The NEMO experiment: 10 years of R&D for neutrinoless double beta decay and status of the NEMO 3 detector

F. Piquemal
CEN Bordeaux Gradignan (France)

NEMO Collaboration

CENBG, IN2P3-CNRS et Université de Bordeaux, **France**
LSCE, CNRS Gif sur Yvette, **France**
FNSPE, Prague University, **Czech Republic**
INEEL, Idaho Falls**, USA**
IReS, IN2P3-CNRS et Université de Strasbourg, **France**
ITEP, Moscou, **Russia**
JINR, Dubna, **Russia**
JYVASKYLA University, **Finland**
LAL, IN2P3-CNRS et Université Paris-Sud, **France**
LPC, IN2P3-CNRS et Université de Caen, **France**
MHC, USA
Saga University, Japon

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Goal of the experiment

To lower the **sensitivity** to **$<m_\nu>$** down to **0.1 eV** by looking for the **$\beta\beta(0\nu)$ process**

Aspects taken into account

Several kg of source enriched in ββ emitter

Possibility to measure various isotopes

Tracking

Calorimeter

Reduction

Radiopure materials

γ and neutron shieldings

Rejection

α, γ detection

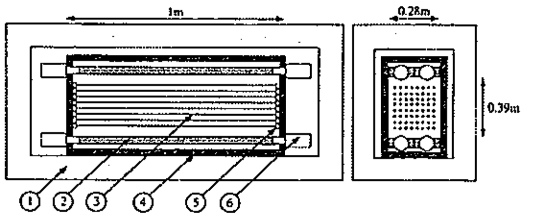
ToF

B for e^+e^- pairs

NEMO STORY

1987

NEMO 1



The 64 cell detector: (1)-shielding, (2)-plastic scintillators, (3)-wires of Geiger cells, (4)-copper wall (1 cm thick), (5)-cathode ring, (6)-phototube.

64 Geiger Cells
Tracking of electrons down to 100 keV

(D.Dassié et al., NIM A309(1991), 465-475)

1991

NEMO 2

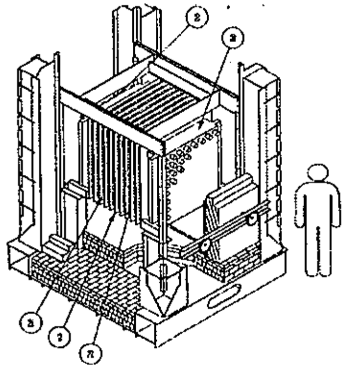


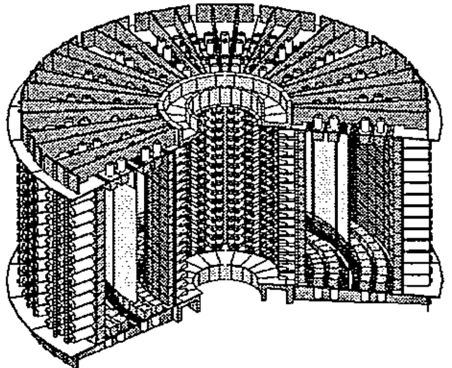
Fig. 2. Diagram of the experimental configuration. 1 – Central frame supporting the source. 2 – Copper frames which support the Geiger cells. 3 – 8×8 arrays of scintillator counters.

Test calorimeter: plastic scintillators + low activity PMT
Test of analysis and simulation events with e,γ,α.
- internal contamination measurements in ^{214}Bi and ^{208}Tl
- radon deposit on the surface of source foil
- external n and γ flux
- $T_{1/2}$ $\beta\beta(2\nu)$ for ^{100}Mo, ^{82}Se, ^{116}Cd, ^{96}Zr
+ angular distribution

(R. Arnold et al., NIM A354(1995), 338-351)

