of the spectrum of the HEIDELBERG-MOSCOW collaboration in the region of neutrinoless double beta decay to the ground and first excited state of the daughter nucleus after a measuring time of 2924 kg d.

THERMAL DETECTORS AT LOW TEMPERATURES

E.F. and T. Niinikoski - 1994

$$\Delta T = \frac{Q}{C_V}$$



$$C_V = 1944 \left(\frac{V}{V_m}\right)\left(\frac{T}{\Theta_D}\right)^3 \quad J/K$$

		C_V
EXAMPLES	① 1 mg Si @ 50 mK	3×10^{-14} J/K
	② 1 Kg Ge @ 10 mK	7×10^{-10} J/K

$$\Delta E \approx \sqrt{C_V \cdot T^2 \cdot k}$$

① 2 eV ~ 10 eV

② 160 eV ~ keV

EXPERIMENTS WITH

TeO_2 ^{130}Te i.a. 34% $\Delta E = 2528$ keV

PRESENTLY - ARRAY OF 20 CRYSTALS OF 340 g EACH

PRESENT EXPER. RESULTS
($\beta^-\beta^-$ ONLY)

• $^{48}Ca \to {}^{48}Ti$ i.a. .187 % $\Delta E = 4272$ keV

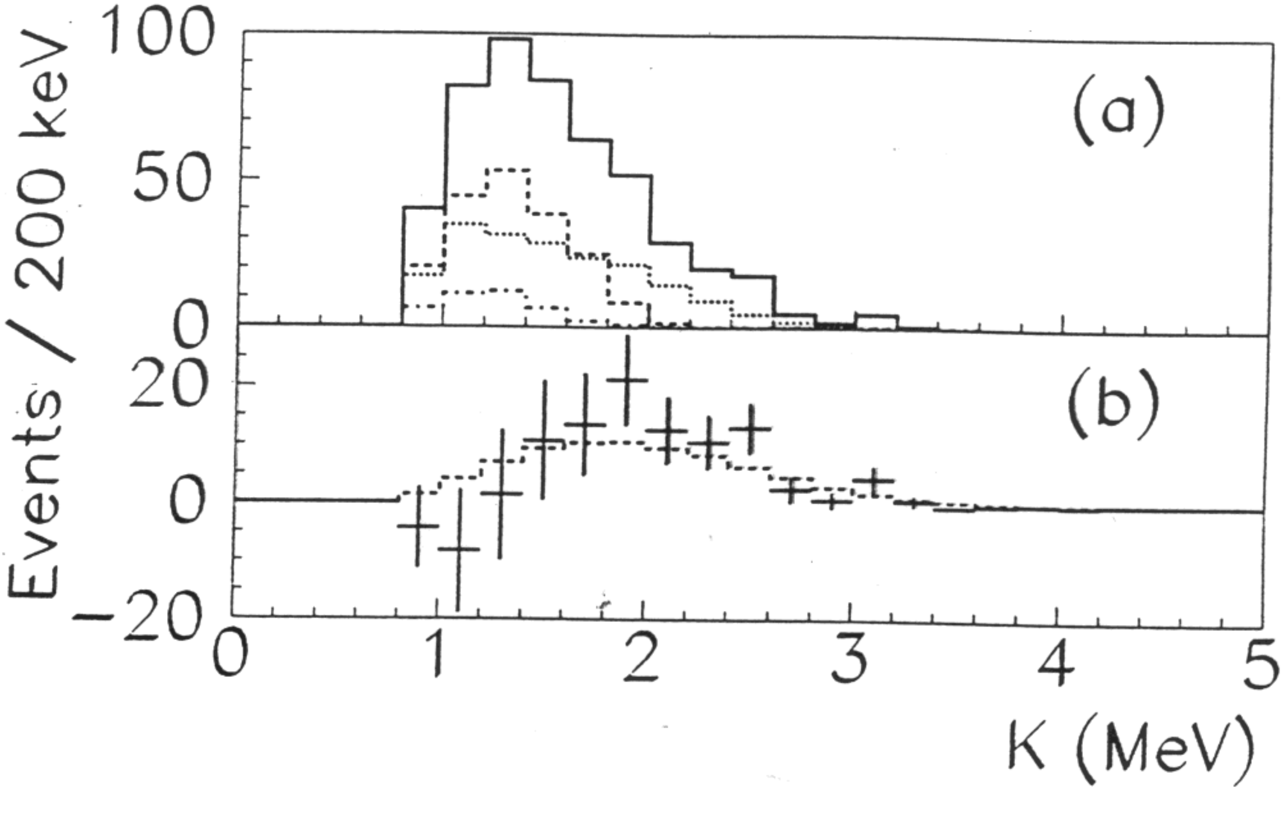
2ν	$0^+ 0^+$	$4.3 \pm^{3.4}_{1.5} \times 10^{19}$ y	$(3-16)\times 10^{18}$
0ν	$0^+ 0^+$	$> 9.5 \times 10^{21}$	$\langle m \rangle < (12-55)$ eV
$0\nu\chi$	$0^+ 0^+$	$> 7.2 \times 10^{20}$	$\langle g_M \rangle < (1-2)\times 10^{-3}$
$0,2\nu$	$0^+ 2^+$	$> 1 \times 10^{21}$	$\tau_{2\nu} \approx 5 \times 10^{25}$
$0,2\nu$	$0^+ 0^{+*}$	$> 8 \times 10^{18}$	—

• $^{76}Ge \to {}^{76}Se$ 7.44 % 2038.7 keV

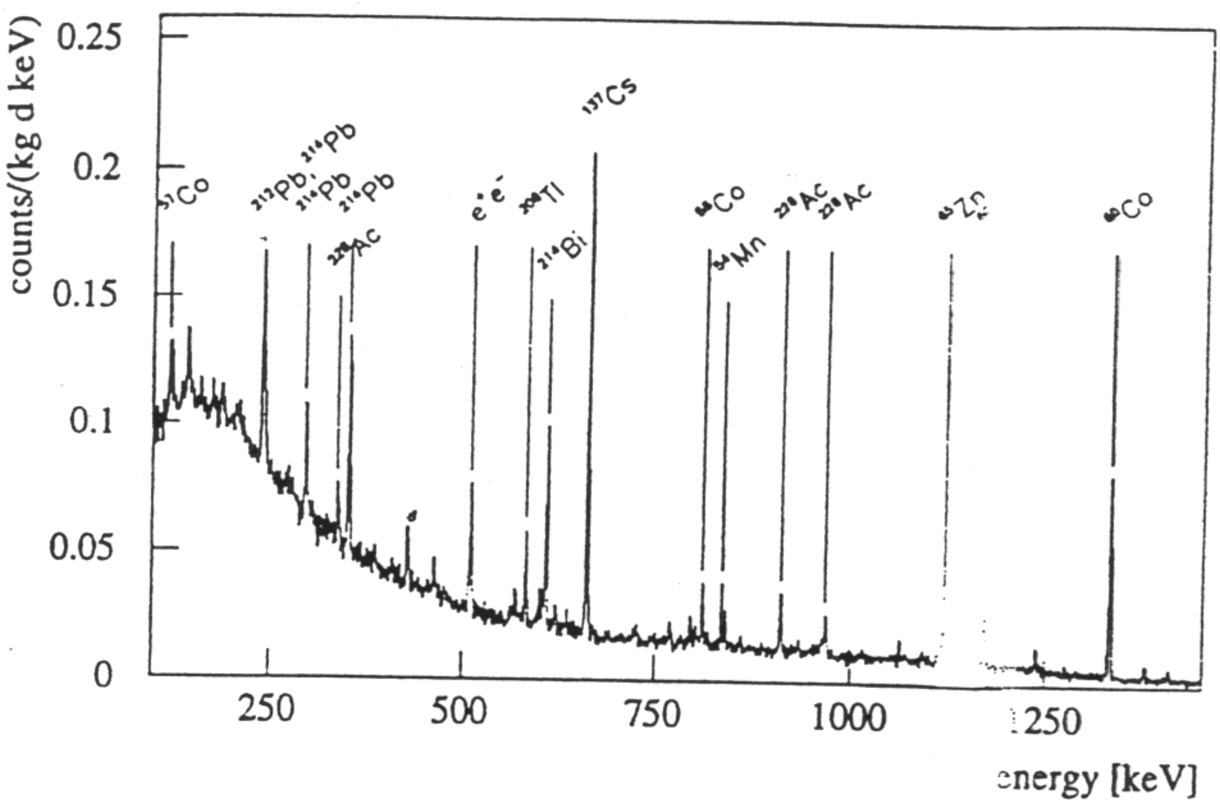
2ν	$0^+ - 0^+$	$(1.1\times 10^{21} - 1.8\times 10^{21})$	$(8-9)\times 10^{20}$
0ν	$0^+ - 0^+$	$> 1.1\ (.8)\times 10^{25}$	$\langle m_\nu \rangle < 0.3 - 1.3$
$0\nu\chi$	$0^+ - 0^+$	$> 3.9 \times 10^{22}$	$\langle g_M \rangle < (1-5)\times 10^{-4}$
$0,2\nu$	$0^+ 2^+$	$> 1.4 \times 10^{21}$	$\tau_{2\nu} \nearrow (6-800)\times 10^{23}$
$0,2\nu$	$0^+ 0^{+*}$	$> 1.7 \times 10^{21}$	$\tau_{2\nu} \searrow (8-300)\times 10^{21}$
0ν	$0^+ - 2^+$	$> 8.2 \times 10^{23}$	$0^+ - 0^{+*} > 2 \times 10^{22}$
$0\nu 2\chi$	$0^+ 0^+$	$> 5.9 \times 10^{21}$	

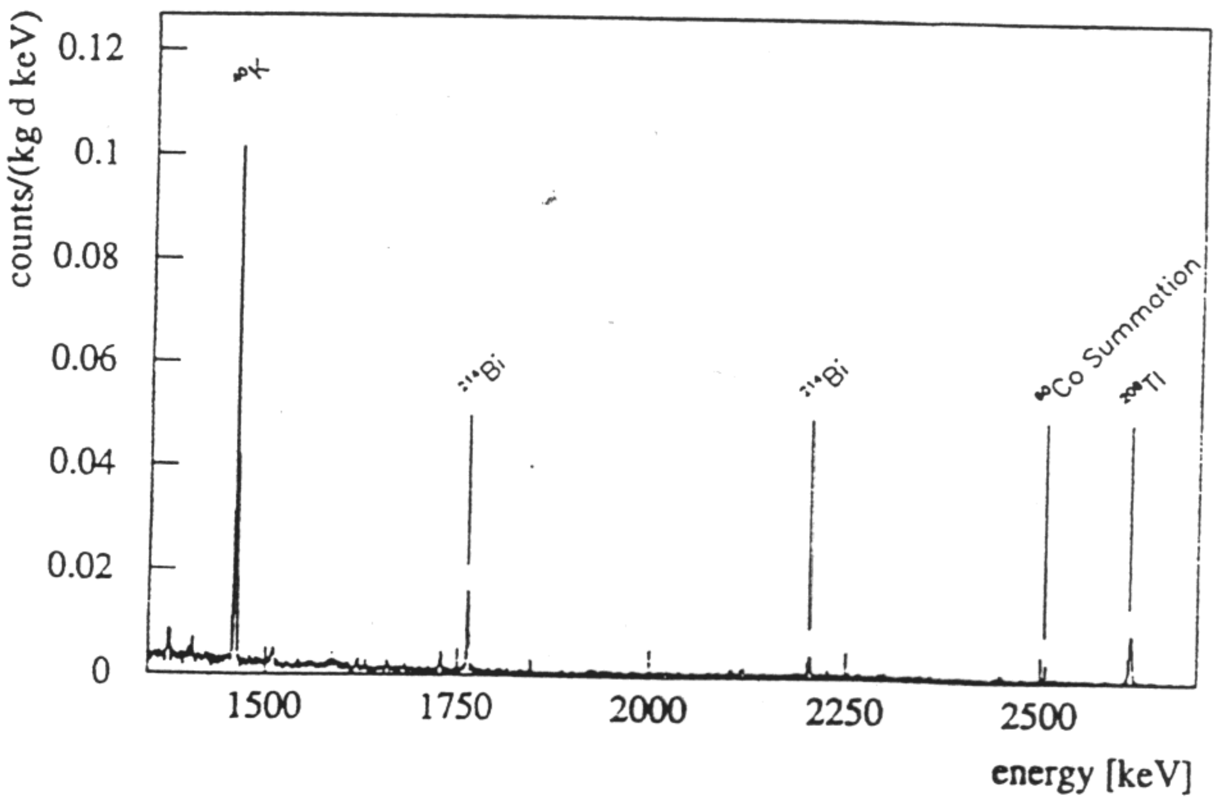
• $^{82}Se \to {}^{82}Kr$ 8.73 % 2995 keV

