DOUBLE BETA DECAY

THE FUTURE

E. Fiorini Subdury 18.6.00

2ν DBD found in 9 nuclei (also in excited state)
Recent theoretical calculations in reasonable agreement with results

0ν, $0\nu\chi$, $0\nu\chi\chi$ have not been found.

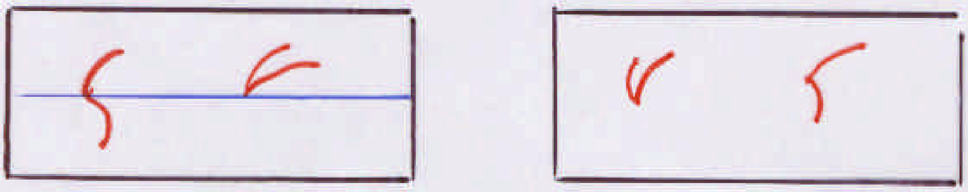
CALCULATIONS ON LIFETIMES OF NEUTRINOLESS DOUBLE BETA DECAY SHOULD BE EASIER, BUT THERE ARE STILL CONSIDERABLE DISAGREEMENTS ON $\langle m_\nu \rangle$ and g_χ (η, λ)

THE FUTURE

THE RESULT ON THE 2ν DBD ARE EXCELLENT, BUT STILL SOME UNCERTAINTIES (^{128}Te, ^{130}Te, ^{136}Xe ...)

DIRECT EXPERIMENTS

SOURCE ≠ DETECTOR   SOURCE = DETECTOR



CONVENTIONAL AND NEW TECHNIQUES

1. GOOD FOR 2ν DBD
   CHOICE OF MATERIALS ($\beta\beta$ active nuclei)
2. GOOD FOR 0ν DBD (resolution, mass)
   So far only few nuclei

SENSITIVITY ON HALF LIFETIME FOR NEUTRINOLESS DBD

$$F(\tau) = 4.17 \times 10^{26} \frac{i.a.\, M^{1/2}\, t^{1/2}}{A\, B^{1/2}\, \Delta^{1/2}}\, \varepsilon$$

i.a. isotopic abundance   M = mass (kg)

t = measured time (y)   B = background (c keV^{-1} y^{-1} kg^{-1})

Δ = energy resolution (keV) ε efficiency

SENSITIVITY ON $\langle m_\nu \rangle$ DEPENDS

ON τ ON phase space (ΔE) and on

NUCLEAR MATRIX ELEMENT

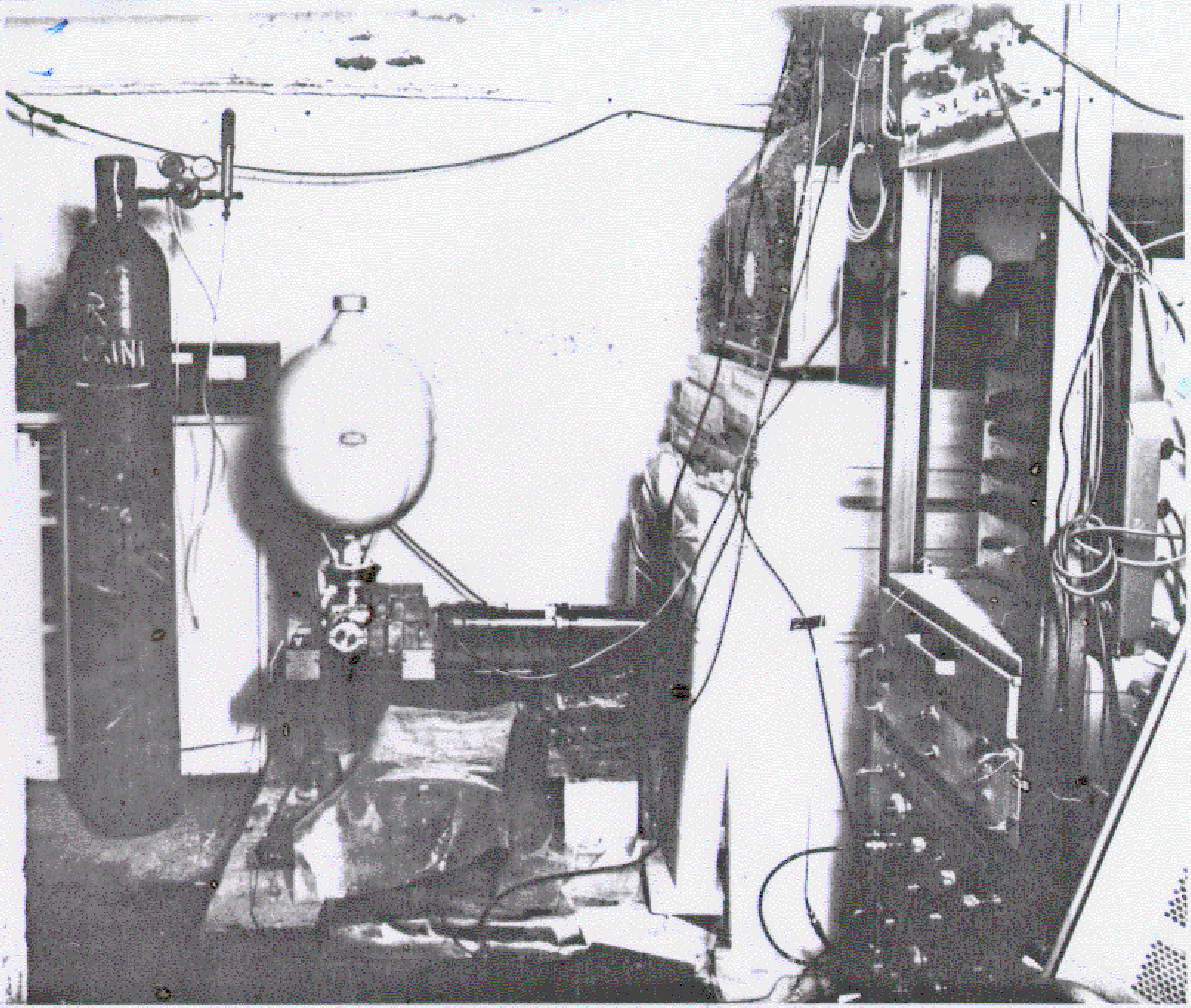
• Theory, particle-particle interaction strenghts, dedicated experiments on nuclear states, possibly favorred intermediate or final (0^{+*}) STATES ecc.

STRATEGY

i.a (improve)	expensive and careful to background
mass	expensive and tech. difficult
time	tedious
Background	already at very low level (~0.1 c keV^{-1} y^{-1} kg^{-1})
Δ (resolution)	Germanium and thermal detectors
ε (efficiency)	near to ~100% in the source = detector approach

FLEXIBILITY ON CANDIDATE NUCLEI

Fiorini - 04



$\tau_{0\nu} > 5 \times 10^{21}$ $\langle m_\nu \rangle < 30$

i.a.	12
mass	$\sqrt{1000}$
t	$\sqrt{3}$
ΔE	$\sqrt{2}$
Back	$\sqrt{15}$

↓

3600

↓

1.8×10^{25}

↓

$\langle m_\nu \rangle < .3$

THE FUTURE WITH NEMO III

- A LARGE COLLABORATION OF 12 GROUPS FROM EUROPE AND USA
- SOURCE ≠ DETECTOR APPROACH
- ~10 kg of enriched isotopes, DRIFT CHAMBERS "A LA GEIGER", SCINTILLATORS, MAGNETIC FIELD, IRON AND NEUTRON SHIELDING.
- IN THE FREJUS TUNNEL
- VERY CAREFUL MEASUREMENT OF THE BACKGROUND
- IMPROVED PURIFICATION

EXPECTED

$\tau > 10^{24}$ y $\langle m_\nu \rangle$ down to 0.1 eV

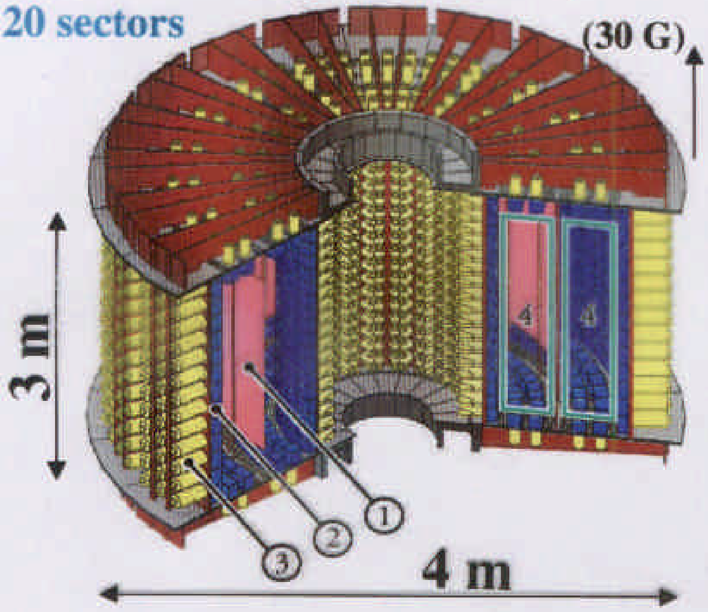
MOUNTING IN PROGRESS

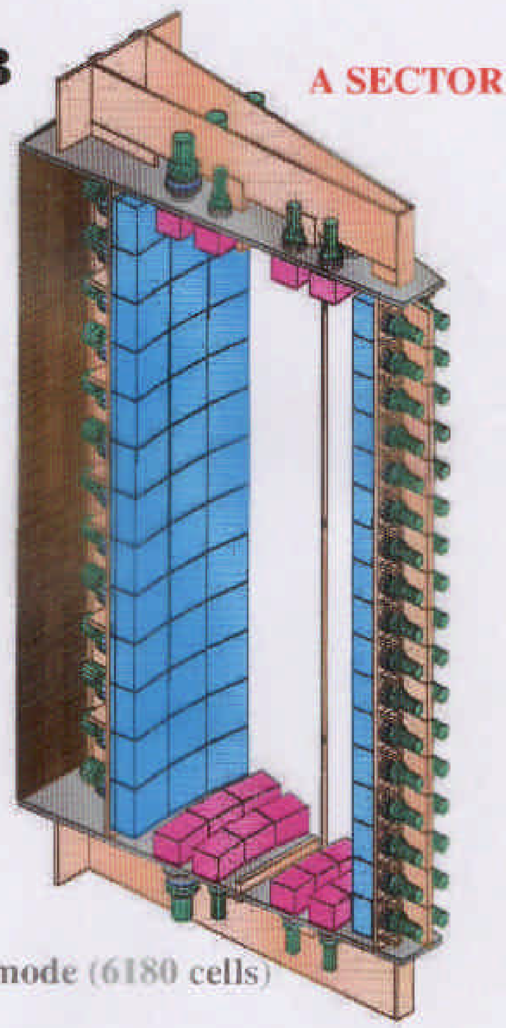
BEGINNING OF 2001

The NEMO3 detector

Fréjus Undergroud Laboratory : 4800 m.w.e.