1997

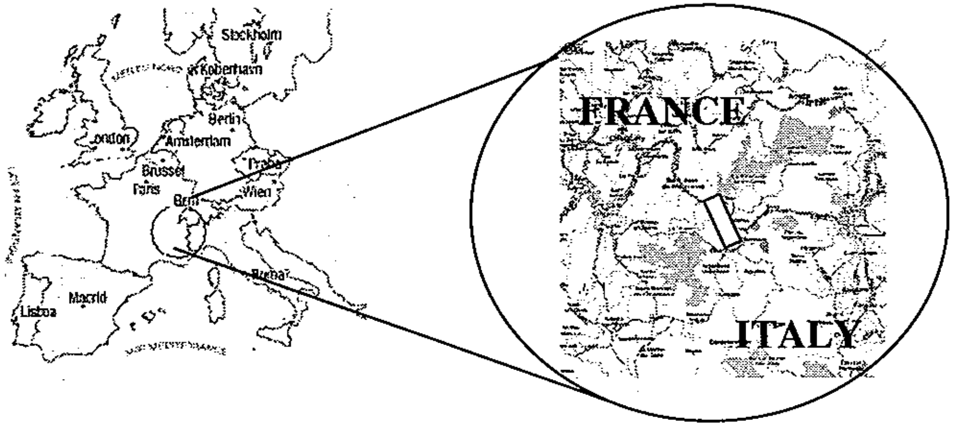
NEMO 3

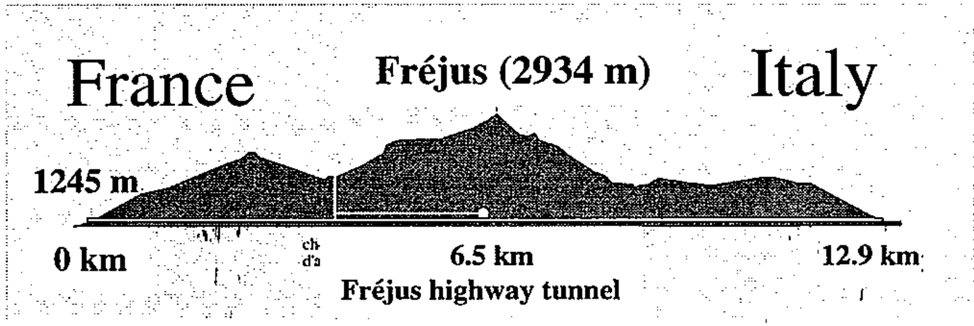


2002

data taking

Modane Underground Laboratory (Fréjus) 4200 m.w.e





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