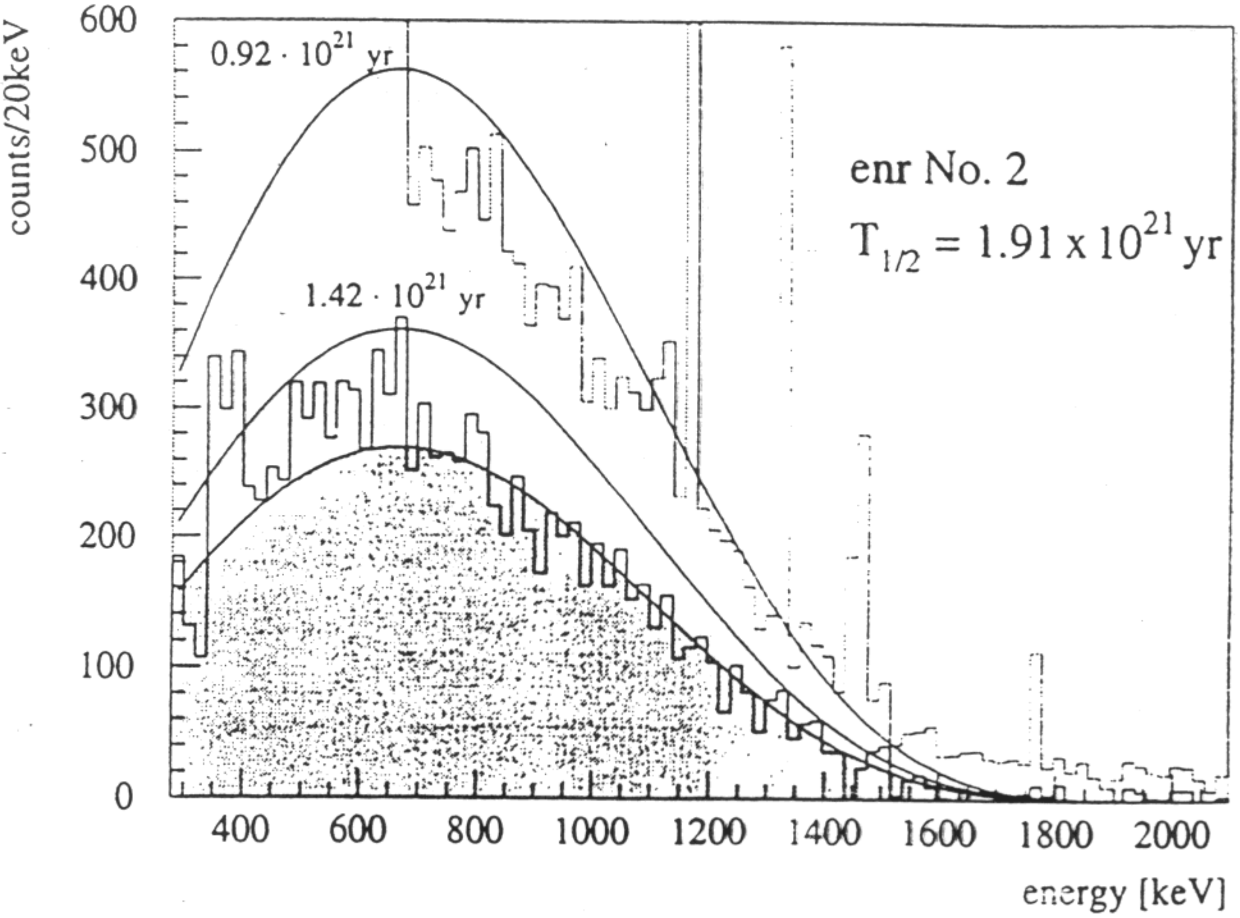
GEOCHEM.		$(1.1\pm.1 - 1.7\pm.2)\times 10^{20}$	
2ν	$0^+ 0^+$	$(7-14)\times 10^{19}$	$(1-15)\times 10^{19}$
0ν	" "	$> 5 \times 10^{21}$	$11-24$
$0\nu\chi$	" "	$> 2 \times 10^{21}$	$\langle g_M \rangle\ (2-6)\times 10^{-4}$
0ν	$0^+ - 2^+$	$> 3.4 \times 10^{21}$	



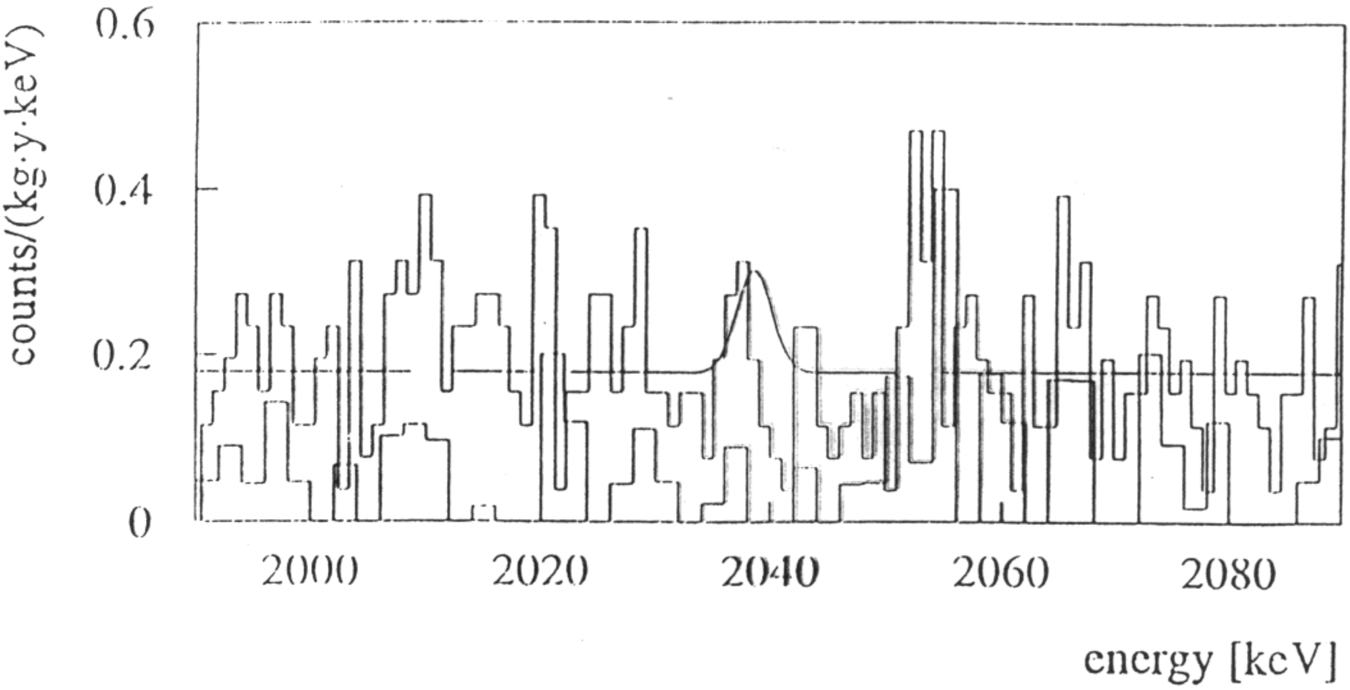
Events / 200 keV
100
50
0
20
0
-20
(a)
(b)
0
1
2
3
4
5
K (MeV)


counts/(kg d keV)
energy [keV]

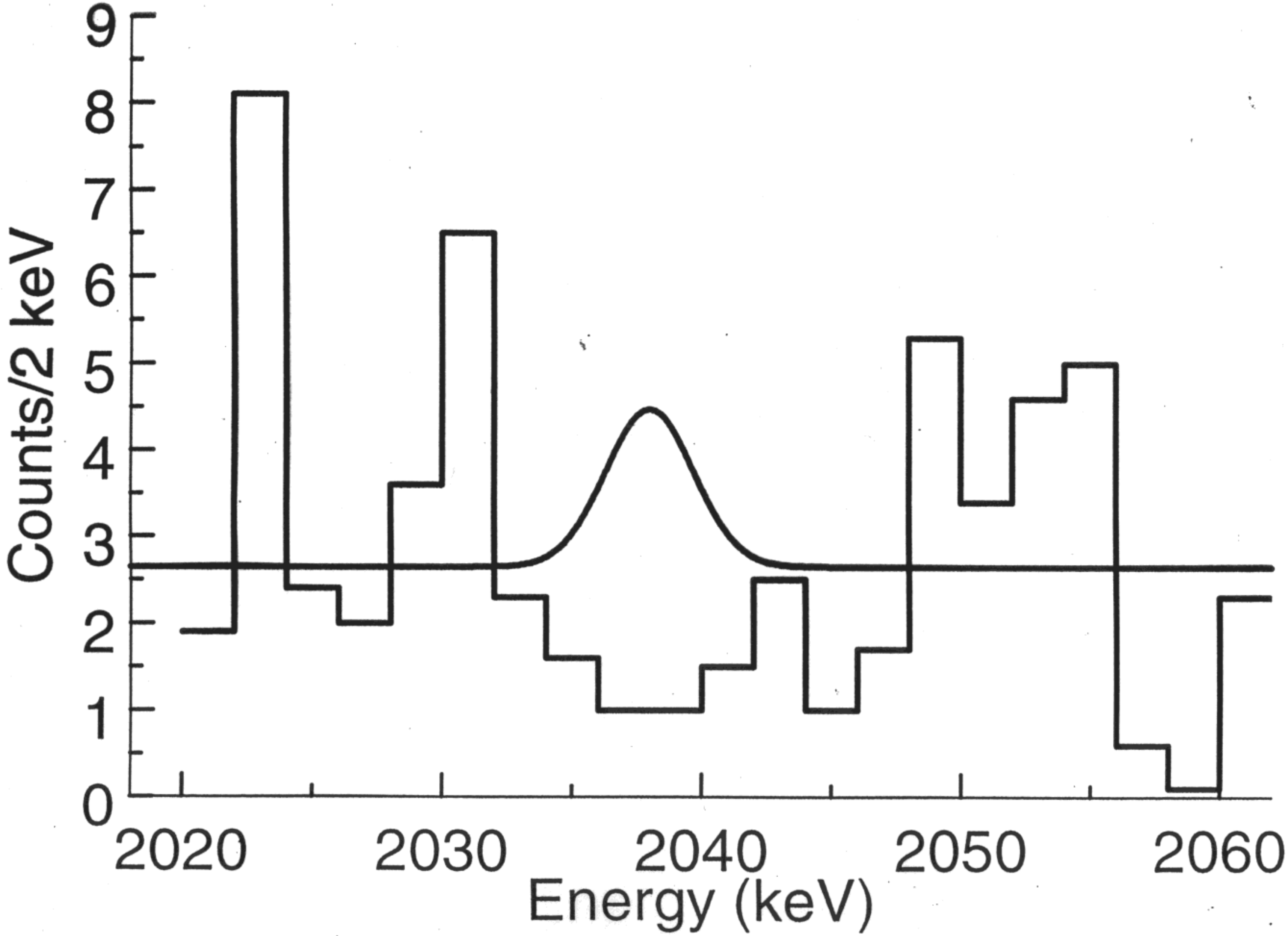

counts/(kg d keV)
Co Summation
energy [keV]



counts/20keV
600
500
400
300
200
100
0
0.92 · 10^21 yr
1.42 · 10^21 yr
enr No. 2
T1/2 = 1.91 x 10^21 yr
400
600
800
1000
1200
1400
1600
1800
2000
energy [keV]



counts/(kg·y·keV)
0.6
0.4
0.2
0
2000
2020
2040
2060
2080
energy [keV]


Counts/2 keV
0
1
2
3
4
5
6
7
8
9
2020
2030
2040
2050
2060
Energy (keV)

• $^{96}Zr - {}^{96}Mo$ 2.8 % 3350 keV

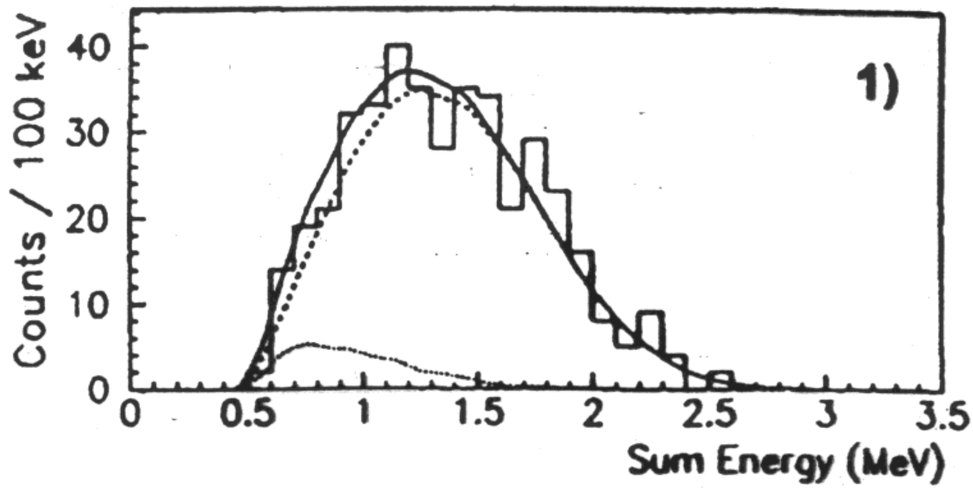
Geochem.		$(3.9\pm.9)\times10^{19}$	
2ν	$0^+\,0^+$	$(2\pm1)\times10^{19}$	$(6-1400)\times10^{17}$
0ν	" "	$>8\times10^{20}$	$(28-186)$
$0\nu\chi$	" "	$>3\times10^{20}$	$(7-47)\times10^{-4}$
$0,2\nu$	$0^+\,2^+$	$>4.1\times10^{19}$	$\tau_{2\nu}$ $(3-700000)\times10^{20}$
$0,2\nu$	$0^+\,0^{+*}$	$>3.3\times10^{19}$	$(2.1-150)\times10^{20}$

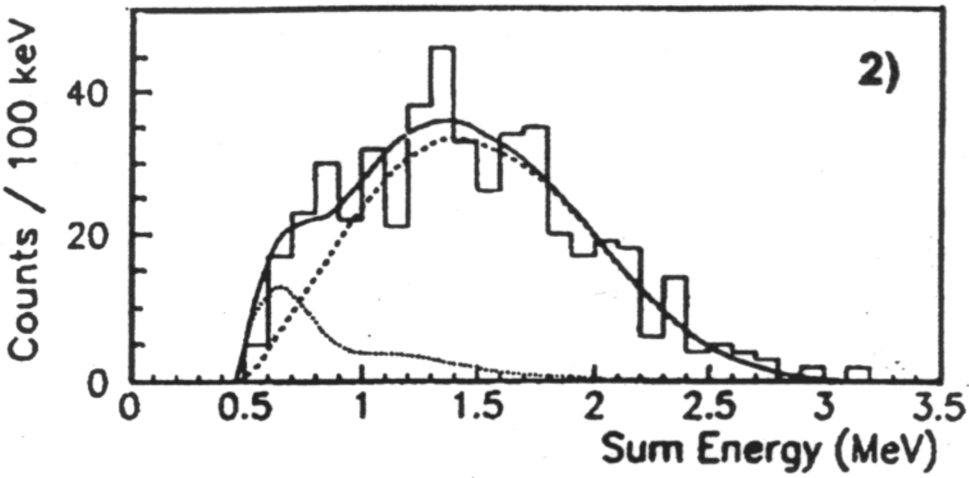
• $^{100}Mo \rightarrow {}^{100}Ru$ 9.63 %