20 sectors





Source :

10 kg of ββ isotopes (from Russia)
cylindrical, $S = 20\ m^2$, $e = 50\ \mu m$

Tracking detector :

Gas mixture of Helium + ethyl alcohol

Drift wire chamber operating in Geiger mode (6180 cells)

Calorimeter :

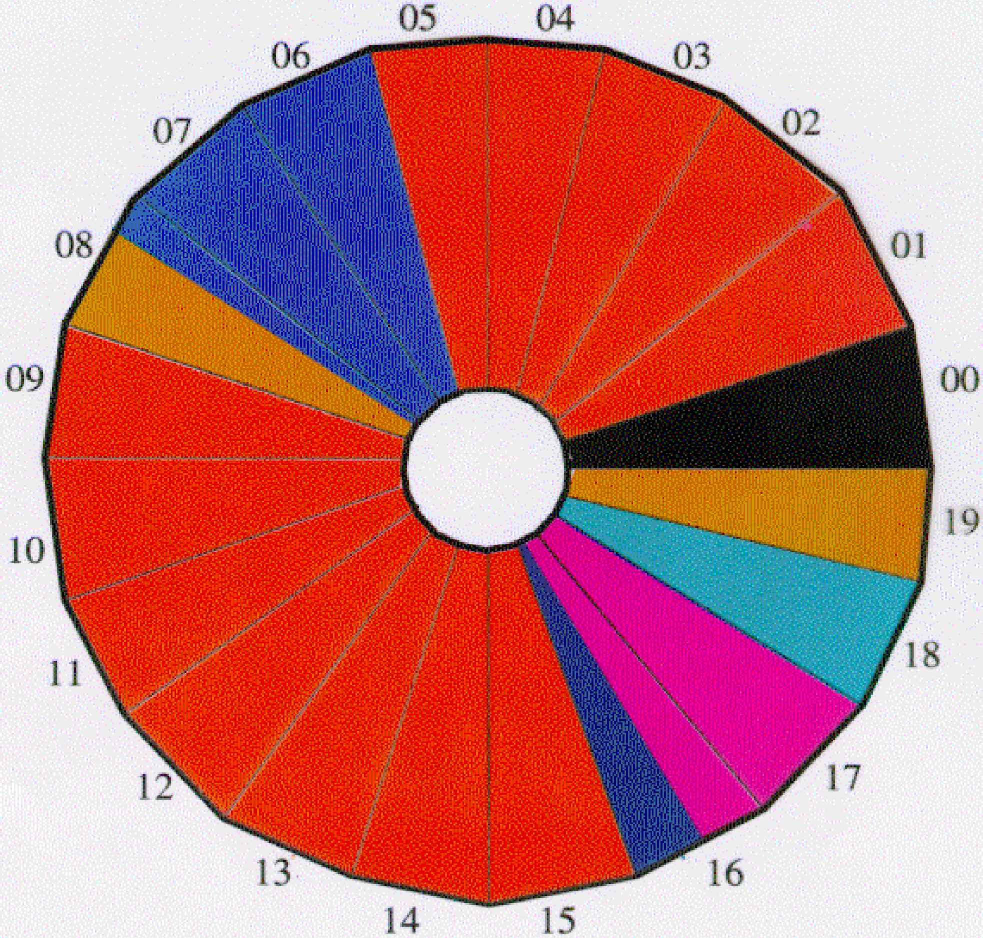
1940 plastic scintillators coupled to low radioactivity PMs ;
$\sigma(E)/E$ at 3 MeV ~ 3.5%

+ Magnetic field + Iron shielding + Neutron shielding

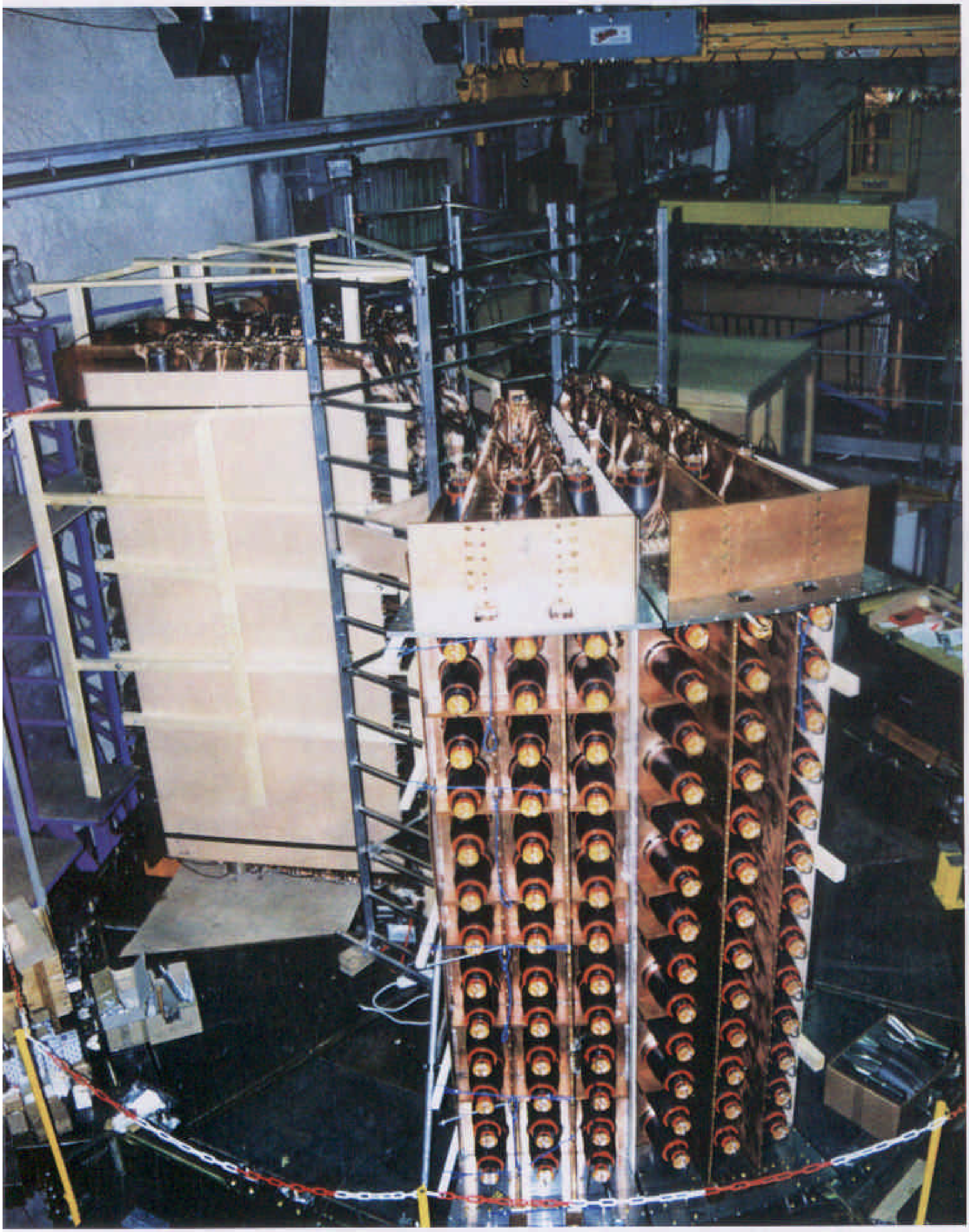
Identification : e^-, e^+, γ, n and delayed-α

- → ββ events detection
- → Measurement of source radiopurity
- → Background rejection

Source distribution in NEMO3



7 kg	^{100}Mo	12 sect.	}	$2\beta2\nu$ and $2\beta0\nu$
1 kg	^{82}Se	2.3 sect.		
0.6 kg	^{116}Cd	1 sect.		
0.9 kg	$^{nat}TeO_2$	1.7 sect.	}	background
1.7 kg	Cu	1 sect.		
	^{130}Te	≈ 1.5 sect.	}	$2\beta2\nu$ ($2\beta0\nu$)
	^{150}Nd, ^{96}Zr, ^{48}Ca	≈ 0.5 sect.		



GErmanium in liquid
NI trogen
Underground
Set up

BOREX → BOREXINO SNO-INO

CUORE → CUORICINO SOUDAN-INO

GENIUS → ~~GENIINO~~ → GEMIETTO

GENINO

OLD TECHNIQUE BASED ON

A NEW IDEA :

SHIELD WITH LIQUID NITROGEN
WHERE NAKED GE DETECTORS
ARE OPERATING.

GENINO AS A DARK MATTER
EXPERIMENT IN VIEW OF A
DBD EXPERIMENT WITH GENIUS

Optimistic time schedule

1. step: Dark Matter Experiment

GENINO:

End 2001: tank installed

End 2001: 100 kg of natural Ge detectors

+ 2 kg of ^{73}Ge detectors

End 2002: GENINO results

GENIUS:

End 2003: tank installed

start of full scale DM experiment

End 2005: results for nat. Ge competitive to LHC plans

2. step: Double Beta Experiment

2001-2005: production of ^{76}Ge detectors

(1000 kg, 400 detectors)

2003-2004: installation of 100 kg of detectors

after one year: $T^{0\nu}_{1/2} > 6 \times 10^{26}$ y

$\langle m_\nu \rangle < 0.06$ eV

2006: $\langle m_\nu \rangle < 0.01$ eV

GErmanium in liquid NItrogen Underground Setup

GENIUS

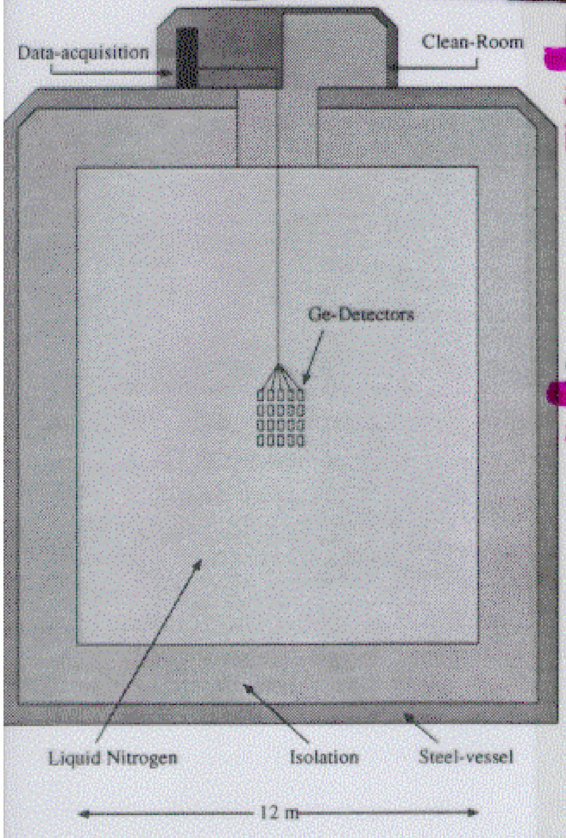
H.V. Klapdor-Kleingrothaus, Beyond the Desert 1997, IOP Bristol 1998, H.V. K-K, Hellmig, Hirsch J. Phys. G 24 (1998)

HEiDELBERG-MOSCOW Col. NIMA, 426 (1999), 425

CERN-Courier, Nov. 1997 and Dec. 1999

H.V. K-K., Int. J. Mod. Physics A13 (1998) 3953

H.V. K-K. et al. hep-ph/9910205



Schematic view of the GENIUS experiment.