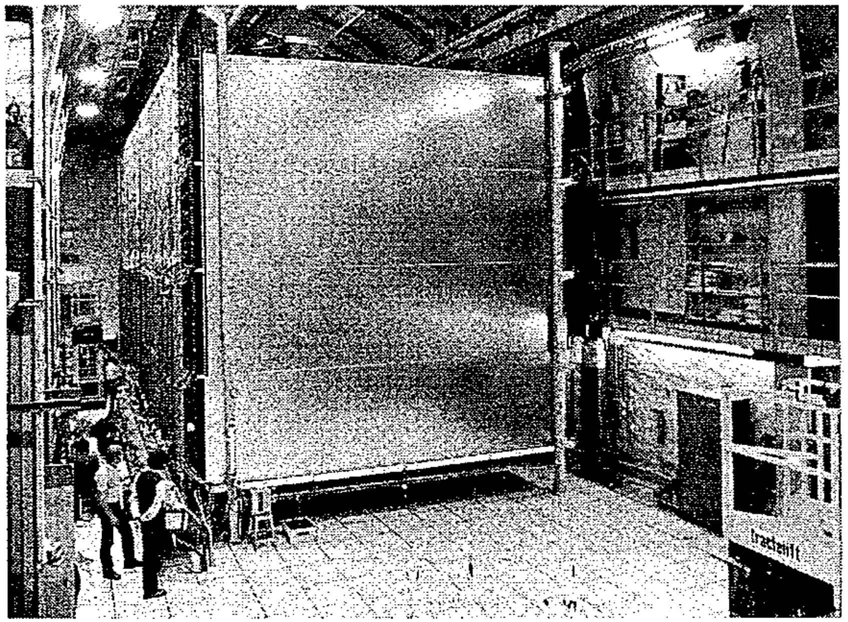
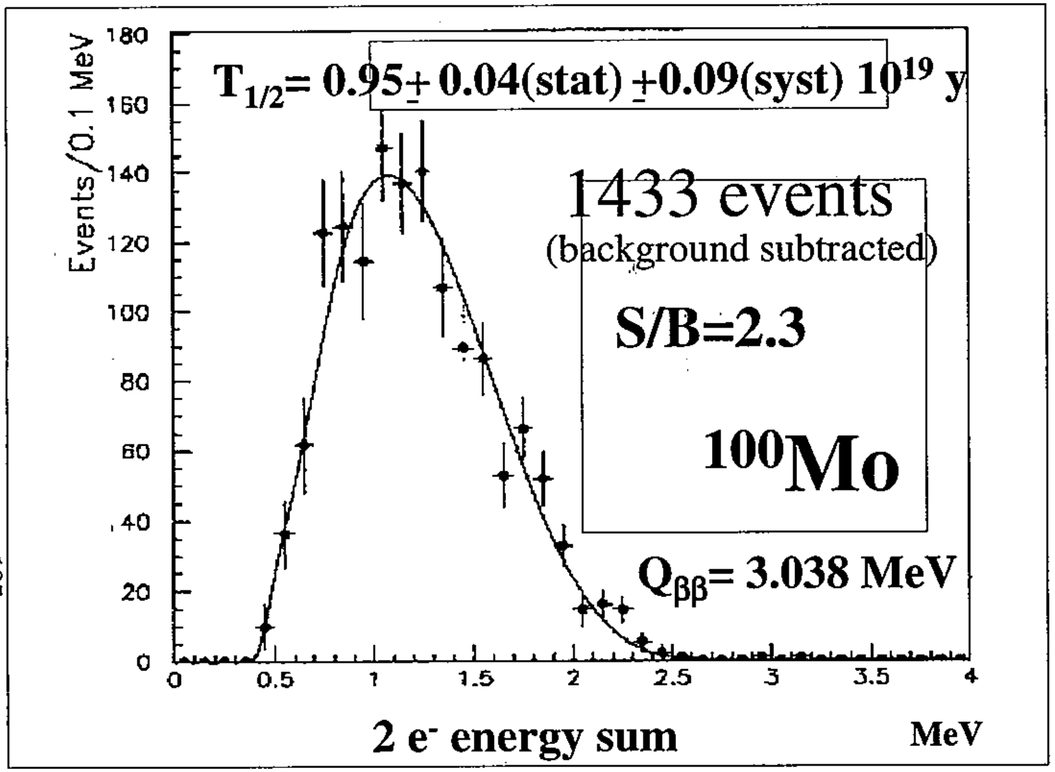
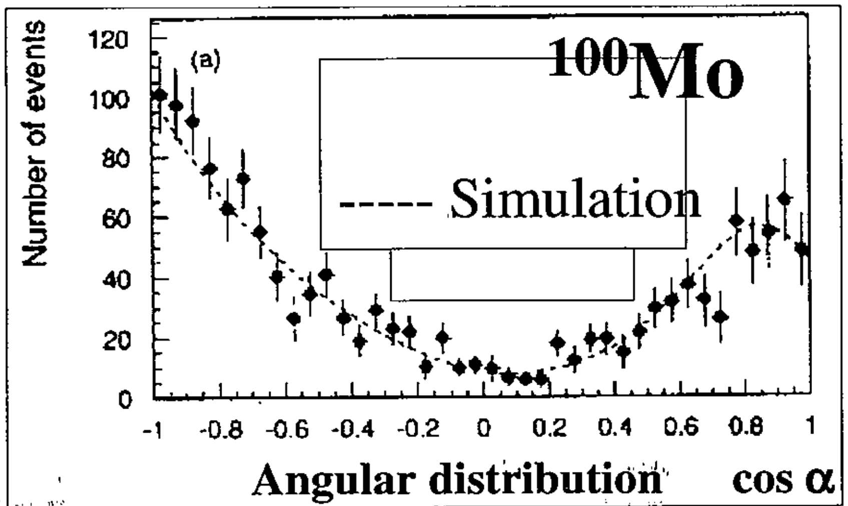
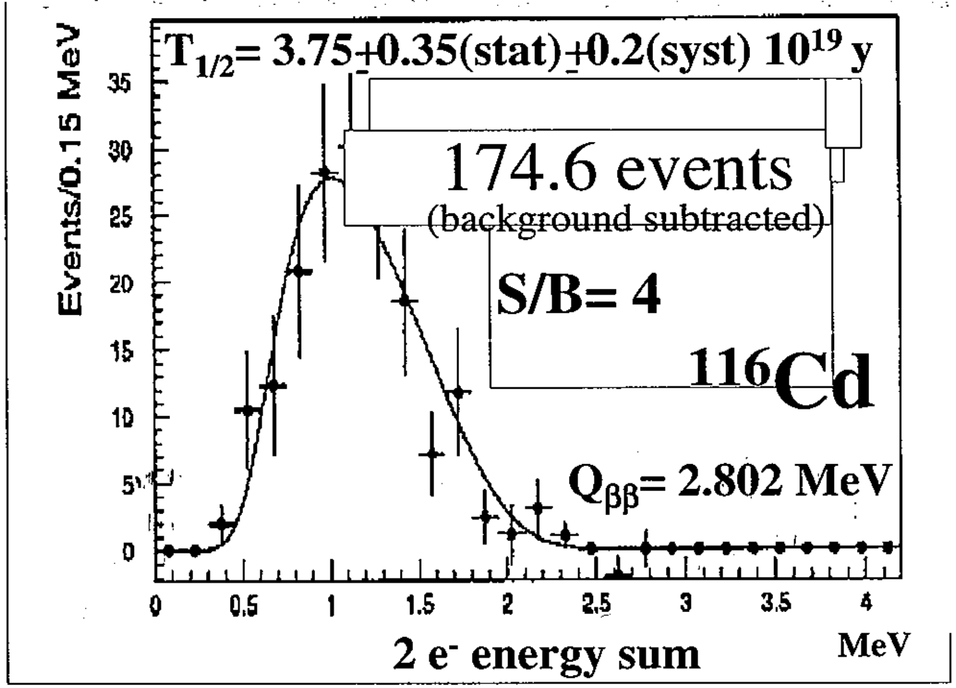
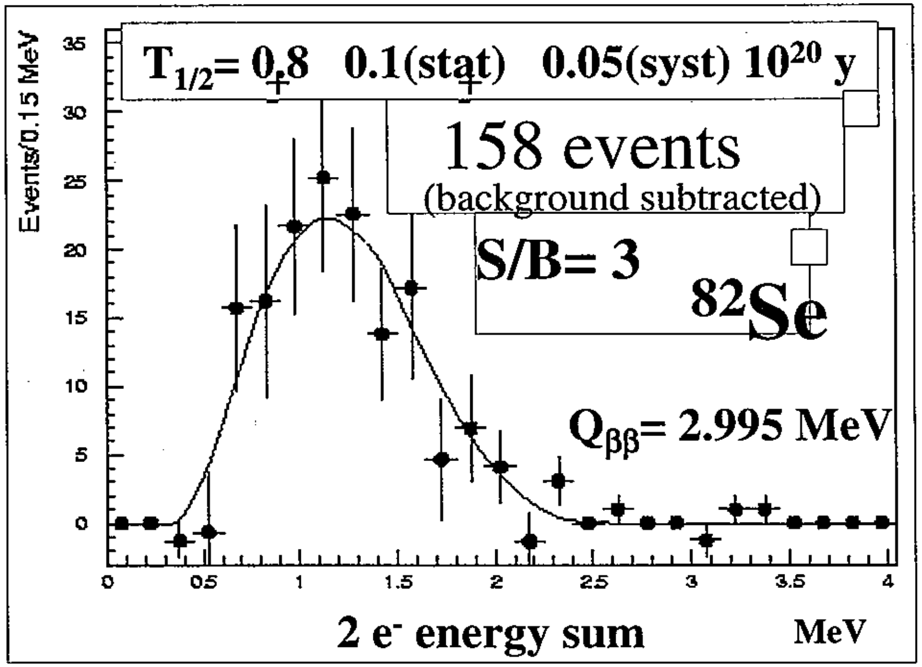