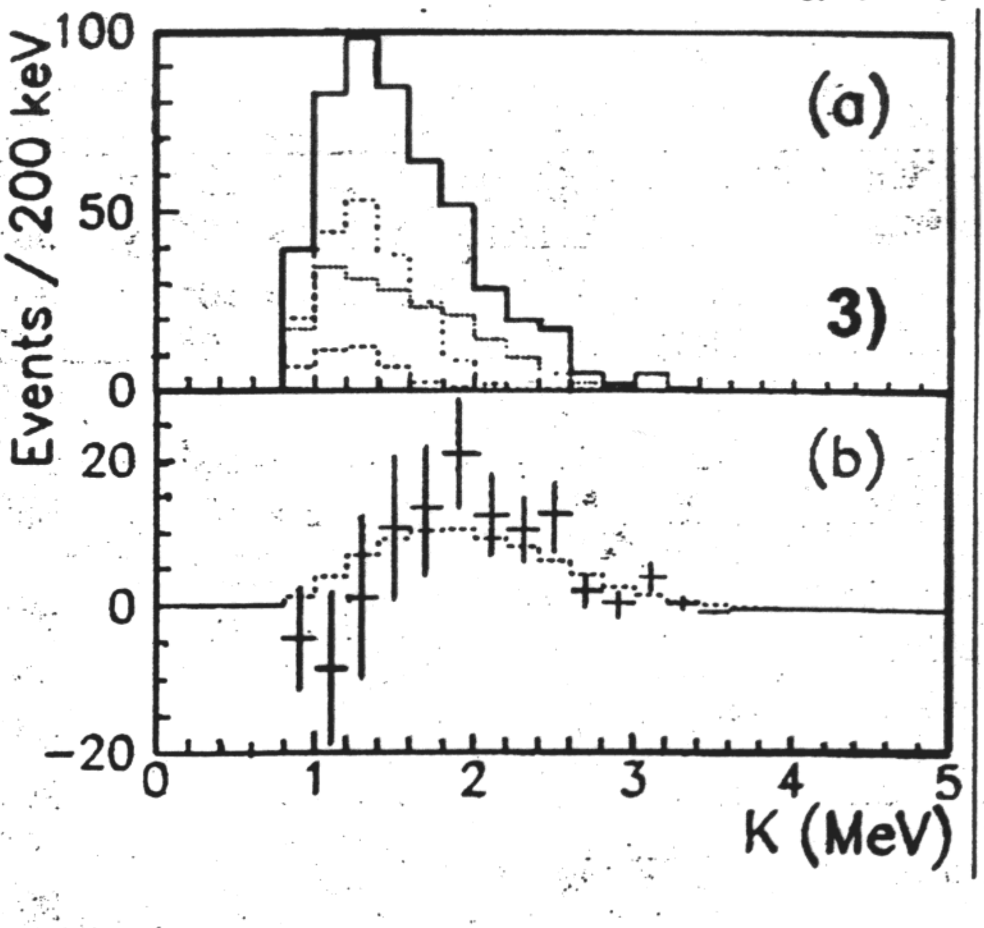
2ν	$0^+\,0^+$	$(9-12)\times10^{18}$	$(1.7-32)\times10^{18}$
0ν	$0^+\,0^+$	$>5.2\times10^{22}$	$(1.4-264)$
$0\nu\chi$	$0^+\,0^+$	$>5.4\times10^{21}$	$(1-130)\times10^{-4}$
$0,2\nu$	$0^+\,2^+$	$>2.3\times10^{21}$	$(5-1000000)\times10^{20}$
$0,2\nu$	$0^+\,0^{+*}$	$(8\pm2)\times10^{20}$	$(5-500)\times10^{19}$
$0\nu2\chi$	$0^+\,0^+$	$>5.3\times10^{19}$	

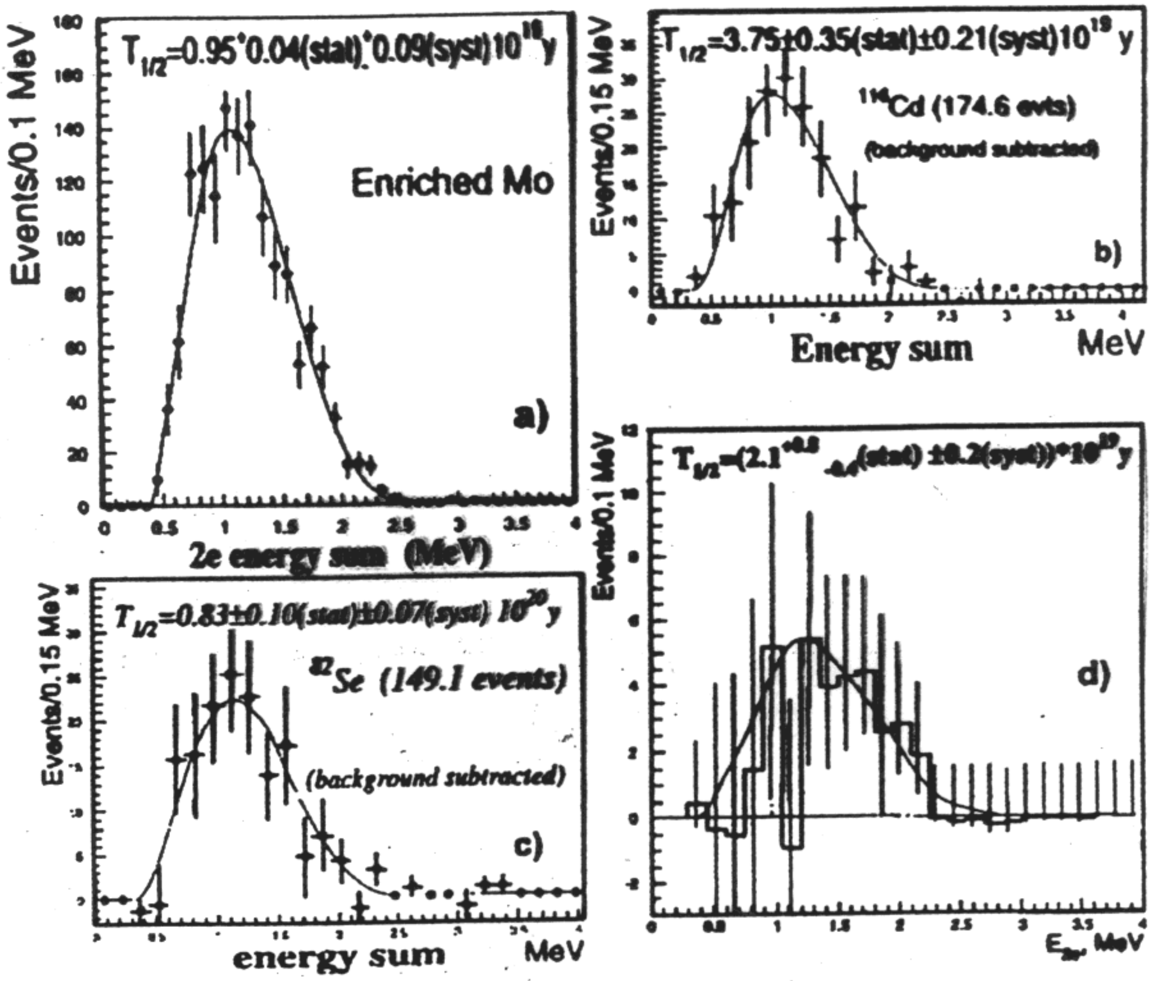
• $^{116}Cd \rightarrow\rightarrow {}^{116}Sn$ 7.49 % 2804 keV

2ν	$0^+\,0^+$	$(2.6-3.8)\times10^{19}$	$(4-10)\times10^{19}$
0ν	$0^+\,0^+$	$>2.9\times10^{22}$	$\langle m_\nu\rangle < 4-13$
$0\nu\chi$	$0^+\,0^+$	$>12\times10^{21}$	$\langle g_M\rangle < (2-11)\times10^{-4}$
0ν	$0^+\,2^+$	$>4.4\times10^{21}$	
$0,2\nu$	$0^+\,2^+$	$>2.4\times10^{21}$	$\tau_{2\nu}$ $(4-80)\times10^{24}$
$0,2\nu$	$0^+\,0^{+*}$	$>2.1\times10^{21}$	$(1-100)\times10^{22}$
$0\nu2\chi$	$0^+\,0^+$	$>2.6\times10^{20}$	

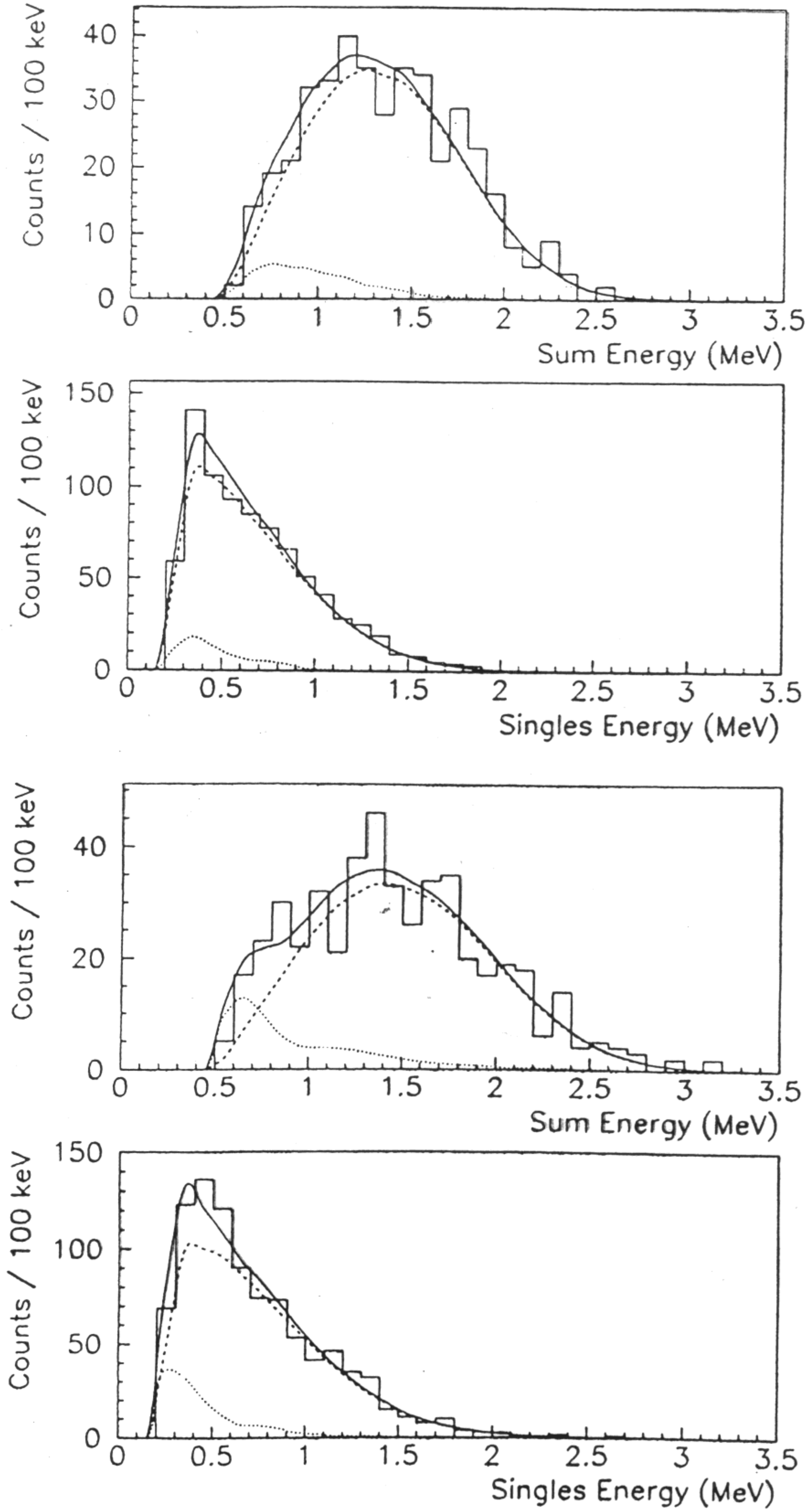

1)
Counts / 100 keV
0
10
20
30
40
0
0.5
1
1.5
2
2.5
3
3.5
Sum Energy (MeV)

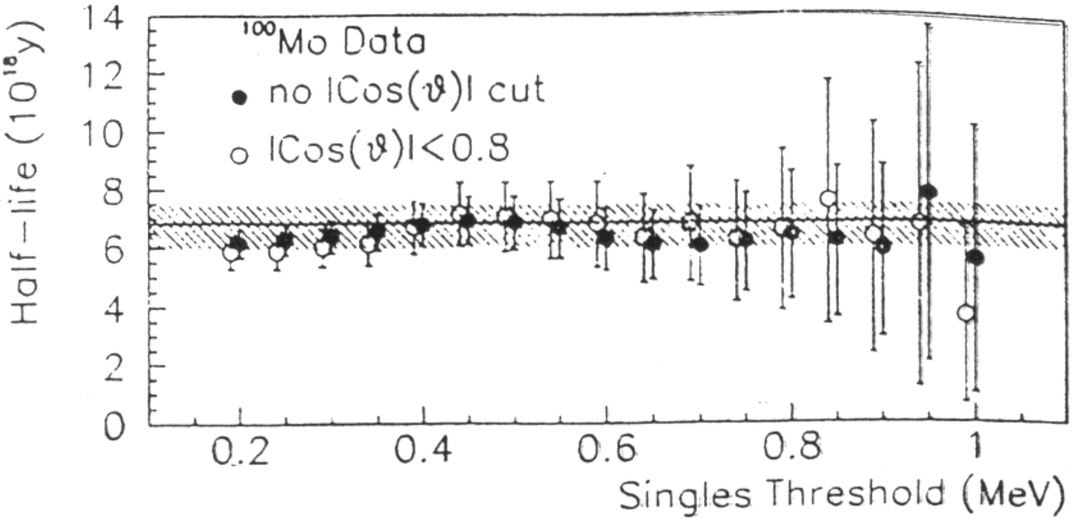

2)
Counts / 100 keV
0
20
40
0
0.5
1
1.5
2
2.5
3
3.5
Sum Energy (MeV)


(a)
3)
(b)
Events / 200 keV
100
50
0
20
0
−20
0
1
2
3
4
5
K (MeV)

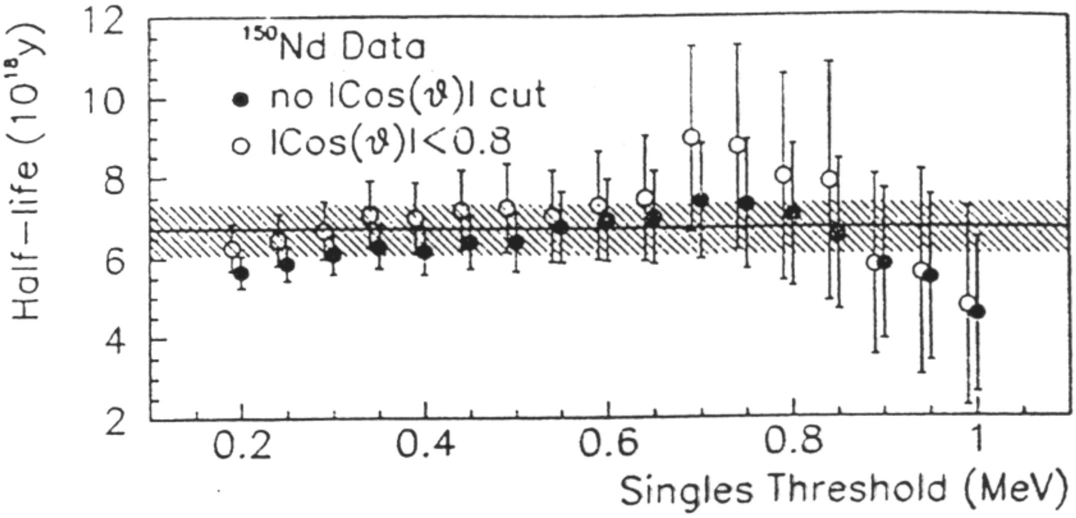


Events/0.1 MeV
Enriched Mo
a)
2e energy sum (MeV)
Events/0.15 MeV
(background subtracted)
b)
Energy sum
MeV
Events/0.15 MeV
(background subtracted)
c)
energy sum
MeV
Events/0.1 MeV
d)