First step:

array of 40 natural Ge detectors (100 kg) in a 12×12 m with LiN filled tank

- → goal: 0.01 events/ kg y keV below 100 keV
- → test a large part of the allowed MSSM

Second step:

array of 300 ^{76}Ge detectors (1000 kg) (10 tons)

- → goal: test Majorana neutrino mass down to 0.01 eV (0.002 eV)
- → decisive to solve the neutrino osc. and neutrino mass problem

Bilenky, Sept 1999

Already done

- very detailed M.C. calculations
- 3 "naked" Ge detectors (300 g) in a 50 ℓ LN in Gran Sasso

$0\nu \rightarrow 0.01\,eV$

- A new project (de Brabeleer) USA-RUSSIA

GUERNICA → $0^+ \rightarrow 0^{+*}$ with γ-γ coinc.

MAJORANA → 500 kg of ^{76}Ge

ββ and SOLAR NEUTRINOS

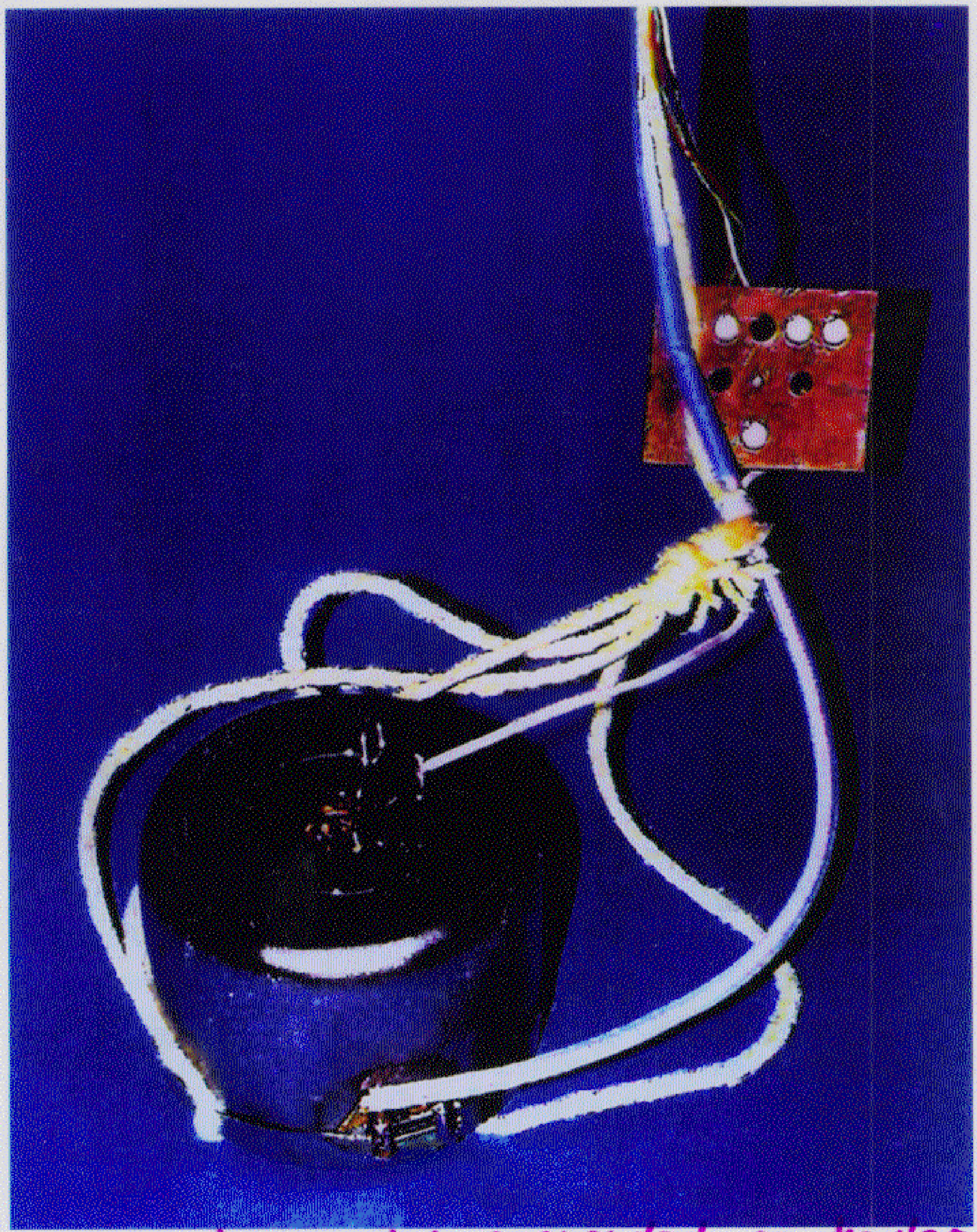
^{100}Mo (H. Ejiri)

3.3 tons of ^{100}Mo (34 tons natural)

Thin foils interleaved with

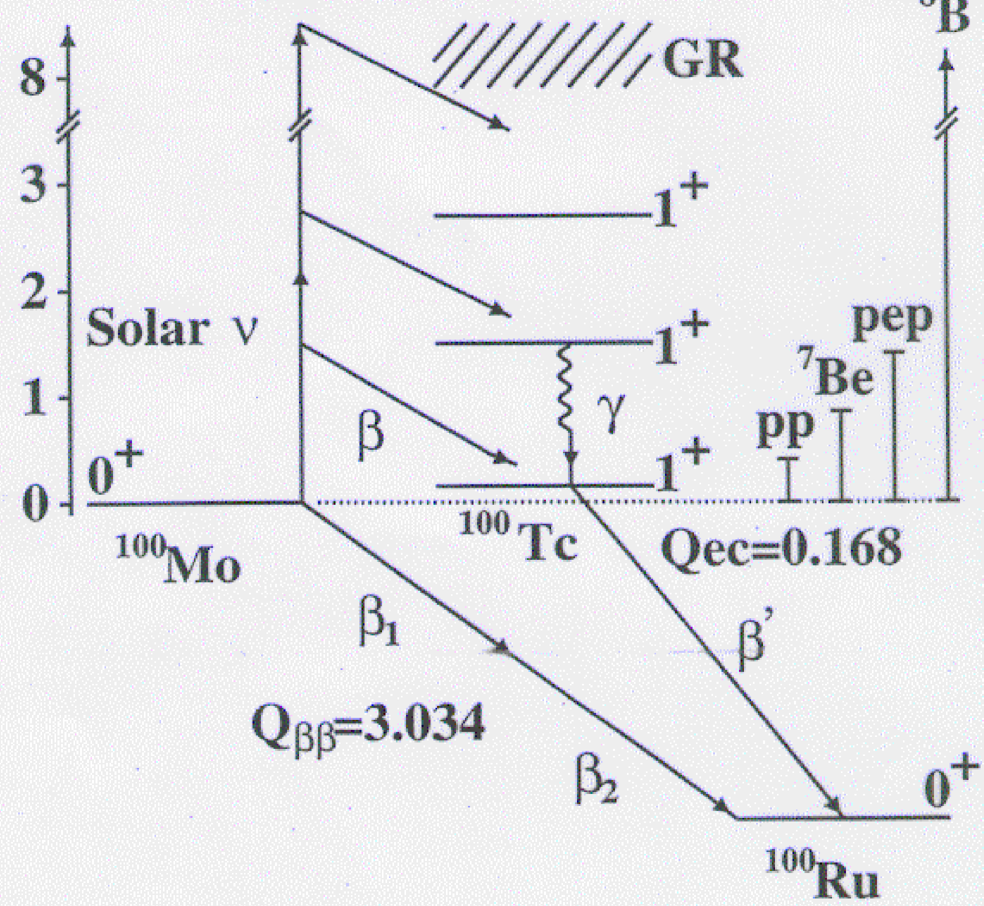
SCINTILLATORS $6 \times 6 \times 5\ m^3$.

MOON



NAKED Ge crystal suspended on kevlar wires
Only 3g in total (Kevlar and electron. cont.)

Ettore Majorana, the theoretical physicist who proposed that the neutrino could be its own antiparticle. This possibility continues to haunt us today.

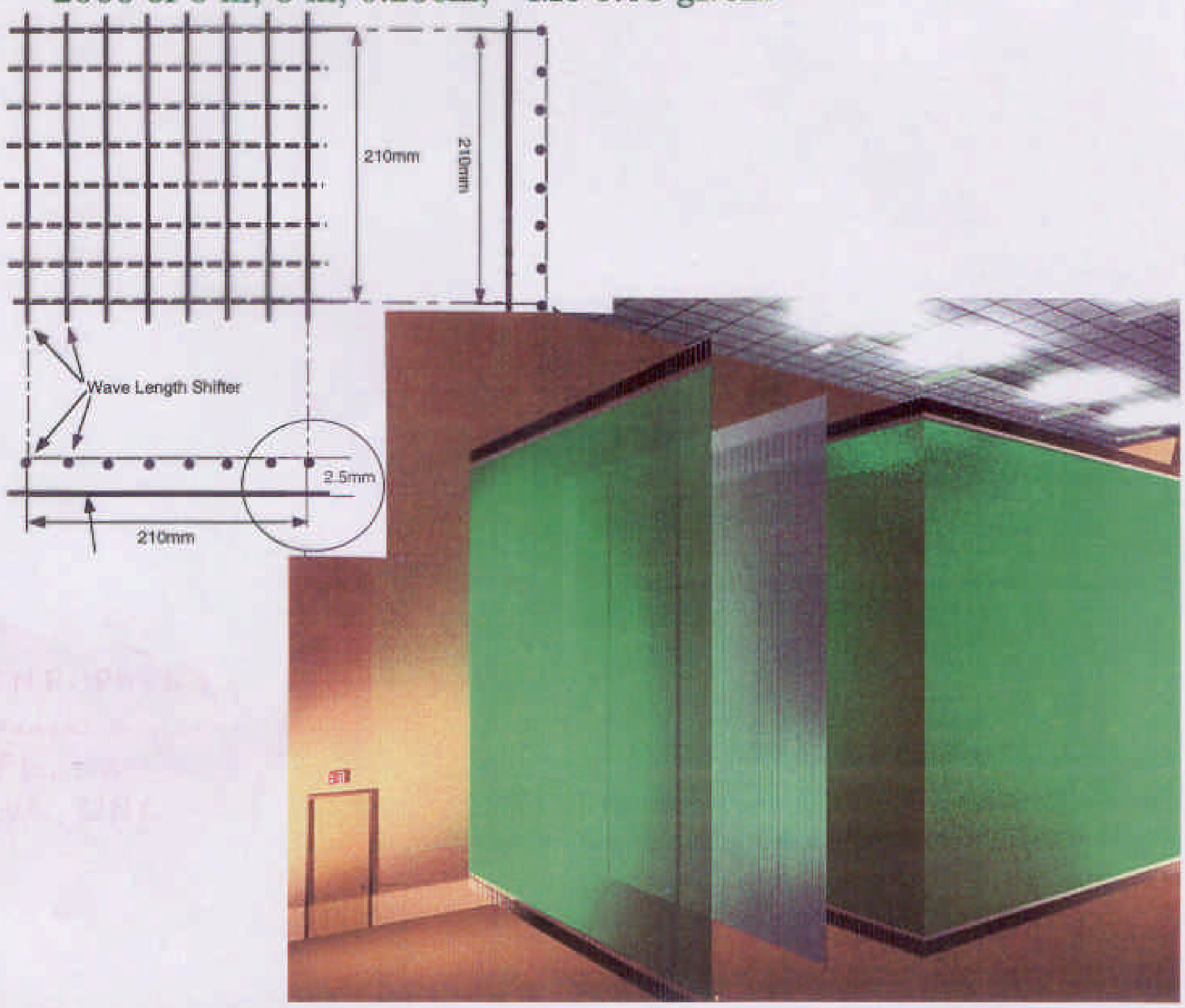

8
3
2
1
0
Solar ν
0+
100Mo
GR
1+
1+
1+
β
γ
100Tc
Qec=0.168
8B
pep
7Be
pp
β1
β'
Qββ=3.034
β2
0+
100Ru