NEMO 2 ββ(2ν) RESULTS









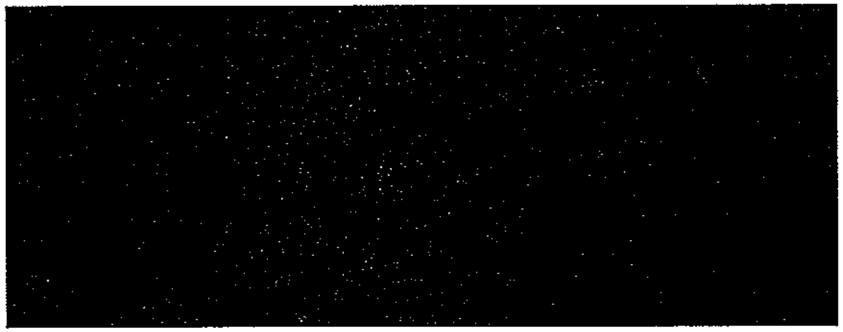
^{96}Zr $Q_{\beta\beta}$=3.350 MeV

$T_{1/2} = 2.1^{+0.8}_{-0.4} \pm 0.09$(syst) 10^{19} y

Tokyo 2002/05/09

Conclusions of NEMO 2 studies

•**Ability of the detector to measure the internal contaminations of the source by itself**



•**Understanding of neutrons induced background**

•**Reliability of the technics (6 years of data taking)**

•**Control of backgrounds: measurement of $\beta\beta(2\nu)$ for several isotopes**

Main R&D for NEMO 3

Source:

Required levels $^{214}Bi < 0.3$ mBq/Kg
$^{208}Tl < 0.02$ mBq/kg

Chemical (INEEL, CFR) and Physical purification
γ spectroscopy Ge

Tracking:
3 m Geiger cells, aging control

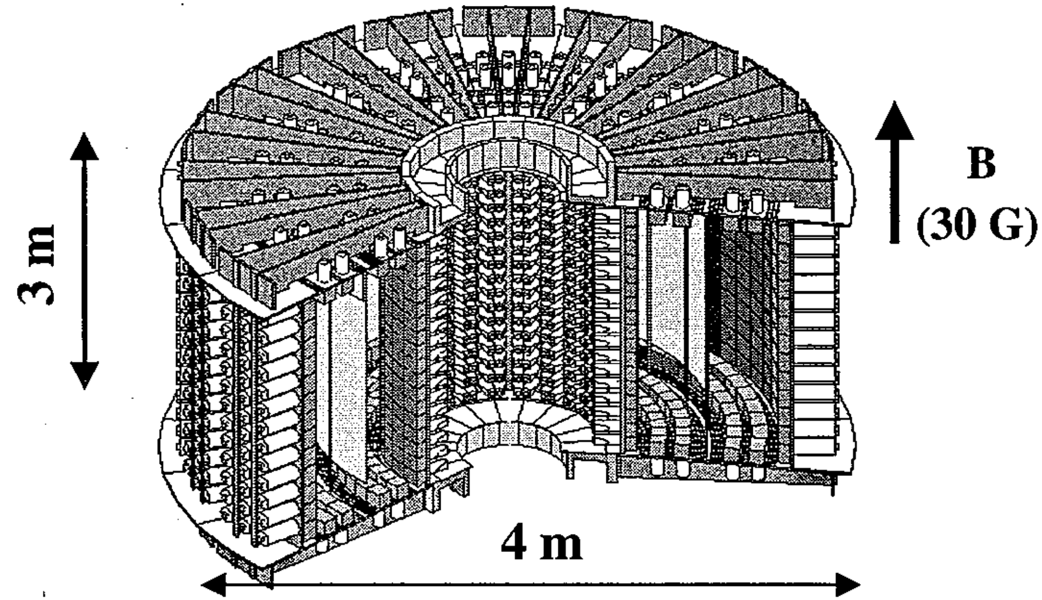
Calorimeter:
Improvement of plastic scintillator resolution
Production of 10 t of plastic scintillators
Low background photomultipliers

Neutron shielding

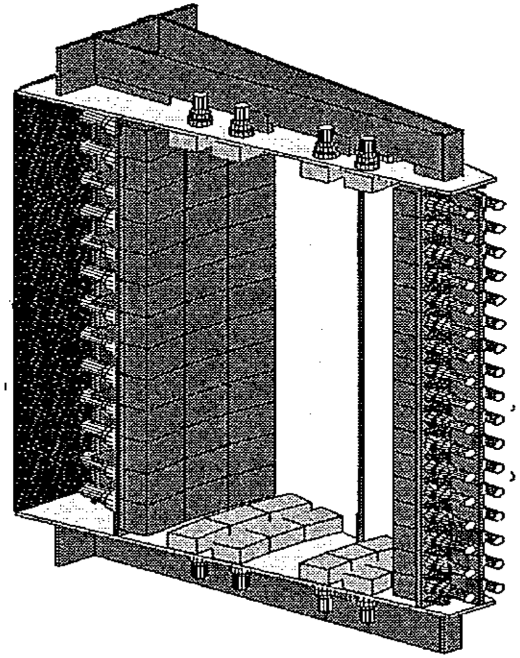
~ 1000 measurements for the selection of all the materials by γ spectroscopy with Ge detector (~45 t)

The NEMO3 detector

20 sectors



A sector



Source:

10 kg of ββ isotopes (20 m^2, 50 μm)

Tracking detector:

Gas mixture of Helium + ethyl alcohol
Drift wire chamber operating in Geiger mode (6180 cells)

σ_l = 1 cm σ_r = 0,5 mm

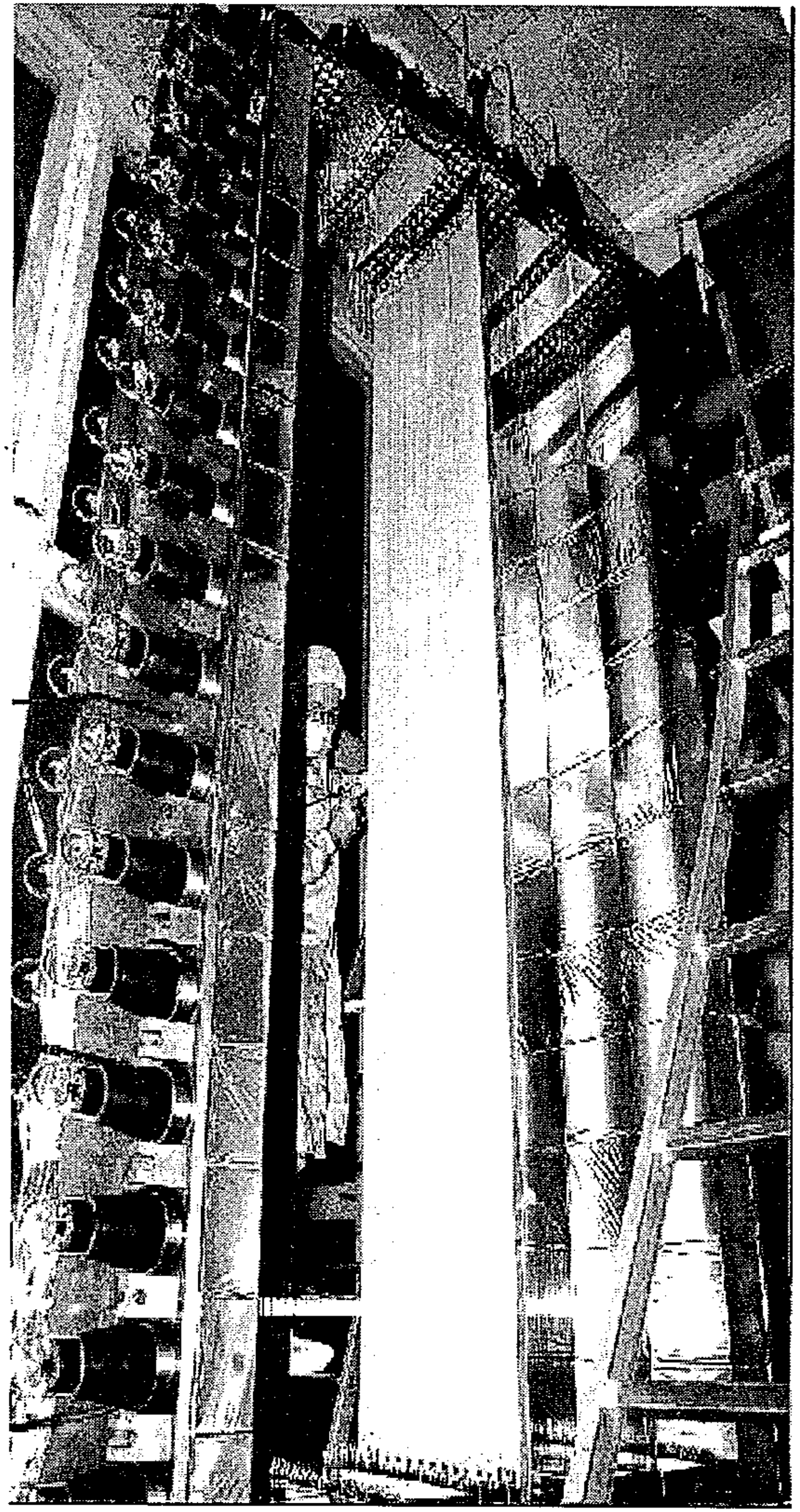
Calorimeter:

1940 plastic scintillators coupled to low radioactivity PMs
σ(E)/E ~3 % at 3 MeV , σ(t)= 250 ps at 1 MeV

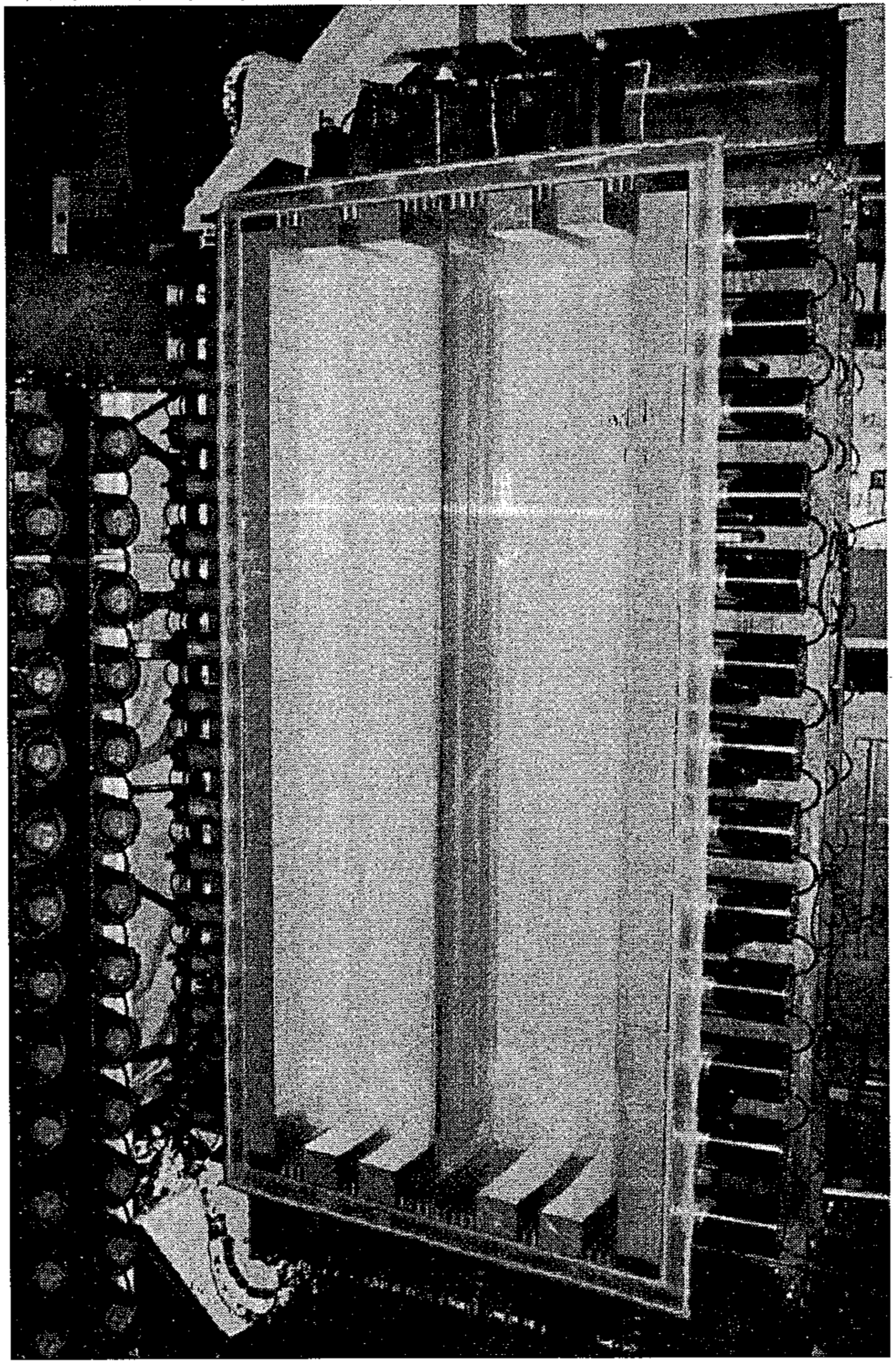
Selection of materials by γ spectroscopy + Magnetic field
+ Iron shielding + Neutrons shielding
+ Fréjus Laboratory (4800 m.w.e.)