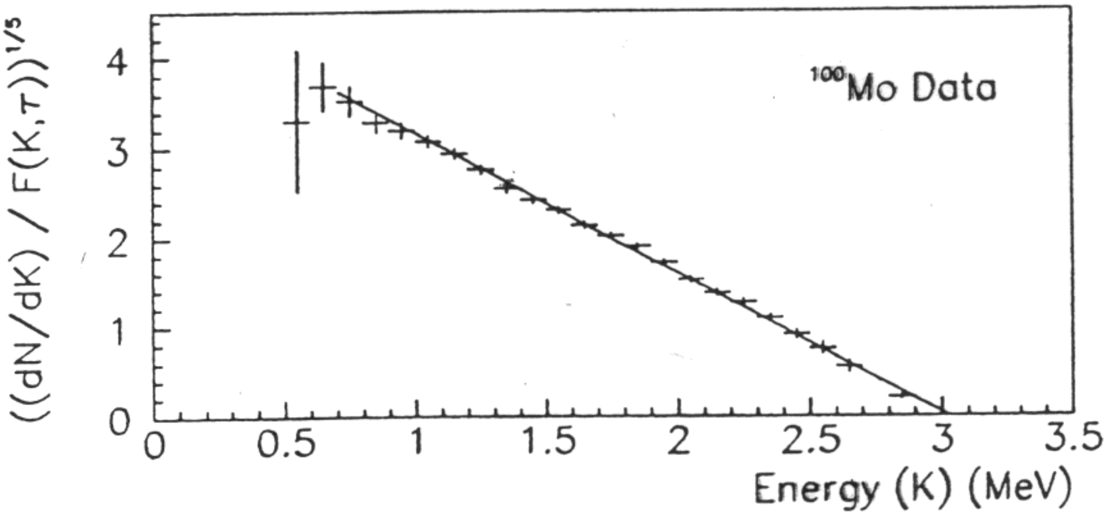

Counts / 100 keV
Sum Energy (MeV)
Counts / 100 keV
Singles Energy (MeV)
Counts / 100 keV
Sum Energy (MeV)
Counts / 100 keV
Singles Energy (MeV)



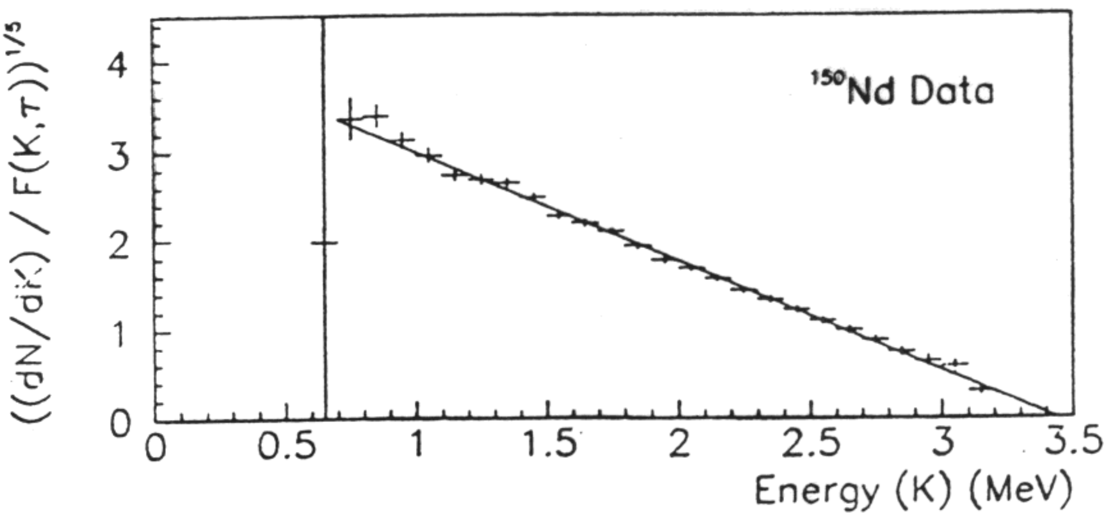
^{100}Mo Data
no |Cos(ϑ)| cut
|Cos(ϑ)|<0.8
Half-life (10^{18}y)
Singles Threshold (MeV)



^{150}Nd Data
no |Cos(ϑ)| cut
|Cos(ϑ)|<0.8
Half-life (10^{18}y)
Singles Threshold (MeV)



^{100}Mo Data
$((dN/dK) / F(K,\tau))^{1/5}$
Energy (K) (MeV)



^{150}Nd Data
$((dN/dK) / F(K,\tau))^{1/5}$
Energy (K) (MeV)

- $^{124}Sn \to {}^{124}Te$ 5.79 % 2287 keV

2ν	$0^+ \; 0^+$	$> 1 \times 10^{17}$	$(8 - 200000) \times 10^{19}$
0ν	" "	$> 2.4 \times 10^{17}$	$\langle m_\nu \rangle < 2600$
$0\nu\chi$	" "	$> 1 \times 10^{17}$	—
$0,2\nu$	$0^+ \; 2^+$	$> 4.1 \times 10^{19}$	$\sim 7 \times 10^{26}$
$0,2\nu$	$0^+ \; 0^{+*}$	$> 2.2 \times 10^{18}$	$\sim 3 \times 10^{21}$

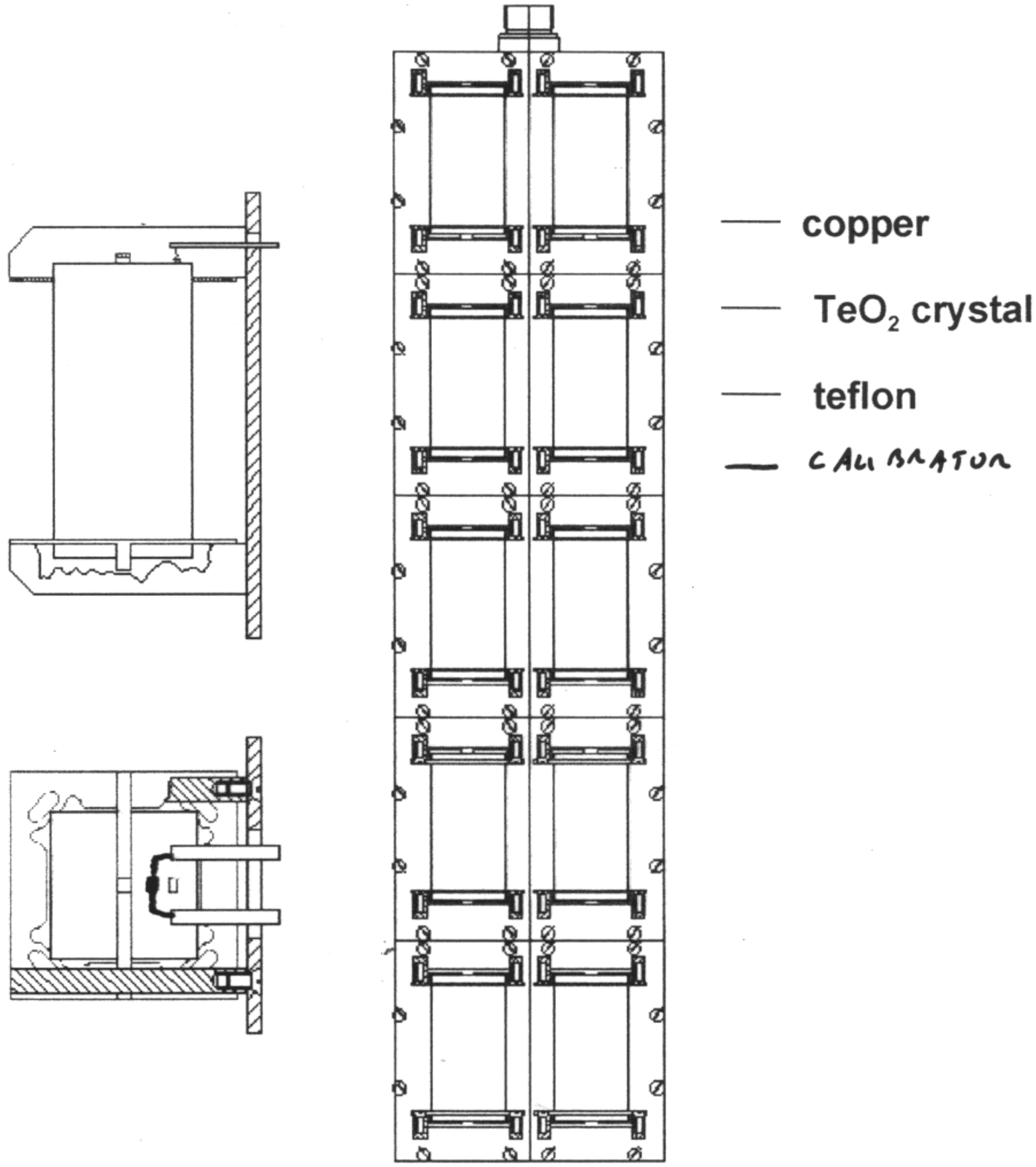
- $^{128}Te - {}^{128}Xe$ 33.8 % 867 keV $(6 - 380) \times 10^{23}$

GEOCH		$(1.4 \pm .4 - 7.7 \pm .4) \times 10^{24}$	$\langle m_\nu \rangle < 1. - 1.8$
0ν	$0^+ \; 0^+$	$> 2.1 \times 10^{22}$	$\langle m_\nu \rangle < 19 - 85$
$0,2\nu$	$0^+ - 2^+$	$> 4.7 \times 10^{21}$	$(2 - 4000) \times 10^{30}$

- $^{130}Te - {}^{130}Xe$ 33.8 % 2528 keV

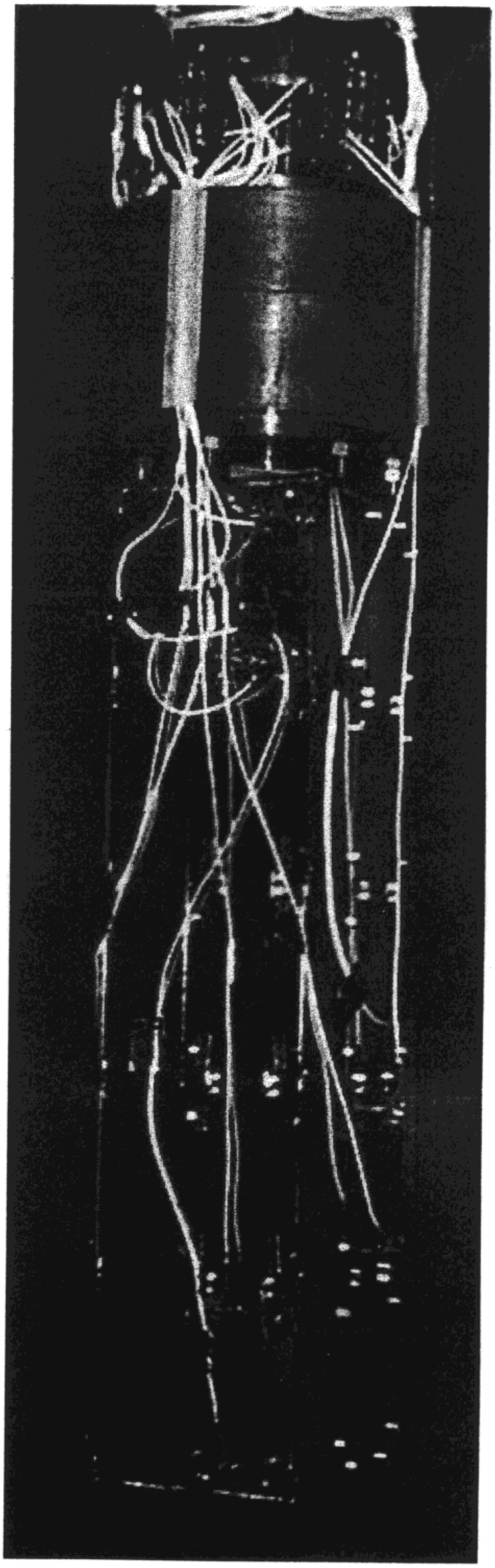
GEOCH.		$[(7 \pm 2) - (27 \pm 1)] \times 10^{20}$	
2ν	$0^+ \; 0^+$	$> 4 \times 10^{20}$	$(2.6 - 26) \times 10^{20}$
0ν	" "	$> 10^{23}$	$\langle m_\nu \rangle <$ ~~22~~ 4.6
$0\nu\chi$	" "	$> 1.4 \times 10^{21}$	$\langle g_M \rangle (2.5 - 7.3) \times 10^{-4}$
$0,2\nu$	$0^+ \; 2^+$	$> 1.6 \times 10^{22}$	$(3 - 300) \; 10^{22}$
$0,2\nu$	$0^+ \; 0^{+*}$	$> 5 \times 10^{21}$	$(3 - 7) \; 10^{20}$
$0\nu\chi\chi$		$> 1 \times 10^{21}$	

What we have done already:
2) 20 MODULAR BOLOMETER TOWER



- The bolometers are not mounted yet: problem with mounting reproducibility (problem under investigation)
- The copper of the tower was measured to be radioactive at the level of 0.1 Bq/Kg, that is too much. We now are polishing it
- it seems to be possible to have the first floor (4 detectors) ready for the end of february, the rest probably in summer