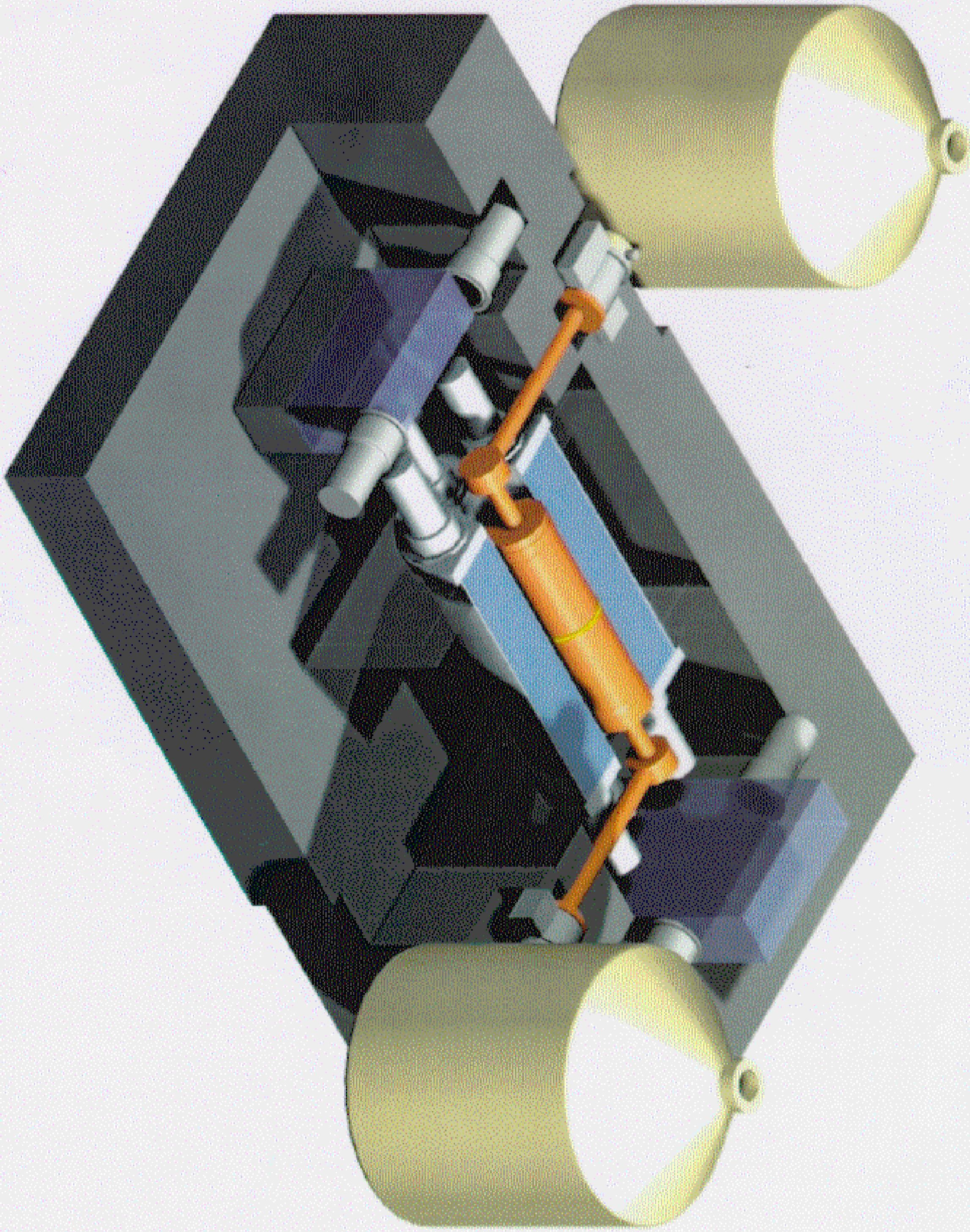
MOON. ^{100}Mo Osaka UW. UW. UNC.

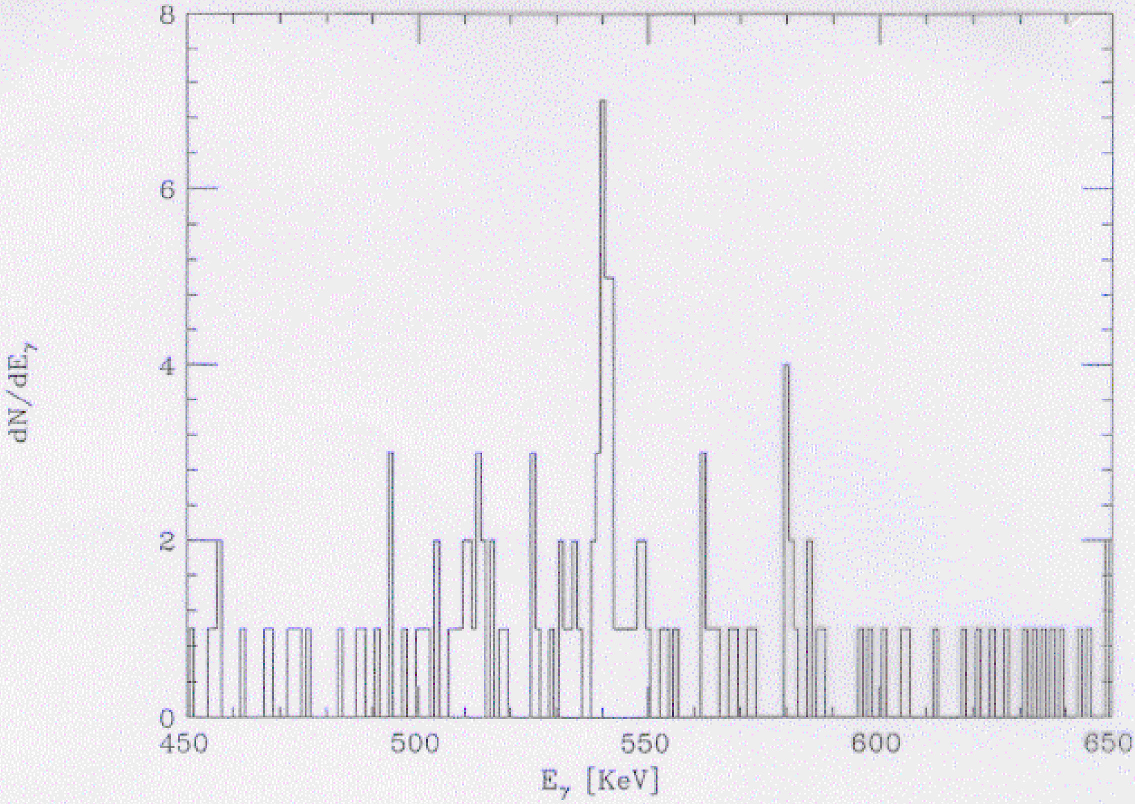
1.Spectroscopic studies of correlated ββ for 0νββ with $<m_\nu>$~0.03 eV of astrophysics interests.

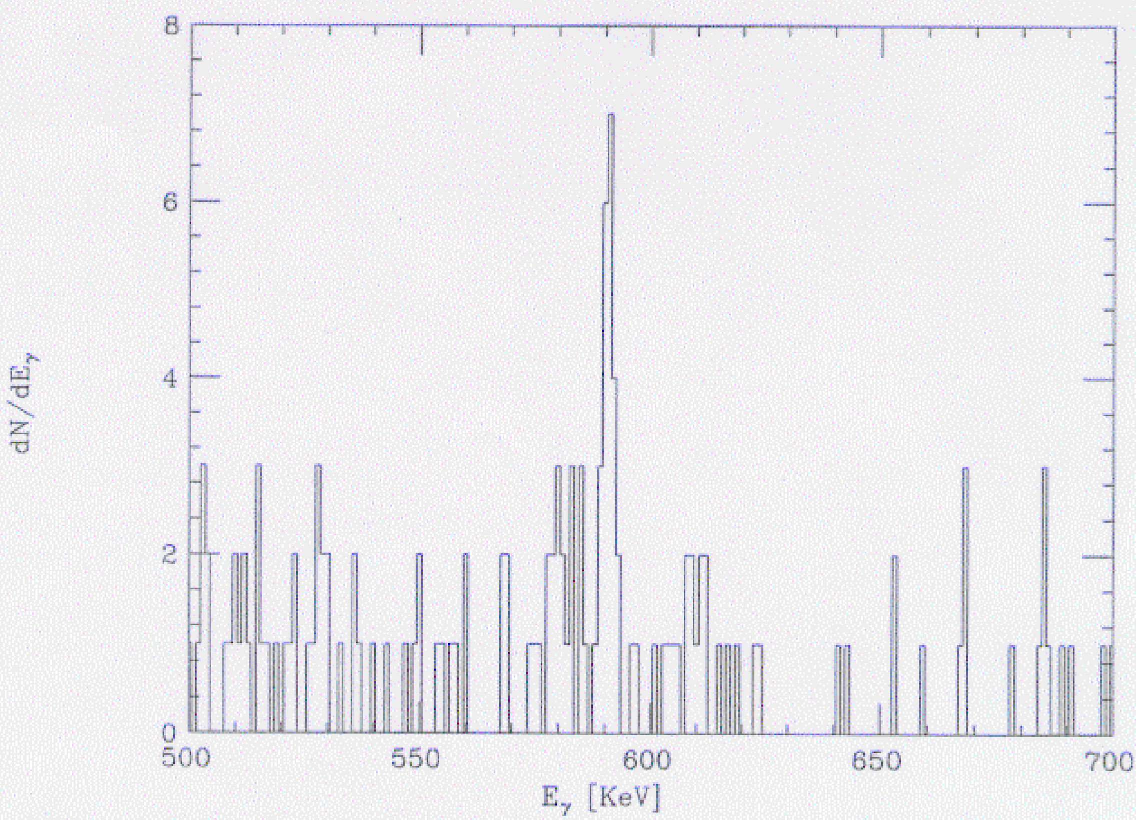
2.Real time low energy solar-ν and supernova-ν detector with low threshold & high efficiency.