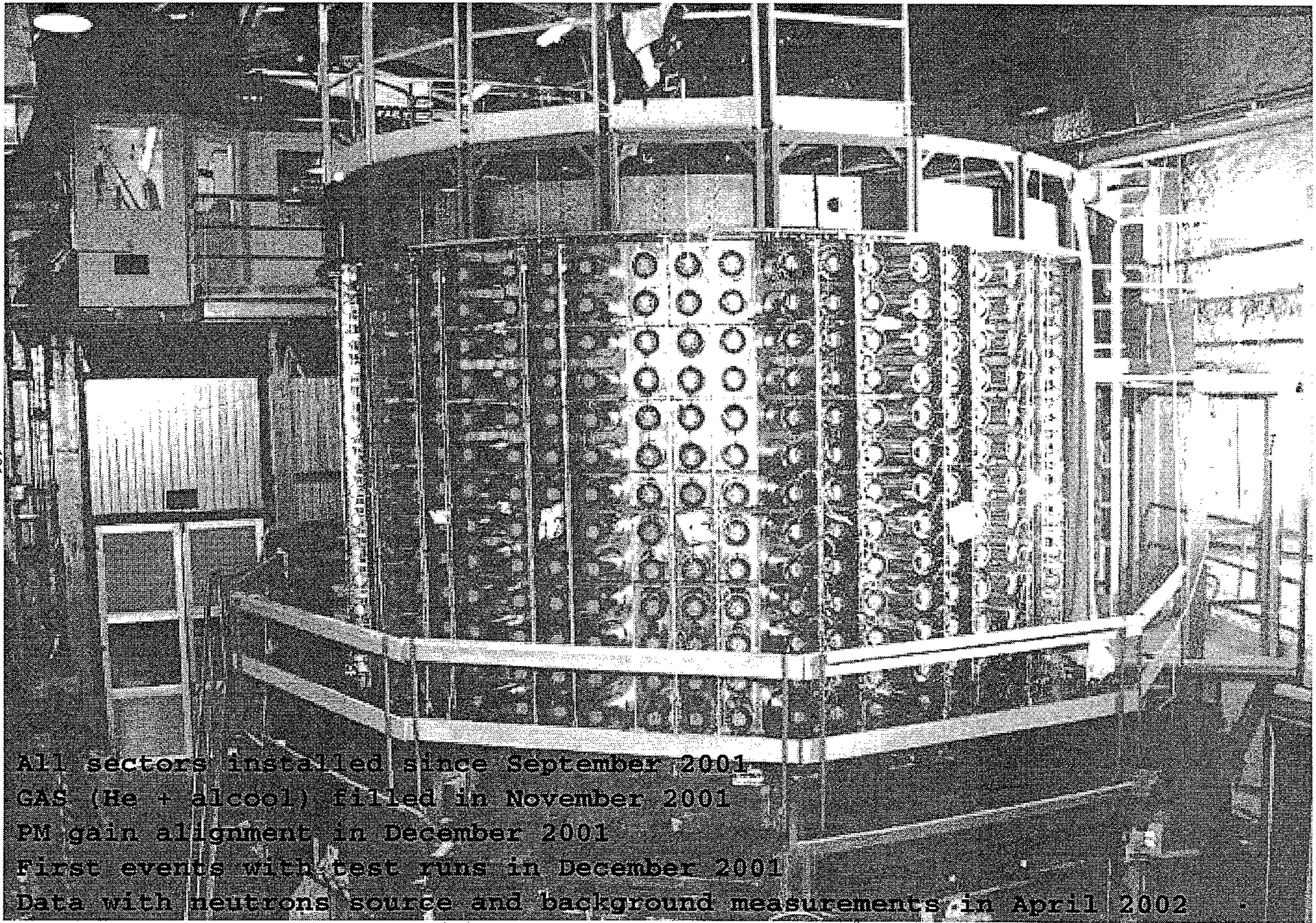
Identification: e$^-$,e$^+$,γ and delayed-α

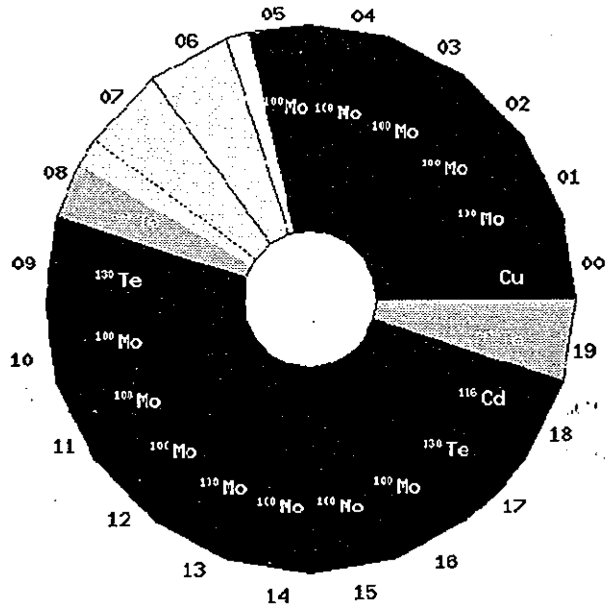
ββ events detection
Measurement of source radiopurity
Background rejection



Tokyo 2002/05/08




All sectors installed since September 2001
GAS (He + alcool) filled in November 2001
PM gain alignment in December 2001
First events with test runs in December 2001
Data with neutrons source and background measurements in April 2002



NEMO3 SOURCE

Several isotopes:

- Search $\beta\beta(0\nu)$, $\beta\beta(0\nu X)$ (Majoron emission)
- Measure $\beta\beta(2\nu)$ to ground state and excited states to test Nuclear Matrix Element calculations
- Measure external background

Nuclei	Weight	Main interest
^{100}Mo	7.2 kg	$\beta\beta$ (0ν), $\beta\beta$ (0νX) $\beta\beta$ (2ν) 10^5 evts/y → angular distribution single electron spectrum
^{82}Se	1.0 kg	$\beta\beta$ (0ν), $\beta\beta$ (0νX), $\beta\beta$ (2ν)
^{116}Cd	0.6 kg	$\beta\beta$ (0νX), $\beta\beta$ (2ν)
^{130}Te	1.3 kg	$\beta\beta$ (2ν)
^{150}Nd	48 g	$\beta\beta$ (2ν), measurement of radiopurity
^{96}Zr	20 g	$\beta\beta$ (2ν), measurement of radiopurity
^{48}Ca	10 g	$\beta\beta$ (2ν), measurement of radiopurity
Cu	0.6 kg	External background
^{nat}Te	0.8 kg	External background