HEWLETT PACKARD HEWLETT PACKARD HEWLETT PACKARD HEWLETT PACKARD



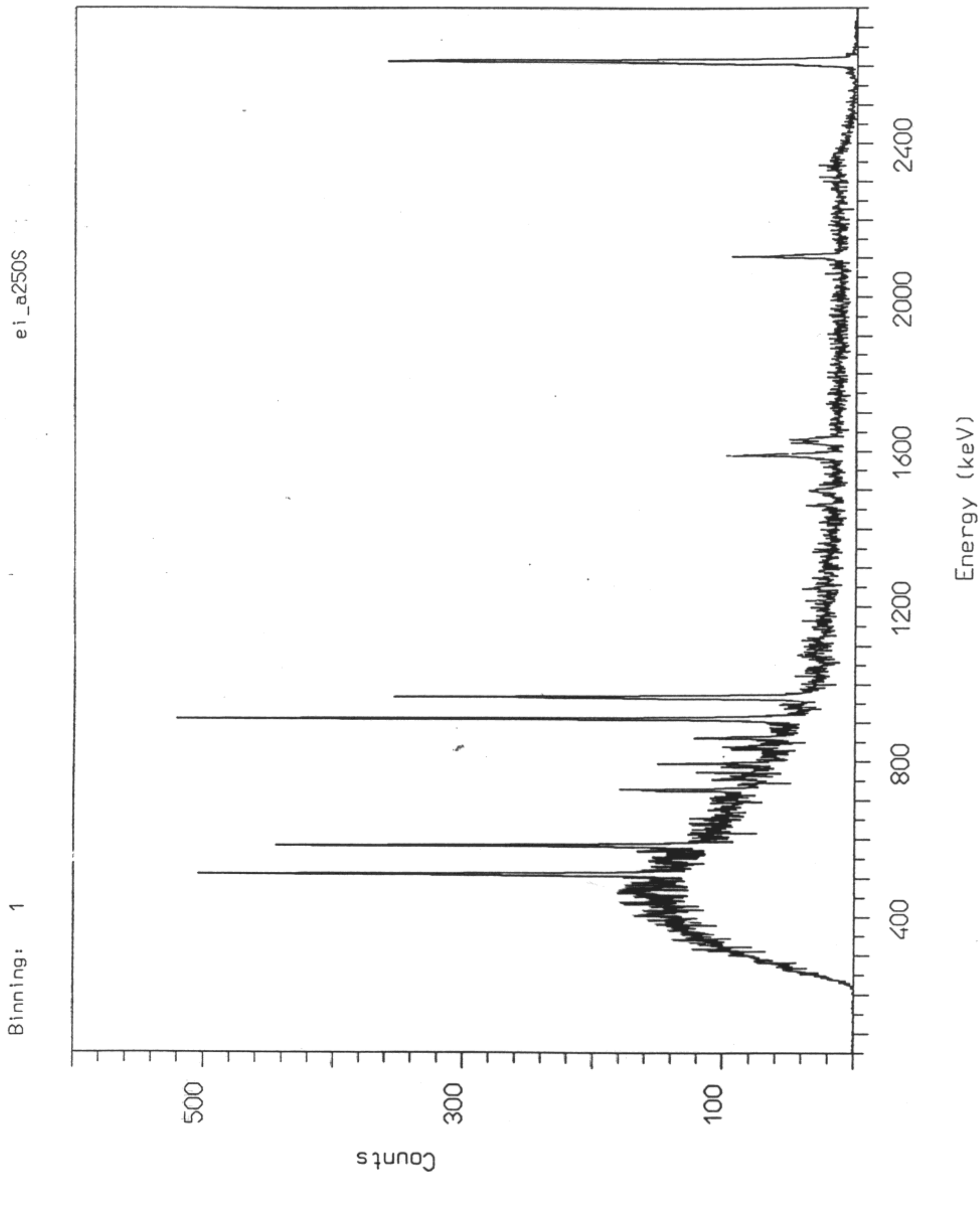
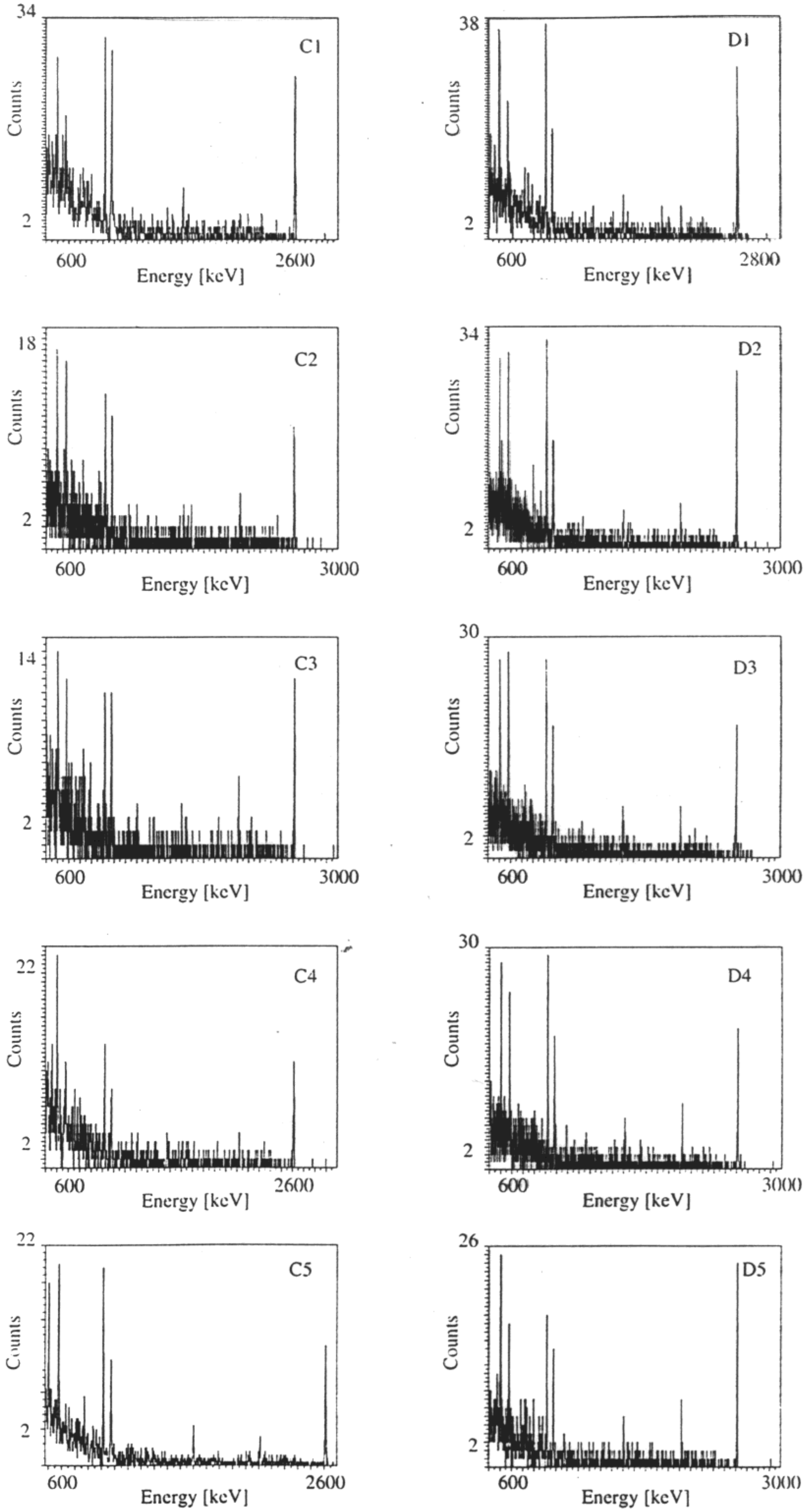

Binning: 1
ei_a250S
Energy (keV)
Counts
400
800
1200
1600
2000
2400
100
300
500

Fig. 3



34
C1
Counts
2
600
2600
Energy [keV]
38
D1
Counts
2
600
2800
Energy [keV]
18
C2
Counts
2
600
3000
Energy [keV]
34
D2
Counts
2
600
3000
Energy [keV]
14
C3
Counts
2
600
3000
Energy [keV]
30
D3
Counts
2
600
3000
Energy [keV]
22
C4
Counts
2
600
2600
Energy [keV]
30
D4
Counts
2
600
3000
Energy [keV]
22
C5
Counts
2
600
2600
Energy [keV]
26
D5
Counts
2
600
3000
Energy [keV]

Fig. 2b

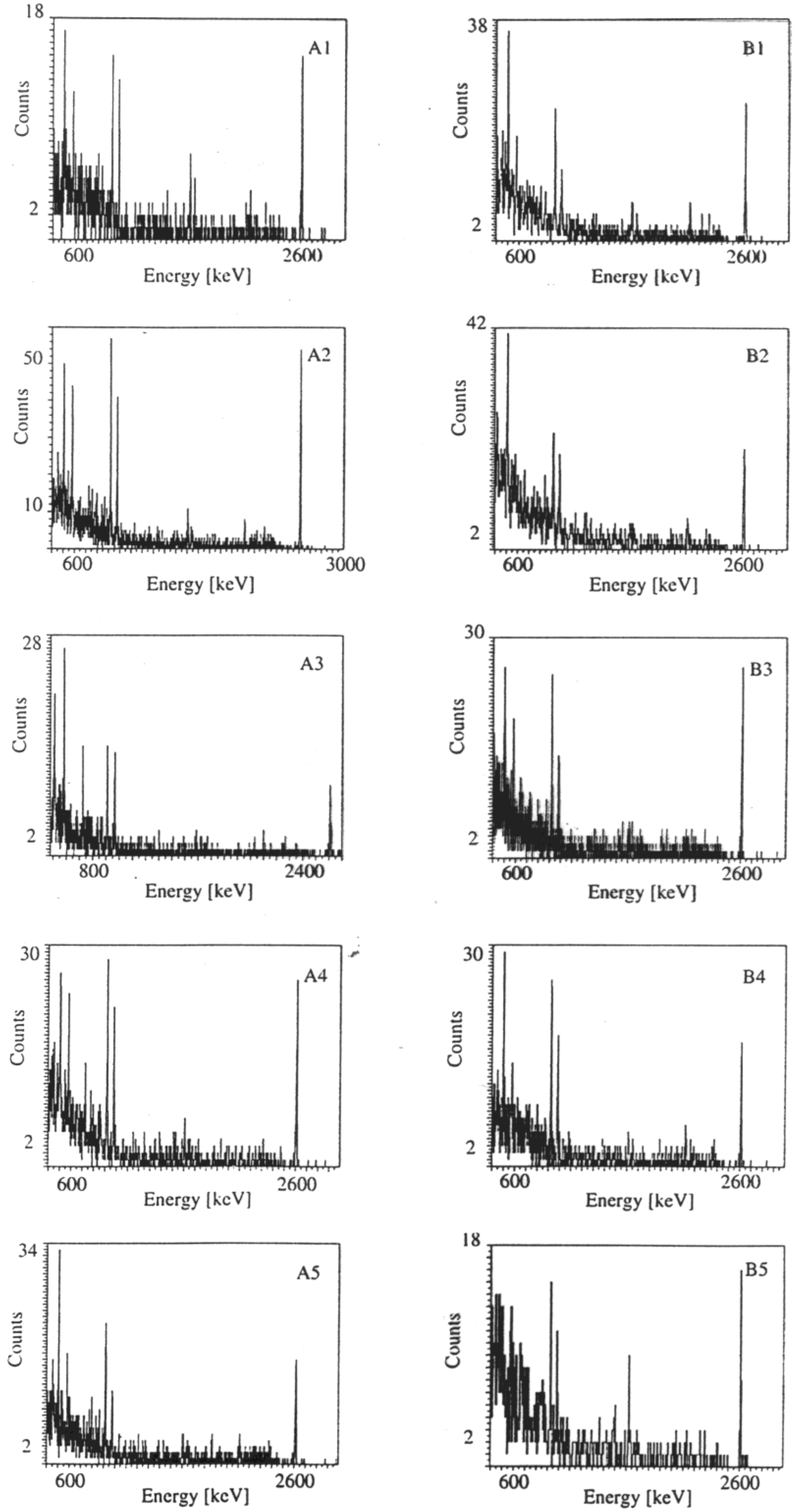
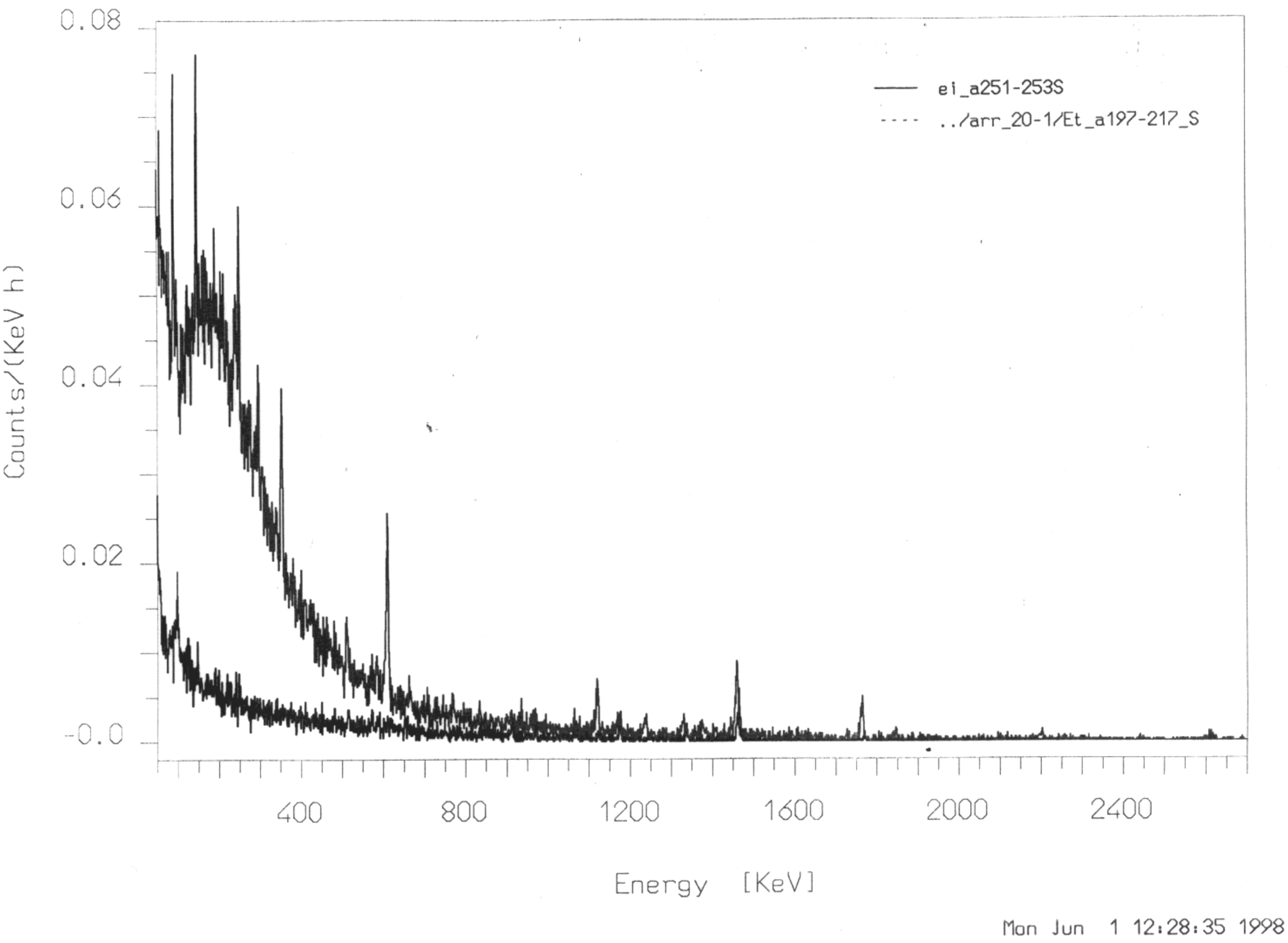
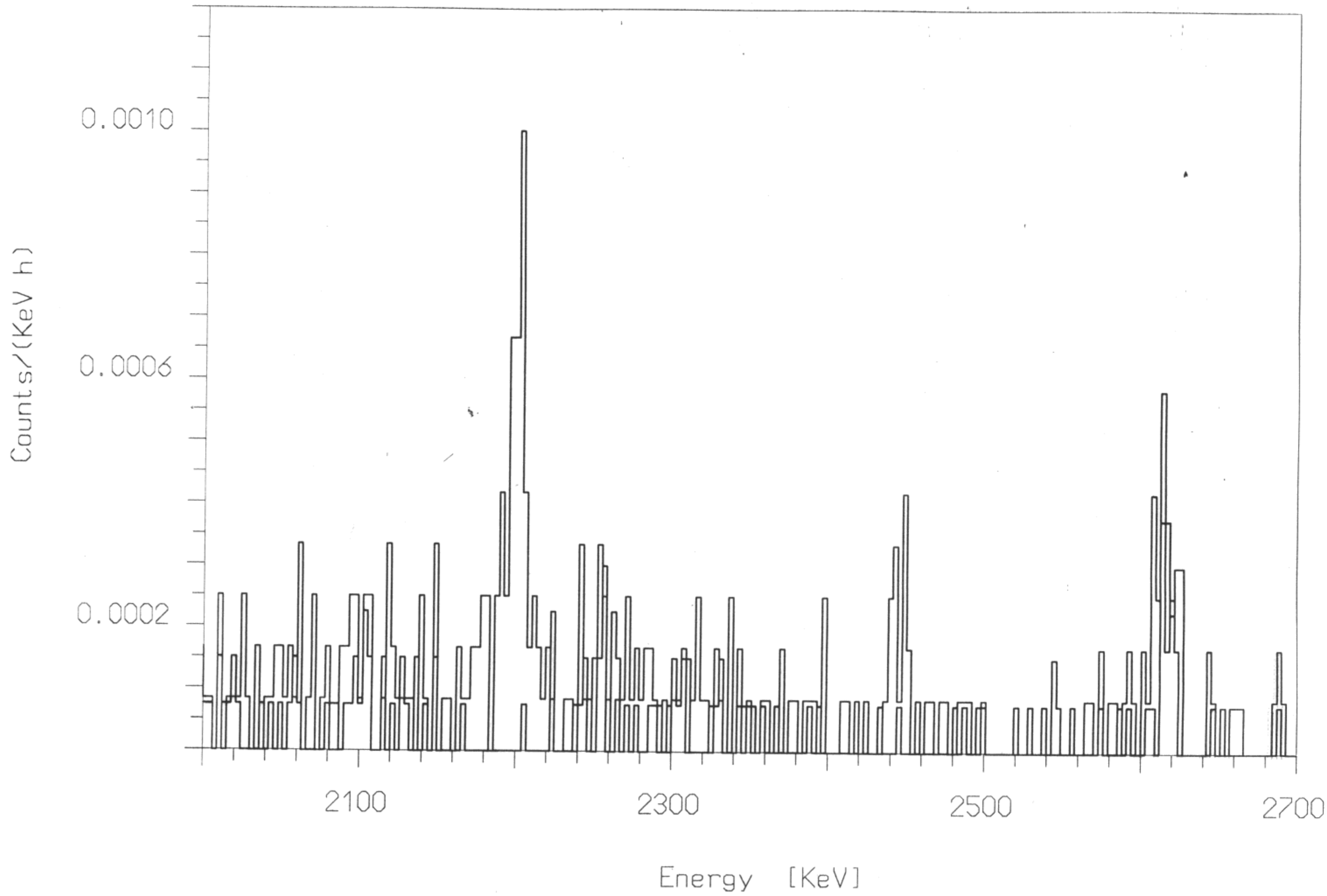