Ensemble of multi-ton(34 tons)Mo/scintillator modules with WLS for Δx=2mm, ΔE=0.15 MeV for 1 MeV, 2000 of 6 m, 6 m, 0.25cm, Mo 0.05 gr/cm^2





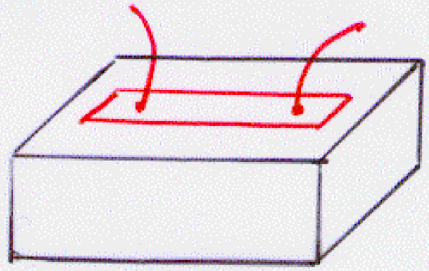

8
6
4
2
0
450
500
550
600
650
dN/dE$_\gamma$
E$_\gamma$ [KeV]


8
6
4
2
0
500
550
600
650
700
dN/dE$_\gamma$
E$_\gamma$ [KeV]

THERMAL DETECTORS

E.F and T. Niinikoski

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



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

RESOLUTION $\simeq \sqrt{k\, C_V\, T^2}$

e.g. 1 kg of Ge @ 10 mK

$\Delta E \sim 100$ eV

PRATICALLY 5 eV @ 6 keV

760 g of TeO_2

SAME RESOLUTION AS Ge DETECTOR FOR γ-RAYS, TWICE BETTER THAN ANY OTHER DETECTOR FOR α-PARTICLES

AMPLE CHOICE OF CANDIDATE NUCLEI IN SUITABLY (THERMALLY) MATERIALS

$^{48}CaF_2$ 0.187 % i.a 4272 keV t.e.

GOOD THERMAL DETECTOR AND
SCINTILLATOR PROVED!
LOW i.a. AND NOT ENRICHABLE WITH
CENTRIFUGUE, BUT.....

^{76}Ge 7.44 % i.a 2038.7 keV t.e.

GOOD THERMAL DETECTOR OPERATED
COULD BE A COMPETITOR TO Ge DIODES
(NO ELECTRONEGATIVE PURITY REQUIRED)

$^{6}CdWO_4$ 7.49 % 2804 keV t.e.

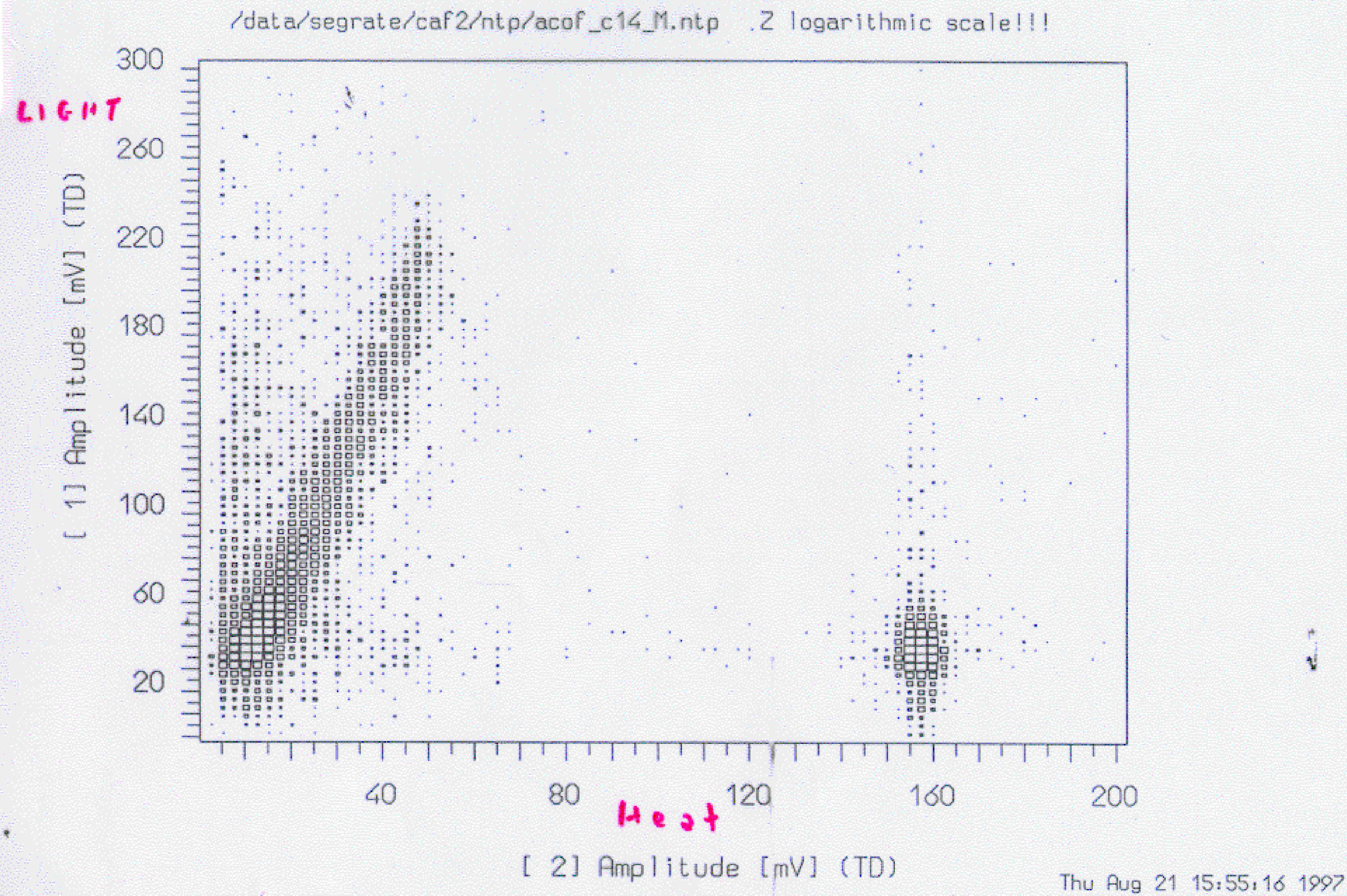
GOOD THERMAL DETECTOR OPERATED
SCINTILLATION + HEAT

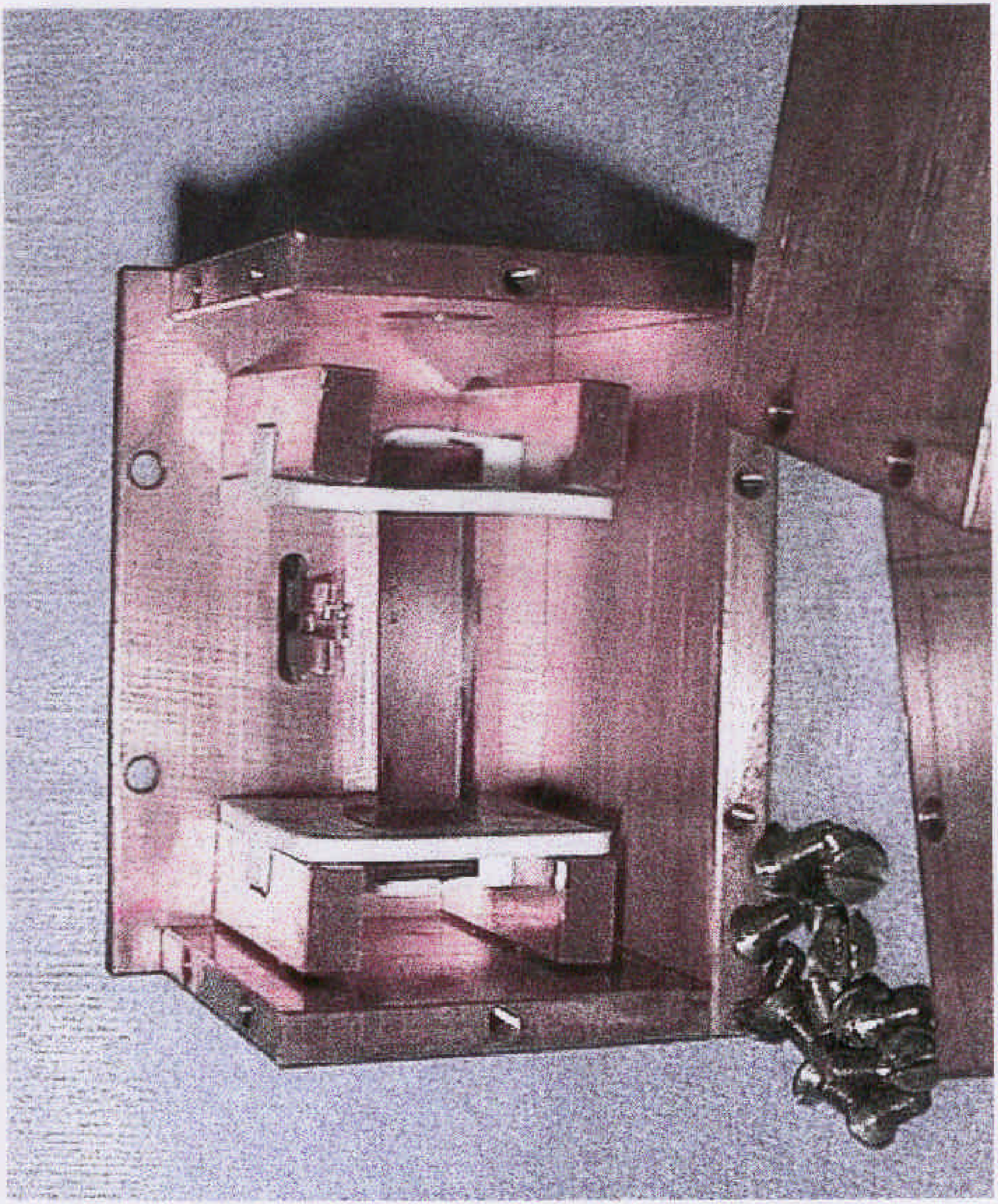
$^{00}MoPbO_4$ 9.63 % 3034 keV

GOOD THERMAL DETECTOR OPERATED
BUT ^{210}Pb activity → ROMAN LEAD

$^{50}NdF_2$ 4.64 % 3368 keV

DIFFICULT TO COOL!


/data/segrate/caf2/ntp/acof_c14_M.ntp .Z logarithmic scale!!!
LIGHT
[1] Amplitude [mV] (TD)
300
260
220
180
140
100
60
20
40
80
120
160
200
Heat
[2] Amplitude [mV] (TD)
Thu Aug 21 15:55:16 1997



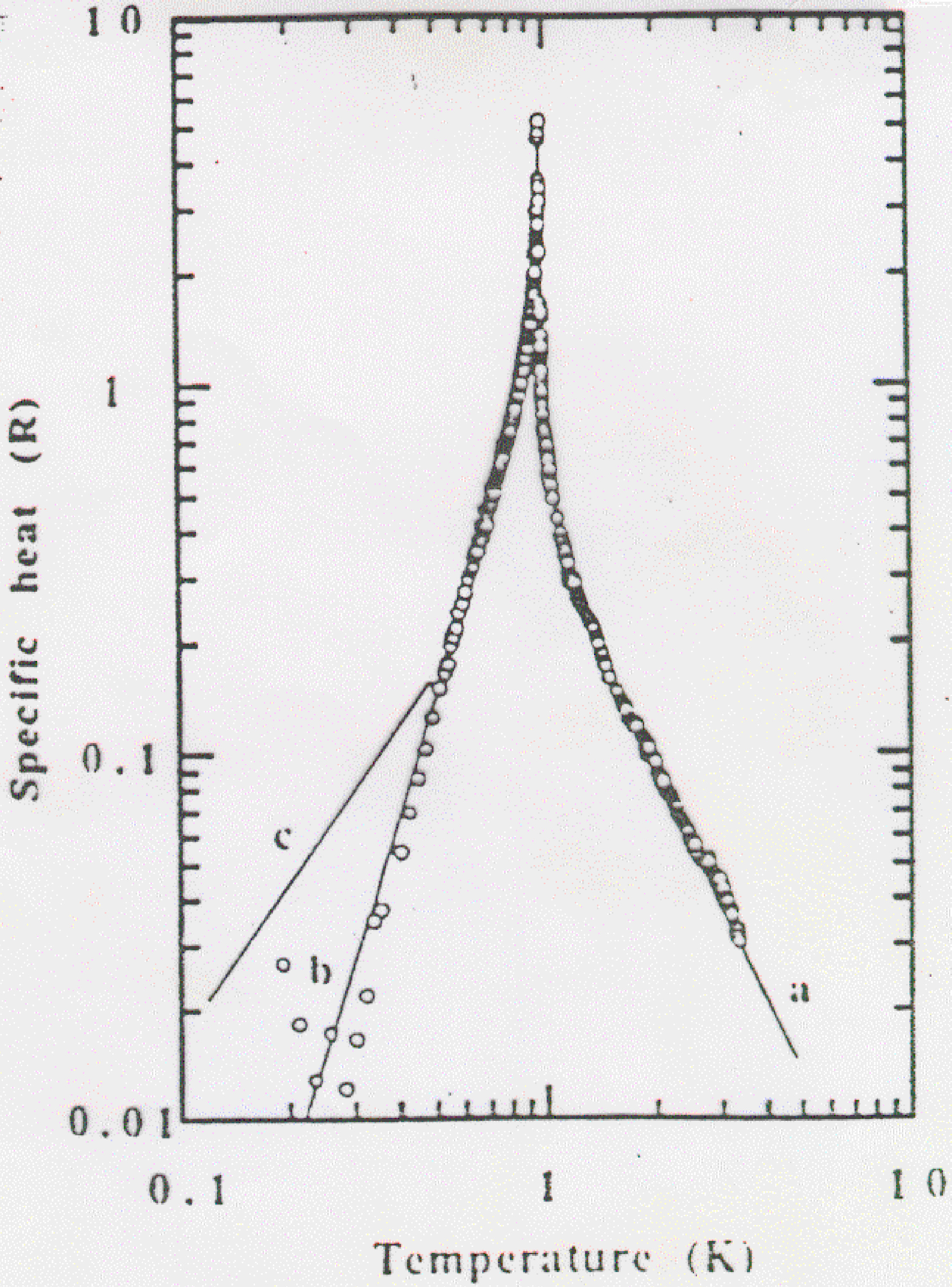


Figure 2. Heat capacity of $NdGaO_3$: a) high-temperature expansion, b) and c) antiferro- and ferromagnetic spin wave theory.

$^{130}TeO_2$ 34% i.a.! 2528 keV

EXPERIMENT DONE WITH 20 CRYSTALS OF 340 g → 6.8 kg

Cryogenic

Underground

Observatory

Rare

Events

1020 CRYSTALS OF TeO_2 OF 760 g (NATURAL) → 775 kg → 210 kg of ^{130}Te

COMPACT STRUCTURE : CAN BE HOUSED IN L.N.G.S.

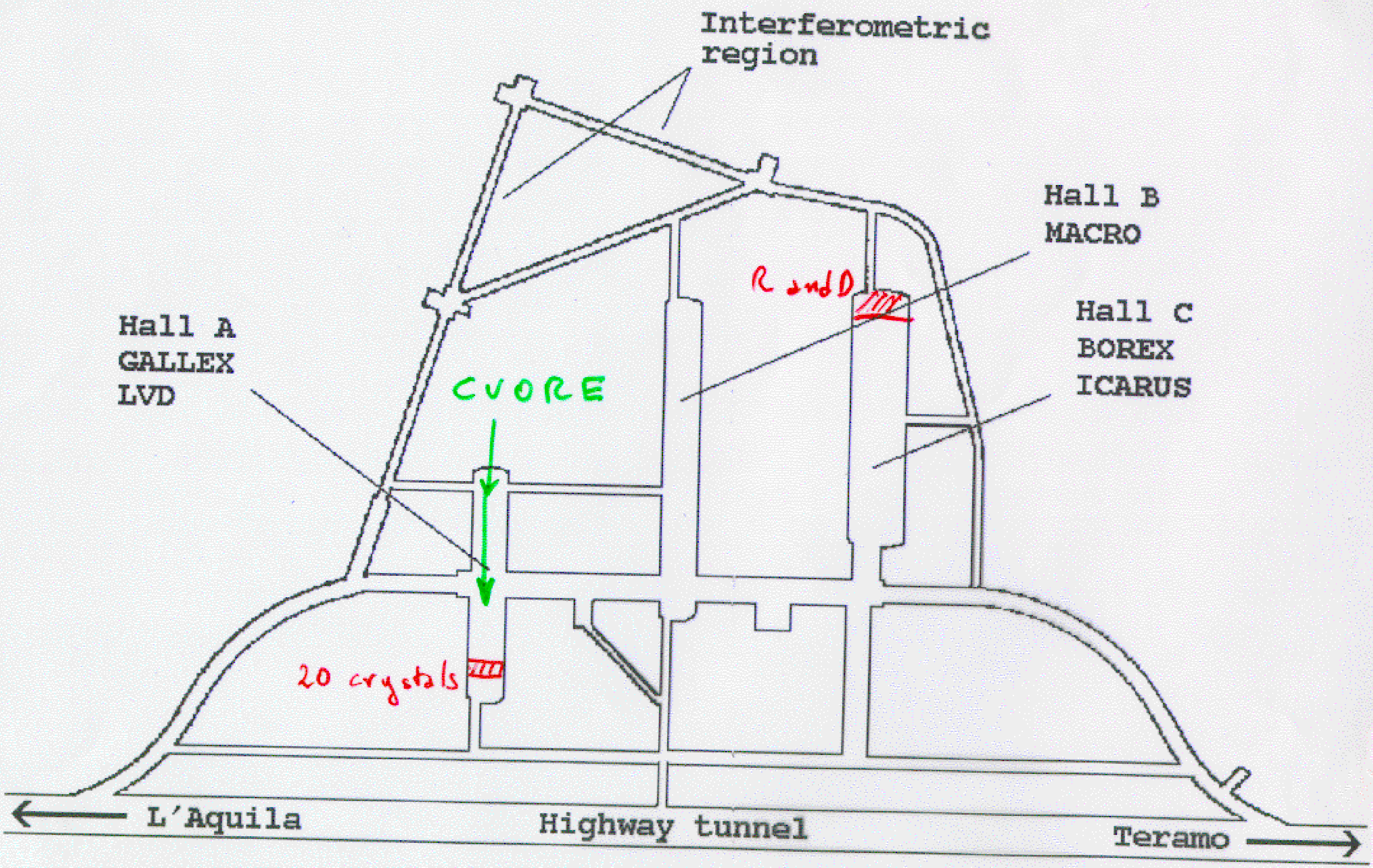
CUORICINO 56 crystals ⇒ 42 kg

APPROVED AND FUNDED

(USA – EUROPE)

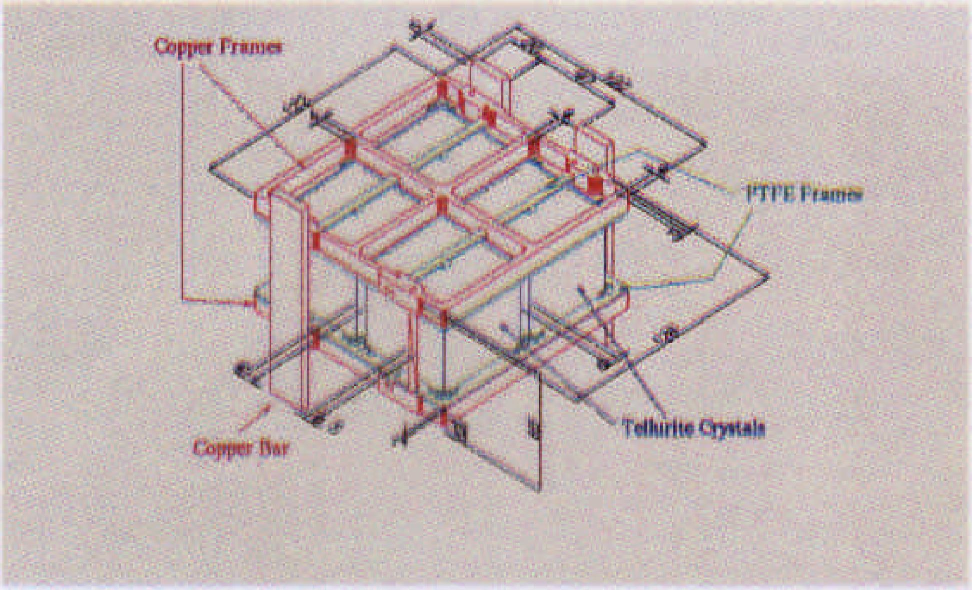
AN ARRAY OF 4 × 760 g CRYSTALS IS IN OPERATION

SAME RESOLUTION AS 2 40 = Ge diodes

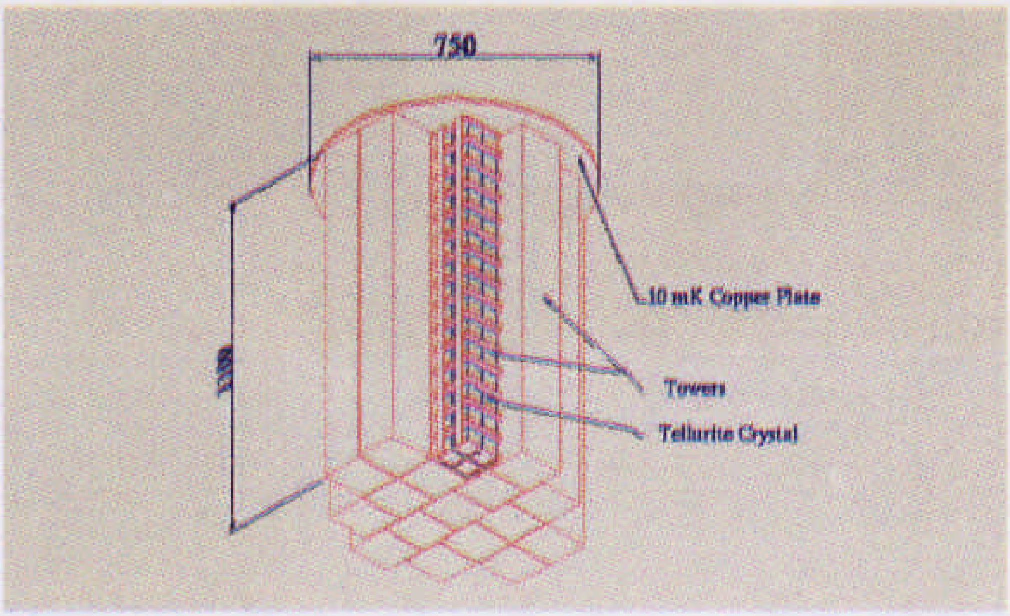

Interferometric
region
Hall B
MACRO
Hall C
BOREX
ICARUS
Hall A
GALLEX
LVD
CVORE
R and D
20 crystals
L'Aquila
Highway tunnel
Teramo