A1
18
2
Counts
600
2600
Energy [keV]
B1
38
2
Counts
600
2600
Energy [keV]
A2
50
10
Counts
600
3000
Energy [keV]
B2
42
2
Counts
600
2600
Energy [keV]
A3
28
2
Counts
800
2400
Energy [keV]
B3
30
2
Counts
600
2600
Energy [keV]
A4
30
2
Counts
600
2600
Energy [keV]
B4
30
2
Counts
600
2600
Energy [keV]
A5
34
2
Counts
600
2600
Energy [keV]
B5
18
2
Counts
600
2600
Energy [keV]

Fig. 2a



ei_a251-253S
../arr_20-1/Et_a197-217_S
Counts/(KeV h)
0.08
0.06
0.04
0.02
-0.0
400
800
1200
1600
2000
2400
Energy [KeV]
Mon Jun 1 12:28:35 1998



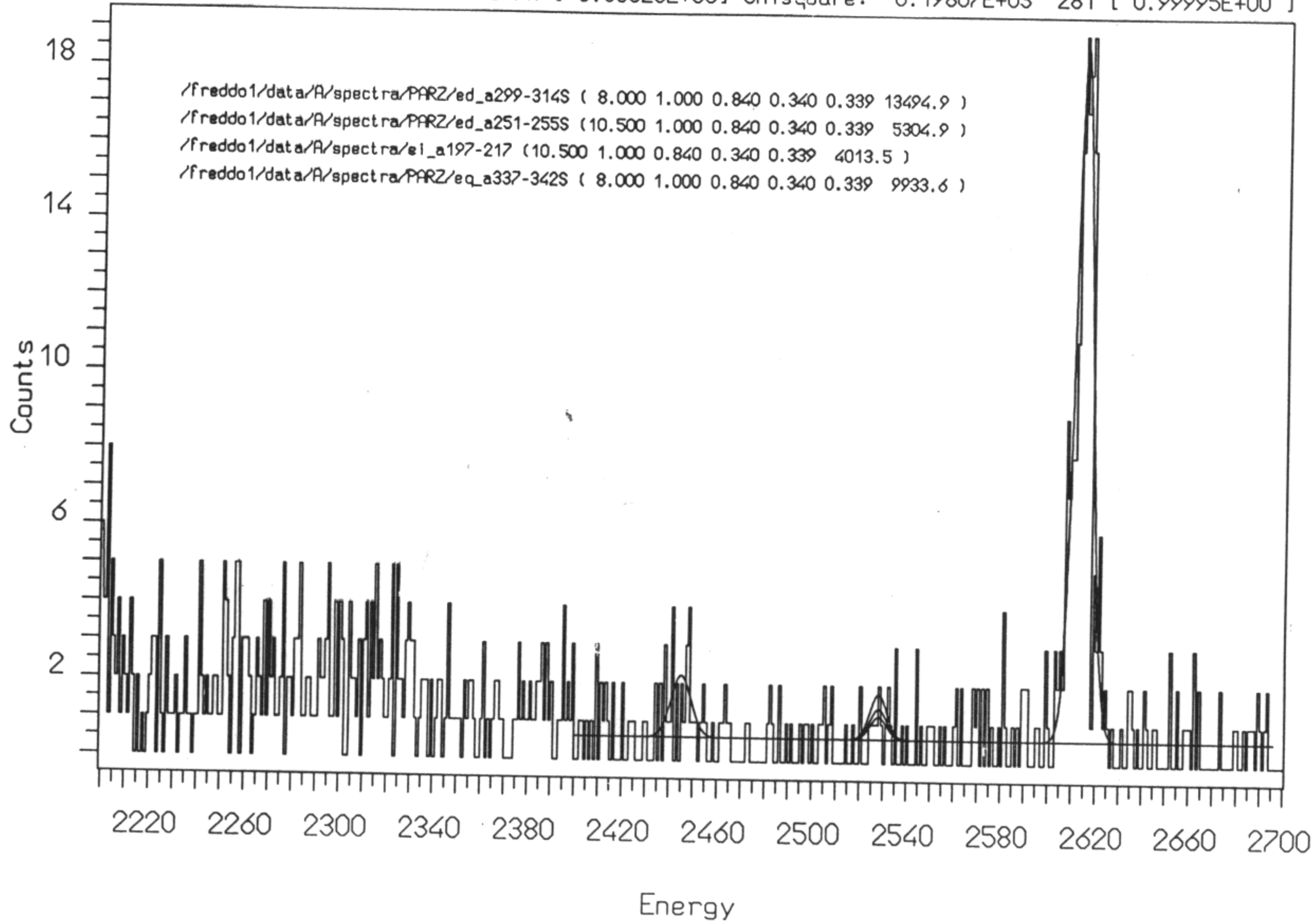
Counts/(KeV h)
0.0010
0.0006
0.0002
2100
2300
2500
2700
Energy [KeV]

Energia picco: 2528.10
Fattore di compattamento: 1

Conteggi/(y*kg) al 68 % C.L.: 20.273 [0.12869E+24] 7.332
Conteggi/(y*kg) al 90 % C.L.: 29.910 [0.87222E+23] 10.818

0.14963E+02 +/- 0.13211E+02

<Background>: 0.20760E-04 c/keV/h [0.53525E+00] Chisquare: 0.19807E+03 281 [0.99995E+00]



0	0.14963E+02
1	0.26139E+04
2	0.74195E+02
3	0.18020E+02
4	0.21540E+02
5	0.49901E+02
6	0.24451E+04
7	0.32001E+01
8	0.22955E-01
9.	0.13795E+02
10	0.67783E-09

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$^{136}Xe \to {}^{136}Ba$ 8.9% 2468 keV

2ν	0^+ 0^+	$> 5.6 \times 10^{20}$	$(1-8) \times 10^{20}$
0ν	" "	$> 4.2 \times 10^{23}$	$\langle m_\nu \rangle < 2 - 5$
$0\nu\chi$	" "	$> 1.1 \times 10^{22}$	$\langle g_m \rangle < (1.5 - 6.2) \times 10^{-4}$

$^{150}Nd \to {}^{150}Sm$ 5.64% 3368 keV

2ν	$0^+ - 0^+$	$1.7^{+1}_{-.5} \pm .35 \times 10^{19}$	$\sim 3 \times 10^{18}$
0ν	" "	$> 2.1 \times 10^{21}$	$4 - 16$
$0\nu\chi$	" "	$> 5.3 \times 10^{20}$	$(1.4 - 6.2) \times 10^{-4}$
$0, 2\nu$	0^+ 2^+	$> 8 \times 10^{18}$	$(7.2 - 12) \times 10^{24}$
$0, 2\nu$	0^+ 0^{+*}	$> 8.8 \times 10^{18}$	$> 10^{22}$

THE FUTURE

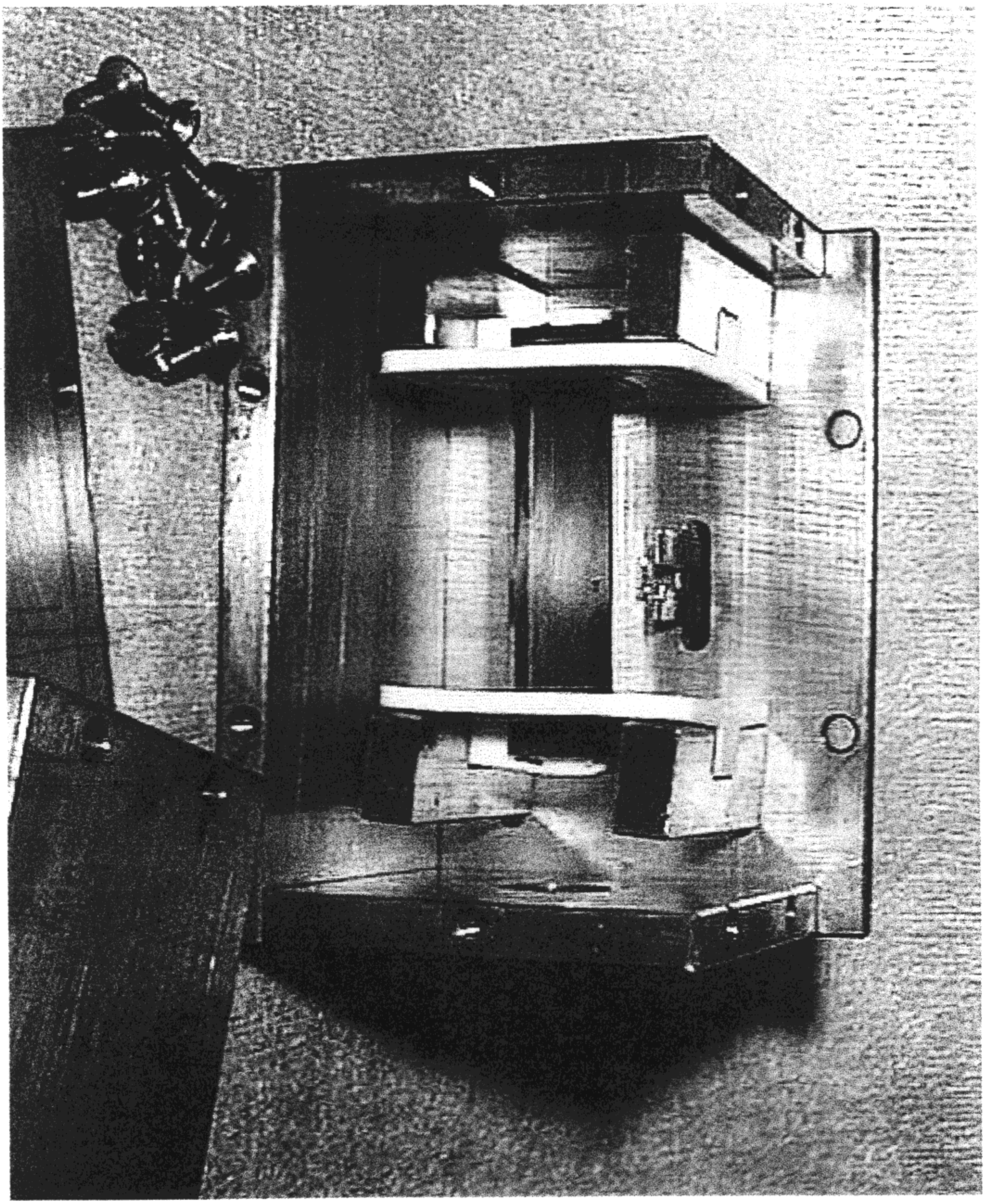
NEW TECHNIQUES

- RESONANT IONIZATION SPECTROSCOPY
- CHEMICAL SEPARATION OF THE DAUGHTER (e.g. $^{136}Xe \to {}^{136}Ba$)
- SCINTILLATION + HEAT IN COINCIDENCE