CUORE POSSIBLE STRUCTURE

Detectors Unit



First Tower=CUORICINO



B-45

4 d

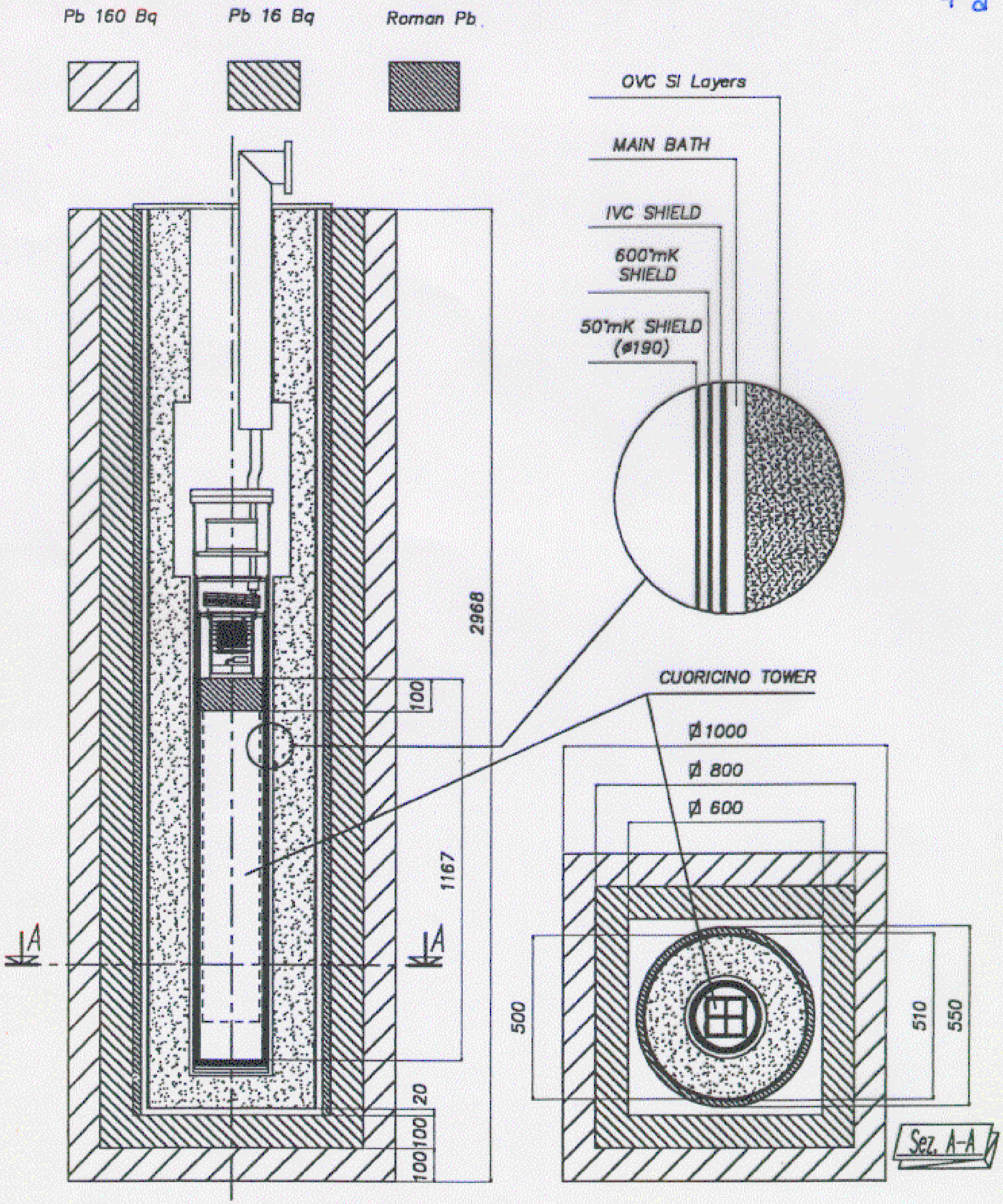

Pb 160 Bq
Pb 16 Bq
Roman Pb
OVC SI Layers
MAIN BATH
IVC SHIELD
600 mK SHIELD
50 mK SHIELD (ø190)
CUORICINO TOWER
ø 1000
ø 800
ø 600
2968
100
1167
20
100
100
500
510
550
A
A
Sez. A-A

Fig. 3

CUORICINO set-up

The CUORICINO array is a set of

56 cubic TeO_2 crystals of 5 cm side and 760 g mass

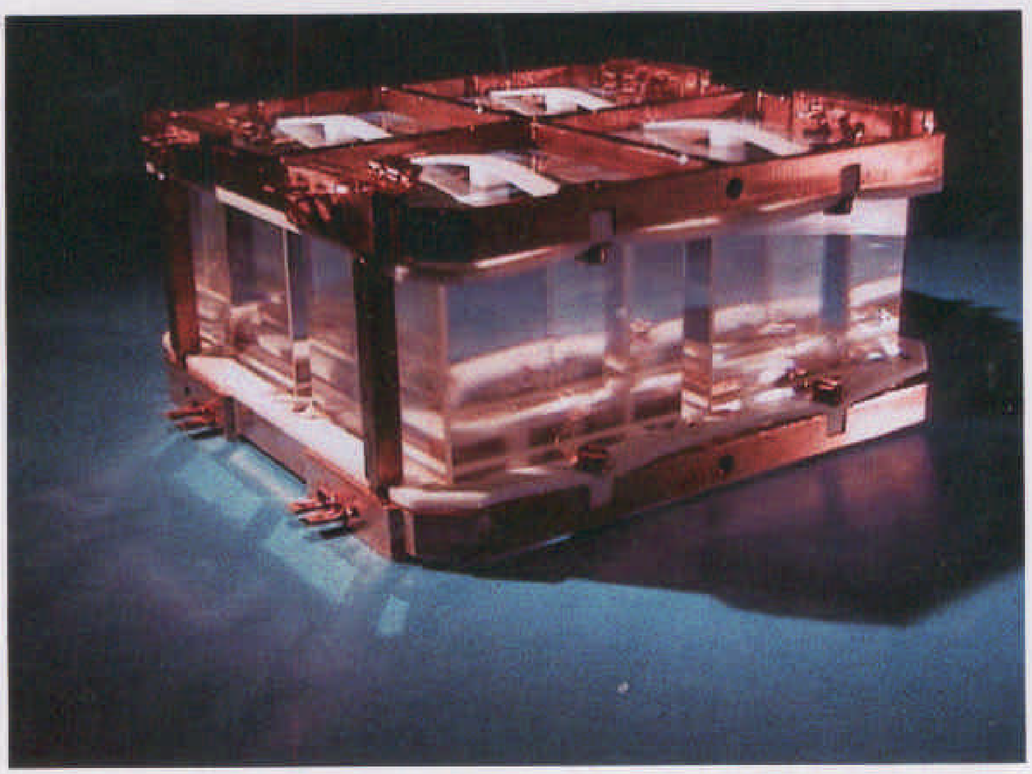
arranged in a tower-like structure of

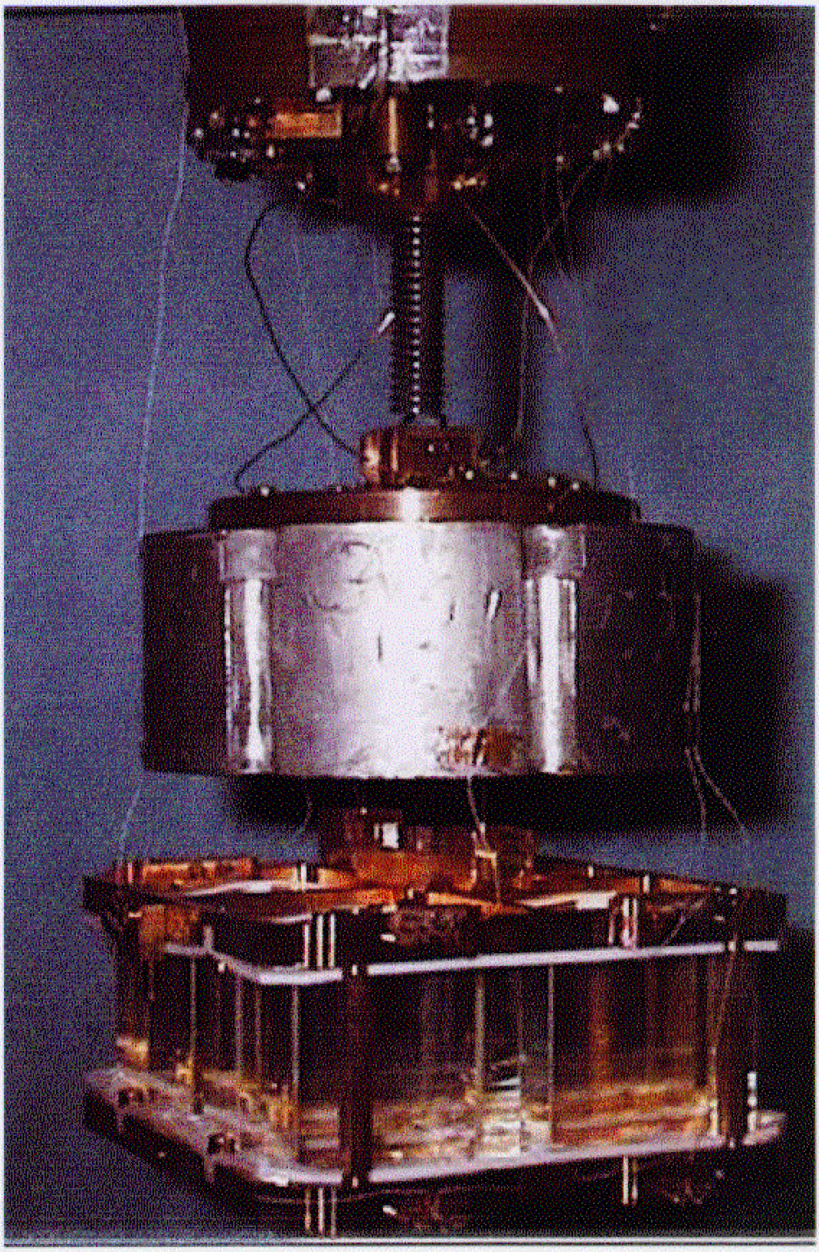
14 planes with 4 crystals per plane

The gap between the crystals is only 6 mm

↳ compact structure which helps in study and reduction of background through coincidence analysis

SINGLE CUORICINO PLANE: now under test





OTHER APPROACHES

PULSE SHAPE DISCRIMINATION, IN Ge DIODES AND SCINTILLATORS ARE ALREADY APPLYED

IN CONNECTION WITH SOLAR NEUTRINO EXPERIMENTS

- LENS using SCINTILLATOR WITH 20 tons of Yb

$$^{176}Yb \rightarrow {}^{176}Hf + 2e^- (+ 2\bar{\nu}_e) \quad (Zuber)$$

12.7% i.a. 1085.5 keV t.e.

$$^{168}Yb \rightarrow {}^{168}Er \quad \beta^+ EC, \; EC.EC$$

0.13 % i.a. 1442 keV t.e.

- BOREXINO and C.T.F.

300 tons 4 tons

Xe or ^{136}Xe (n.a. 8.9%, but can be easily enriched)

Xe solubility in Pseudocumene

$2\nu \rightarrow$ good $\quad 0\nu \rightarrow$ resolution

- CAMEO (I and II) PROJECT

in BOREXINO Counting Test Facility)

(Kiev, Milano, Munich, Princeton)

THREE MUTUALLY ORTHOGONAL DISKS OF $\Phi = 180$ cm IN THE CENTER OF CDF. ^{100}Mo, ^{116}Cd, ^{82}Se, ^{150}Nd (1 kg)

CAMEO II - $\simeq 65$ kg of $^{116}CdWO_4$ AS SCINTILLATING CRYSTALS

CAMEO III $\rightarrow$ 1 ton of $^{116}CdWO_4$

- Drift Chamber Data-ray Analyzer

MEASURE THE MOMENTUM AND POSITION OF THE DECAY VERTEX

A DRIFT CHAMBER $46.4 \times 52.4 \times 68.0$ cm^2

A SOLENOIDAL MAGNETIC FIELD

A COSMIC RAY VETO

THE SOURCE CAN BE EASILY EXCHANGED

Nd natural $\rightarrow$ enriched in ^{150}Nd

Enriched Xenon ββ decay Observatory

ITALY - RUSSIA - SWItzerland - USA.

A Xenon TPC WITH BACKGROUND SUPPRESSION BY TAGGING ^{+}Ba WITH LASER.

$^{136}Xe \rightarrow {}^{++}Ba$ with quenching ^{+}Ba

DOUBLE LASER PULSE

$6^2S_{1/2} \rightarrow 6^2P_{1/2} \rightarrow 5^4D_{3/2} \rightarrow 6^2P_{1/2} \rightarrow 6^2S_{1/2}$

493 nm — 30% — metastable — 650 nm — ↓ 493 nm

^{+}Ba ions in Xe at 5 atm ≈0.7mm in 1s

CICLING 10^7 times → 10^7 493 nm photons

Plan 40 m^3 at 5-10 atm 1-2 tons ^{136}Xe

0.02 — 0.04 eV

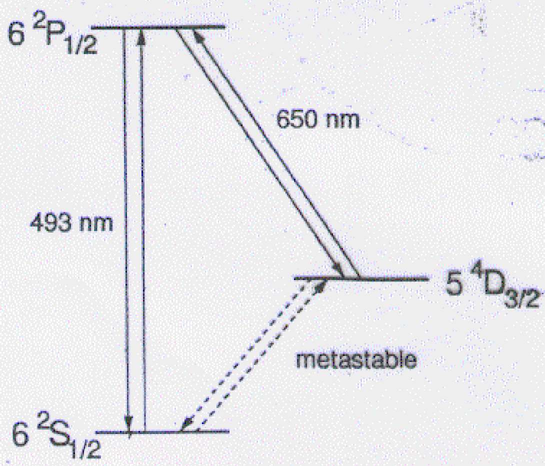
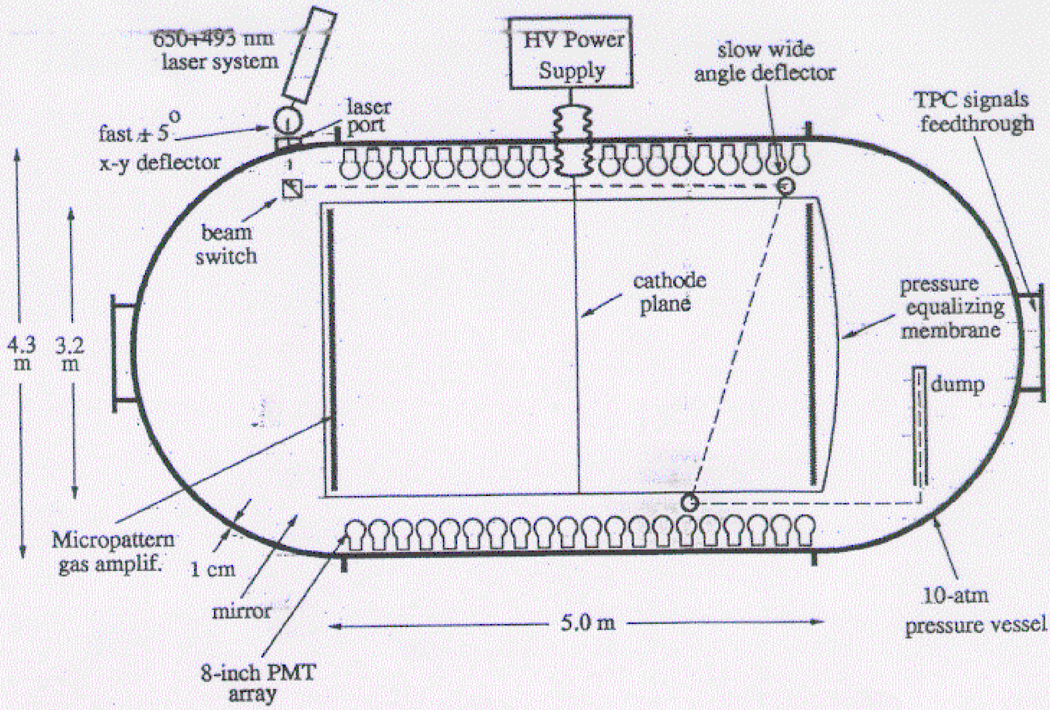
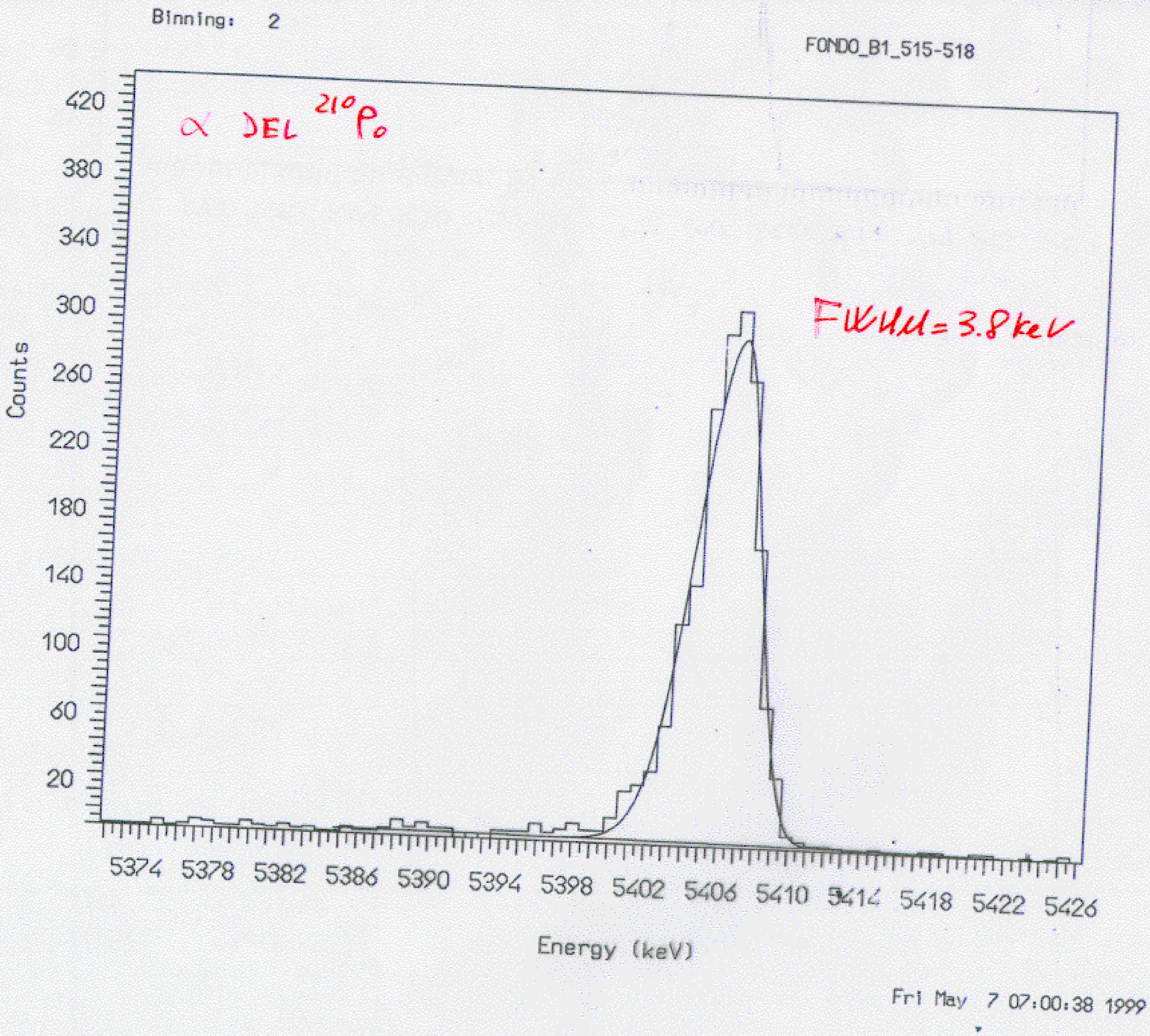


Fig. 1. Atomic level scheme for Ba^+ ions.



CONCLUSIONS

- A VERY ACTIVE AND OFTEN MULTIDISCIPLINARY FIELD - NEW TECHNIQUES
- THEORETICAL CALCULATIONS ARE IMPROVING → MORE BASED ON EXPERIMENTAL DATA
- THE 2ν CHANNEL FOUND FOR ALL GOOD CANDIDATES APART ^{136}Xe. GEOCHEMICAL DATA FOR ^{96}Zr, ^{128}Te AND ^{130}Te TO BE TESTED
- FOR 0ν $\beta\beta$ BACKGROUND
  MASS
  RESOLUTION
  ISOTOPIC ENRICHMENT
  (NEW METHODS !)
- MEASUREMENTS ON VARIOUS NUCLEI (ALSO $\beta^+\beta^+$, β^+EC, ECEC)
- "SUBPRODUCTS" RADIOACTIVITY, NEW RADIOAC. NATURAL NUCLIDES, DARK MATTER, SOLAR ν's
- ARE THESE EXPERIMENTS EXPENSIVE? → INTERNATIONAL COLL.


Binning: 2
FONDO_B1_515-518
α DEL 210Po
FWHM=3.8keV
Counts
420
380
340
300
260
220
180
140
100
60
20
5374
5378
5382
5386
5390
5394
5398
5402
5406
5410
5414
5418
5422
5426
Energy (keV)
Fri May 7 07:00:38 1999