e.g. ^{48}Ca $\Delta E = 4272$

- DISSOLVE ^{136}Xe IN BOREXINO OR CTF

HEWLETT PACKARD HEWLETT PACKARD HEWLETT PACKARD



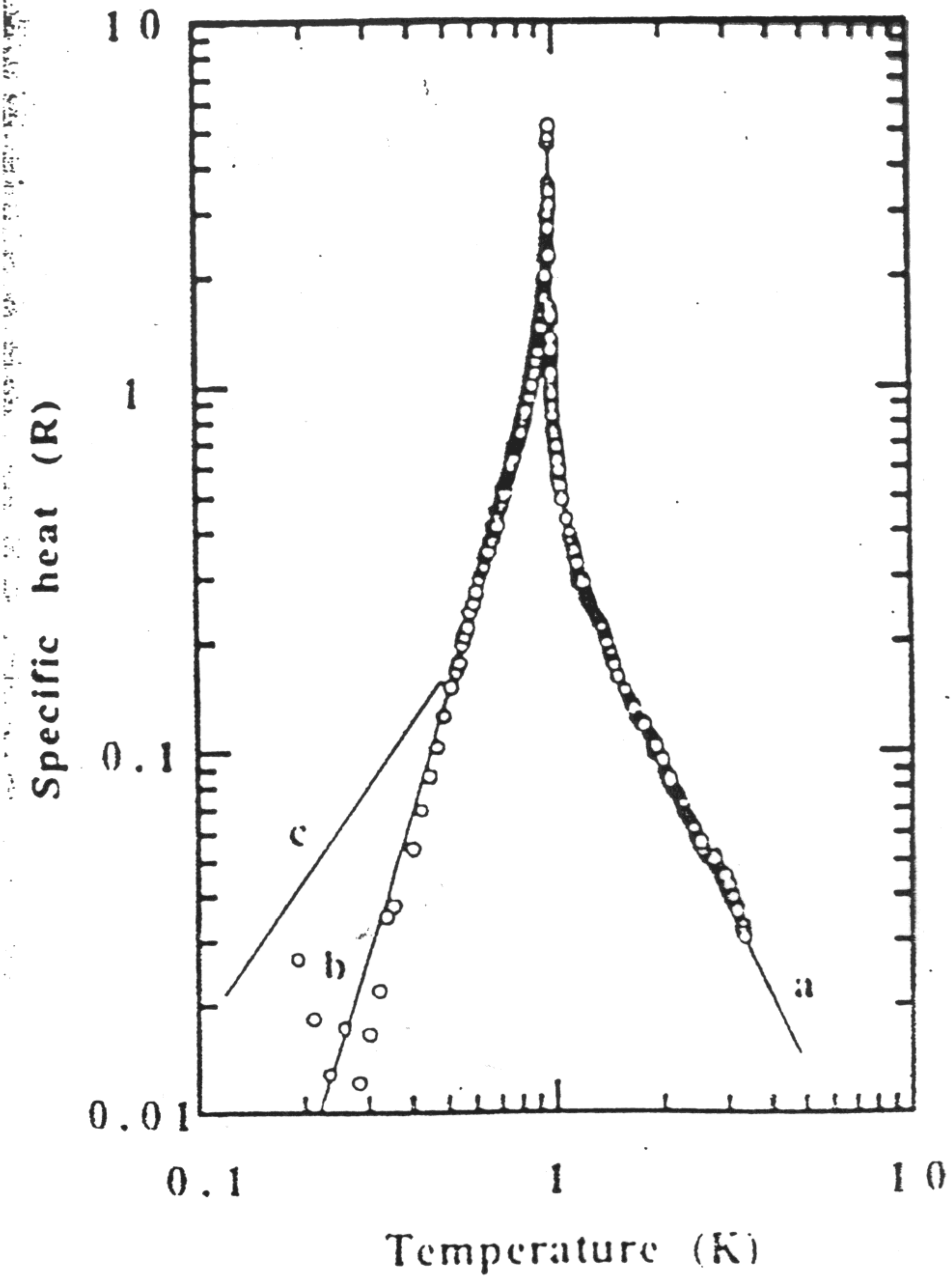


Figure 2. Heat capacity of $NdGaO_3$: a) high-temperature expansion, b) and c) antiferro- and ferromagnetic spin wave theory.

TWO LARGE PROJECTS

SENSITIVITY FOR THE SOURCE = DETECTOR APPROACH

$$S = 4.17 \times 10^{26} \left(\frac{i.a.}{A}\right) \sqrt{\frac{m(kg) \cdot t(y)}{B(c.keV^{-1} y^{-1} kg^{-1}) \Delta}} \, \varepsilon$$

SENSITIVITY ON

$$\langle m_\nu \rangle \propto m^{1/4} t^{1/4} B^{-1/4} \Delta^{-1/4} ia^{1/2} \varepsilon^{1/2}$$

AS A CONSEQUENCE

- increase the mass
- RUN FOR A LONG TIME (STABILITY)
- REDUCE THE BACKGROUND
- IMPROVE THE RESOLUTION
- CHOSE A LARGE i.a. (34 % for ^{130}Te) OR ENRICH

GErmanium in liquid NItrogen Underground Setup

ARRAY OF 300 ^{76}Ge (enriched) DETECTORS SUSPENDEND IN A LIQUID NITROGEN FILLED TANK - SHIELD BY THE NITROGEN ITSELF

Φ AND H $\simeq$ 12 m

GOOD RESOLUTION OF Ge DETECTORS

DETECTORS IN LIQUID NITROGEN ALREADY TESTED

EXTENSIVE MONTE CARLO

AN ARRAY OF 40 NAT. GE DETECTORS (100 kg) in the same tank PRACTICALLY FUNDED FOR D.M. SEARCHES (0.01 ev/kg y keV expected)

Cryogenic

Underground

Observatory for

Rare

Events

TO SEARCH FOR:

- $\beta\beta$ decay of ^{130}Te (34%, 2528 keV)
- DARK MATTER
- SOLAR AXIONS

17 TOWERS OF 15 PLANES OF 4 TeO_2 DETECTORS

1020 ×0.770 kg → 785 kg

⇒ 627 kg Te ⇒ 213 kg ^{130}Te (natural)

⇒ ~ 10^{27} nuclei of ^{130}Te.

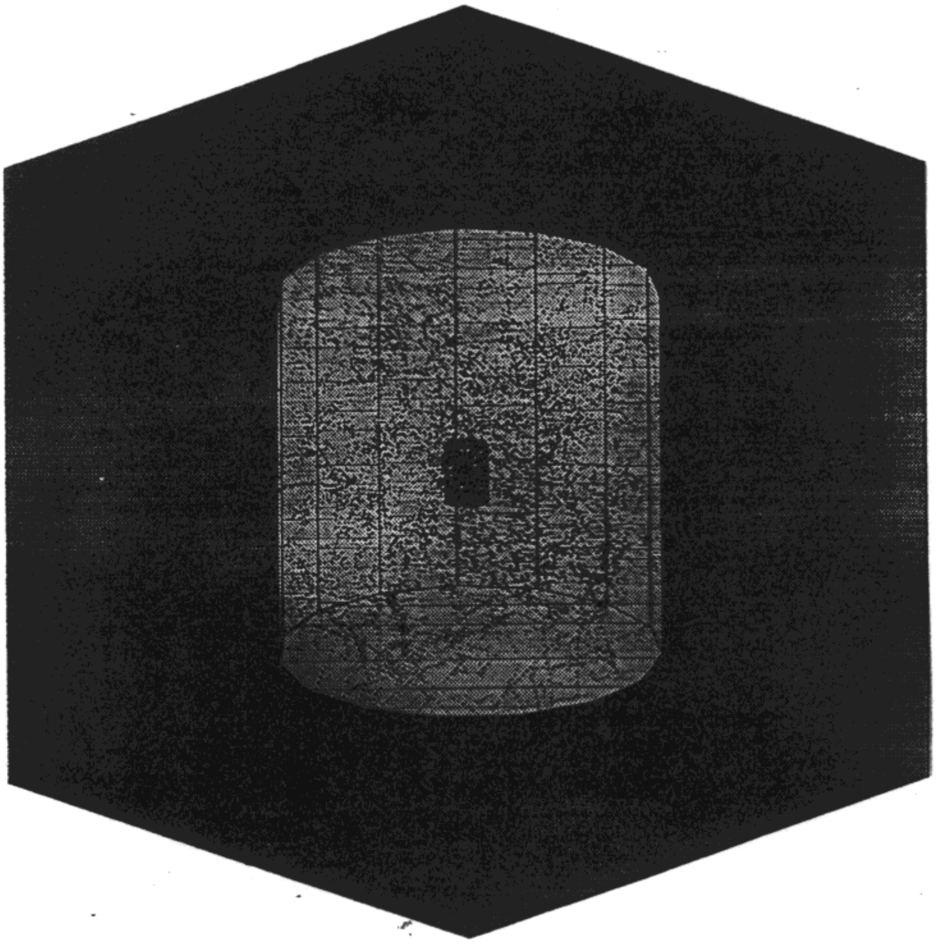


Fig. 4. Simplified model of the GENIUS experiment: 288 enriched ^{76}Ge detectors with a total of one ton mass in the center of a 9 m high liquid nitrogen tank with 9 m diameter; GEANT Monte Carlo simulation of 1000 2.6 MeV photons randomly distributed in the nitrogen is also shown.

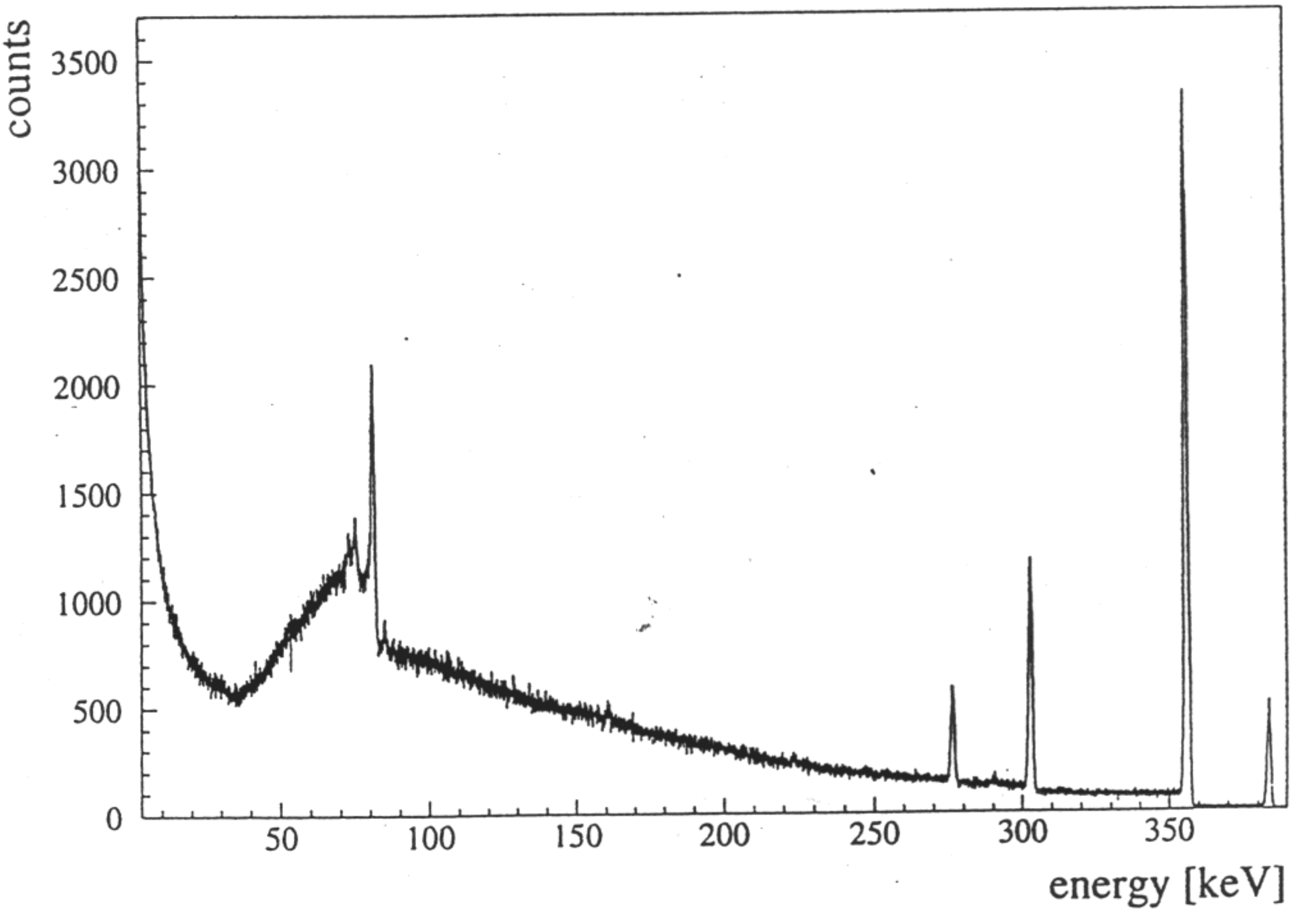


Fig. 7. Spectrum of a ^{133}Ba source measured with a HPGe–detector operated in liquid nitrogen **in the Heidelberg underground low–level laboratory**. X–rays from lead can be seen with energies of 72.8 keV and 75.0 keV.

- COMPACT STRUCTURE
- MUCH LESS EXPENSIVE

~ 10 M\$ ⇒ + 10 M\$ ENRICHMENT

TESTS ALREADY DONE WITH CRYSTALS OF TeO_2 OF $5 \times 5 \times 5$ cm^3

CUORICINO (56 crystals of 770 g ⇒ 42 kg) APPROVED

BOTH CAN ALREADY BE DONE IN GRAN SASSO

"A COMPARISON"

(by a third party)

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CUORICINO

Proposal to the Committee of the LNGS and to the Funding Authorities

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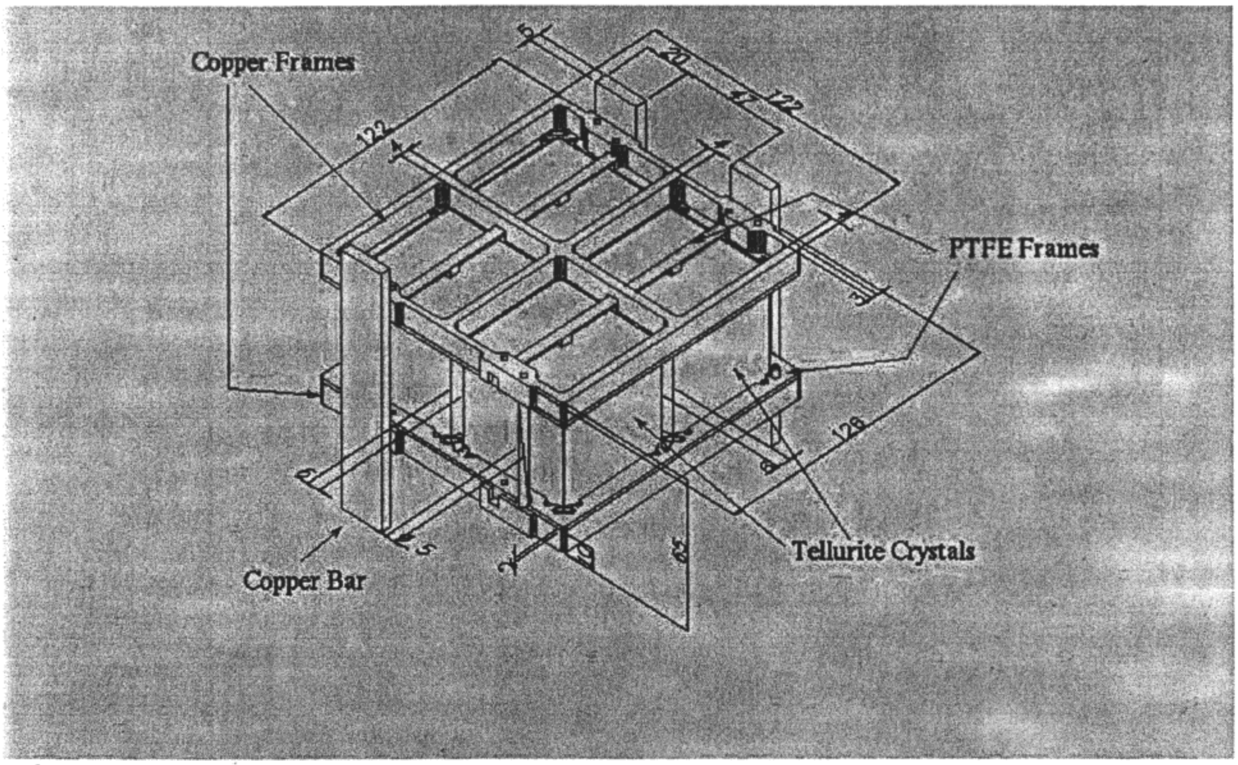
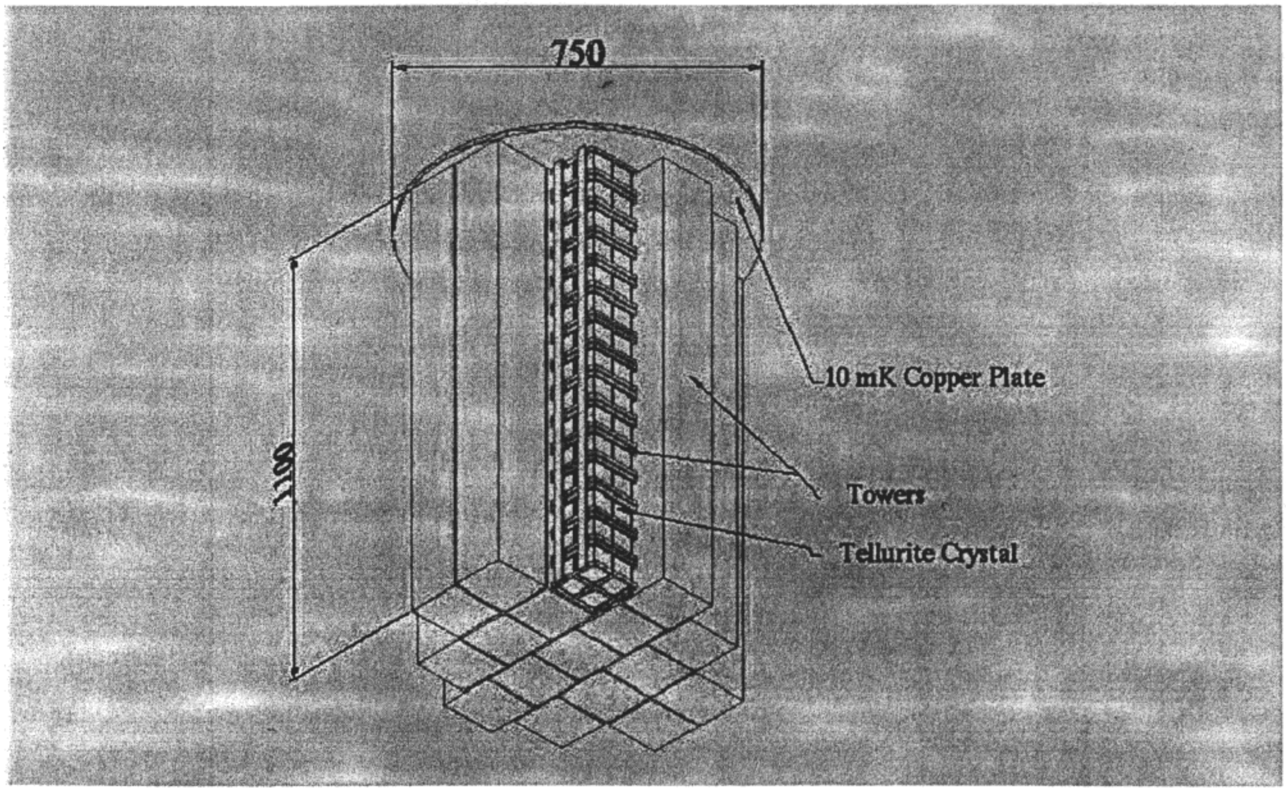
CUORE POSSIBLE STRUCTURE

Detectors Unit



First Tower=CUORICINO

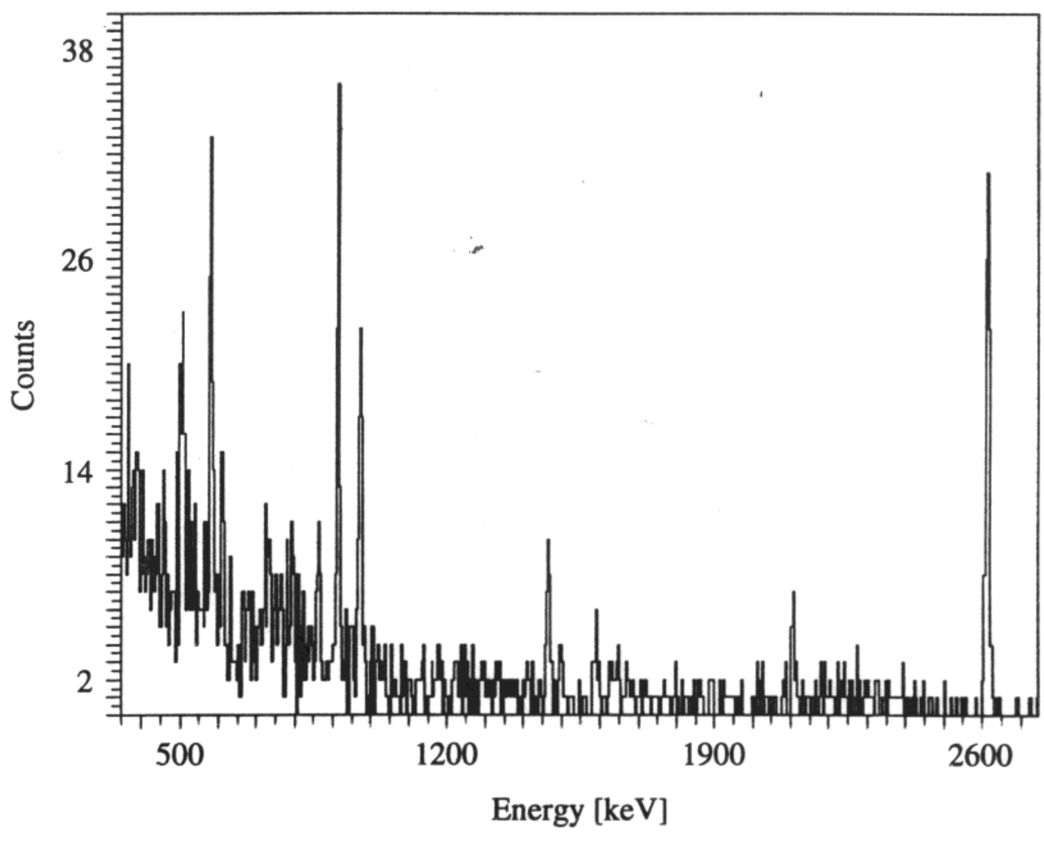


IS CUORE FEASABLE? FIRST TEST

A 5×5×5 cm³ crystal (M = 767.7 g) was cooled in these days

- Reached base temperature: ~ 7 mK
- Working temperature: ~ 9 mK
- Detector response: ≥ 200 μV/ MeV
- FWHM resolution: ~ 10 keV @ 2.6 MeV

VERY PRELIMINARY !!!

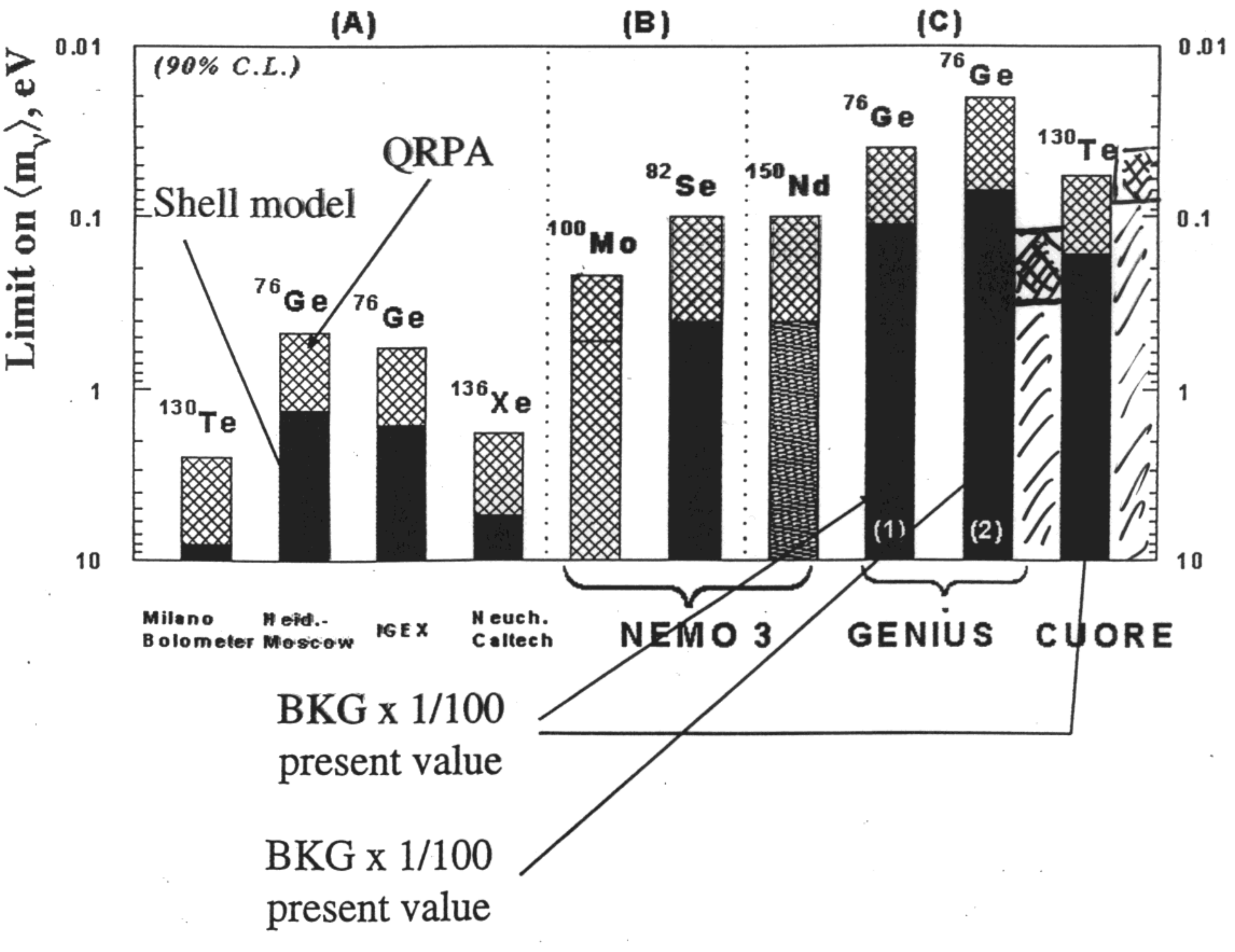


Comparison of GENIUS vs CUORE in terms of effective neutrino mass

⇩

Table prepared by the NEMO collaboration

LIMITS ON NEUTRINO MASS ($2\beta 0\nu$)



CONCLUSIONS

- TWO NEUTRINO $\beta\beta$ DECAY HAS BEEN FOUND FOR ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{150}Nd, $^{100}Mo^*$
- NO EVIDENCE FOR $0\nu X$
- NO EVIDENCE FOR NEUTRINOLESS $\beta\beta$ DECAY
- VERY LONG LIVING NATURAL ISOTOPES HAVE BEEN FOUND
- VERY LOW RADIOACTIVE BACKGROUND REACHED
- HOPE IN $\langle m_\nu \rangle \to 0.01$