NEMO3 $\beta\beta(0\nu)$ sensitivity

5 years

$\beta\beta(0\nu)$ efficiency: 14 % at [2.8 - 3.2] MeV

^{100}Mo

7 kg $Q_{\beta\beta}$=3.034 MeV

Internal background: ^{214}Bi < 0,04 event/y/kg
^{208}Tl < 0,04 event/y/kg
$\beta\beta(2\nu)$ 0.11 event/y/kg

External background: 0 event

Limit (90 % C.L): 6.5 expected bkg events
if 6 observed events
5 $\beta\beta(0\nu)$ excluded events

↓

$T_{1/2}$ > 5.10^{24} years

↓

$\langle m_\nu \rangle$ < 0.2 - 0.7 eV

^{82}Se

1 kg $Q_{\beta\beta}$=2.995 MeV

Internal background: ^{214}Bi and ^{208}Tl rejected
→ Hot spots
$\beta\beta(2\nu)$ 0.01 event/y/kg

External background: 0 event

Limit (90 % C.L): 0.1 expected bkg event
if 0 observed event
2.5 $\beta\beta(0\nu)$ excluded events

↓

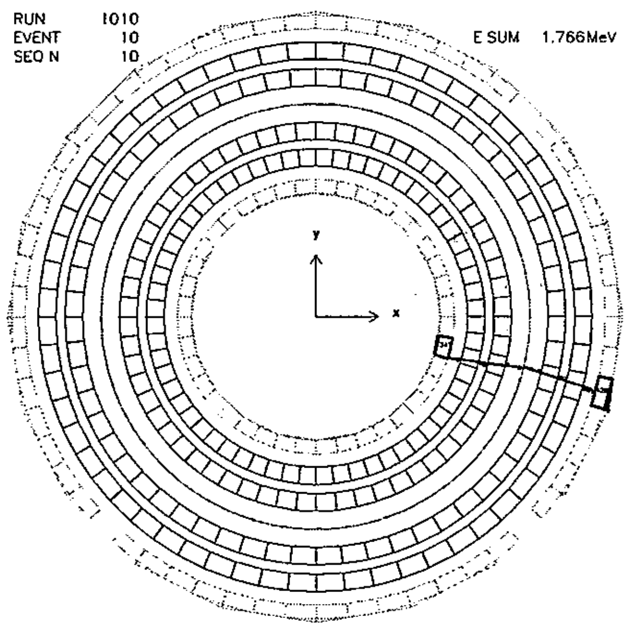
$T_{1/2}$ > 1.10^{24} years

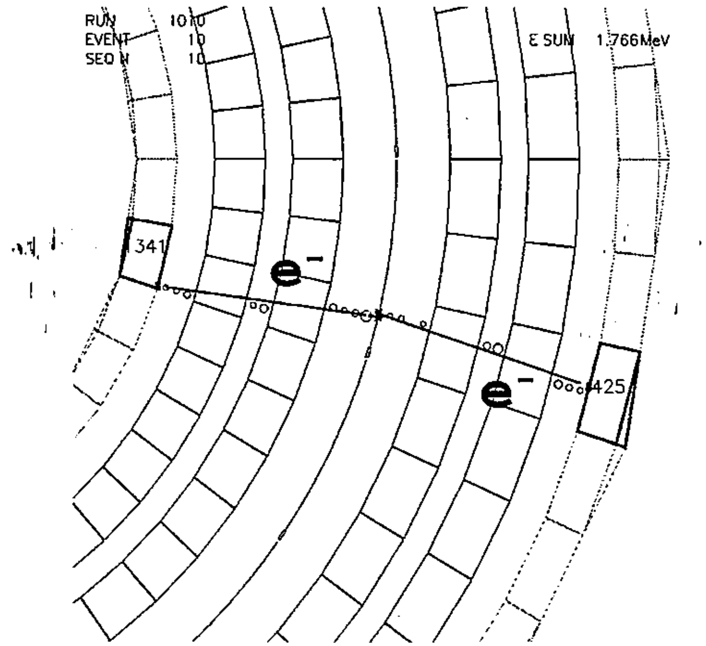
↓

$\langle m_\nu \rangle$ < 0.6 - 1.2 eV

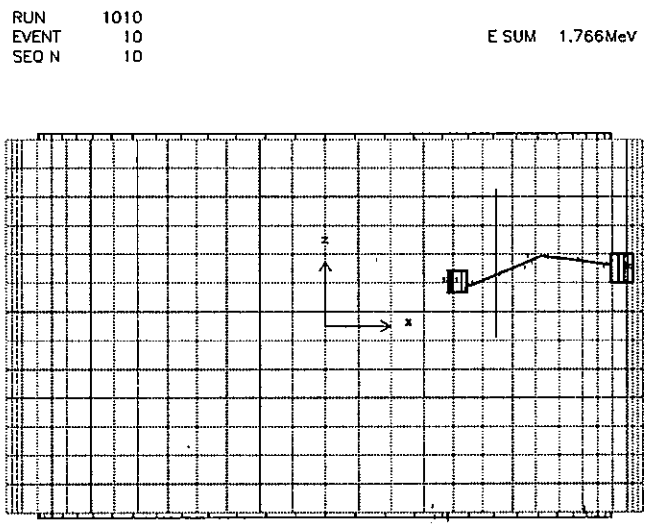
FIRST REAL EVENTS

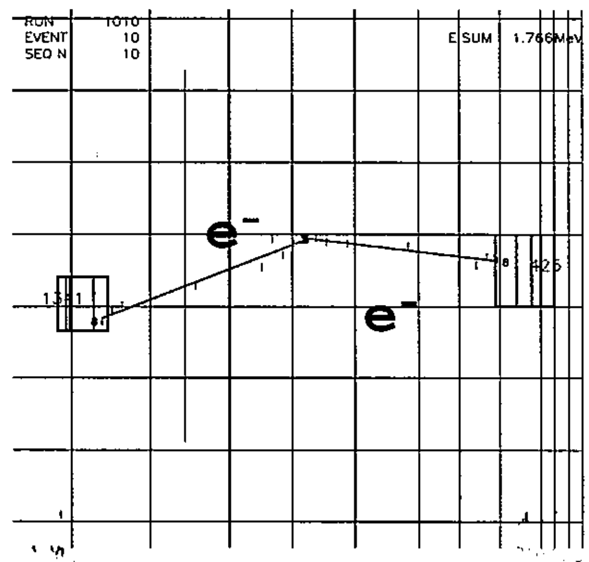
2 e⁻ event





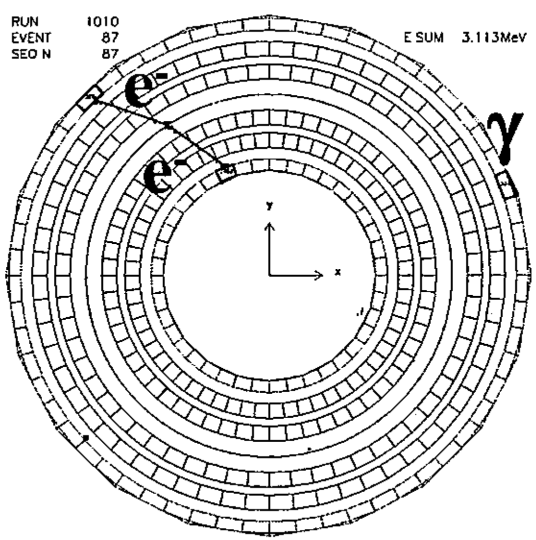
Top view



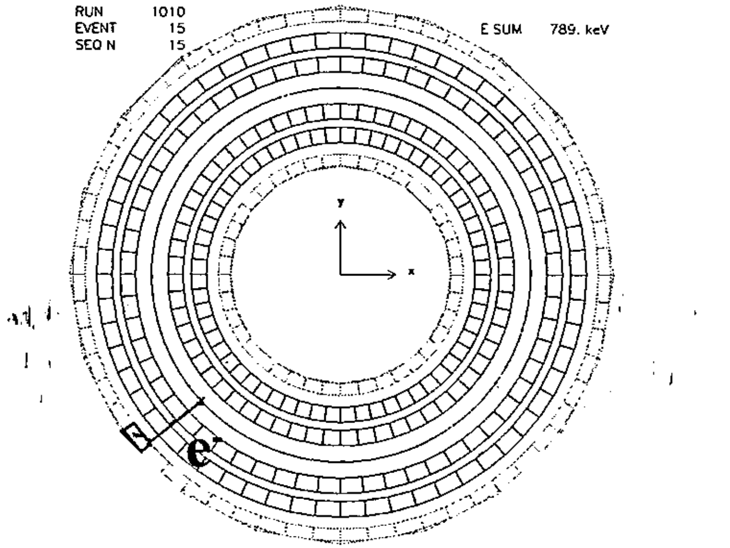


Side view

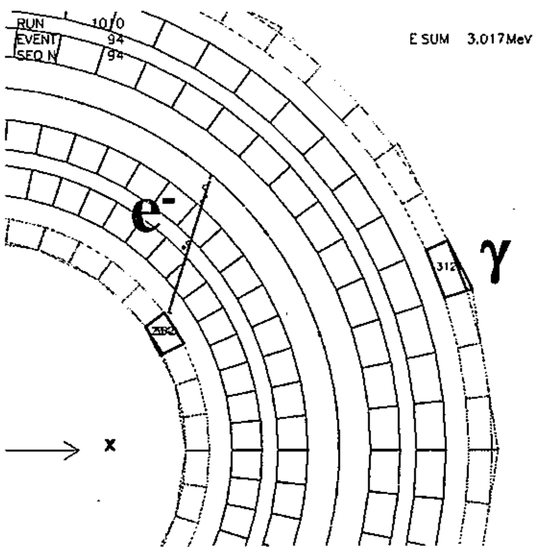
FIRST REAL EVENTS

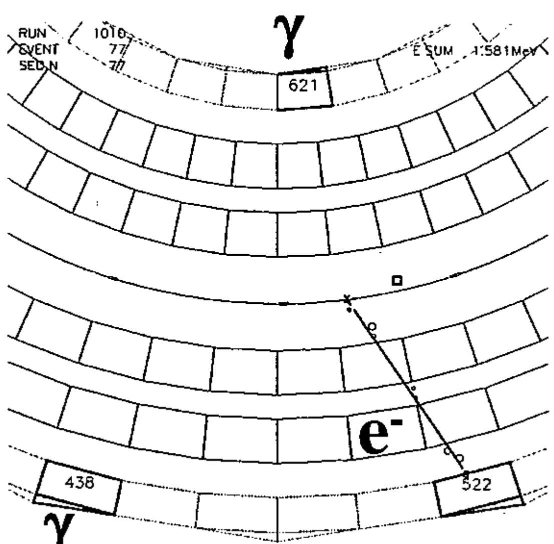


2 e⁻ + γ channel ⟶ ββ excited states



e⁻ channel ⟶ background

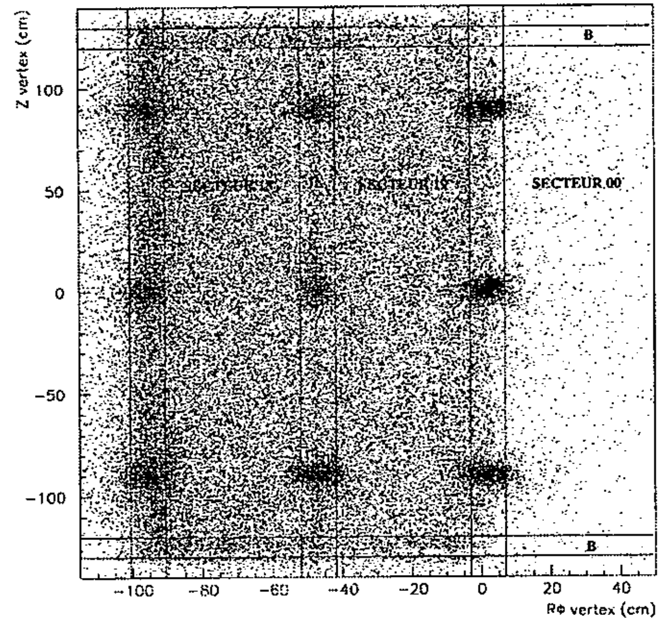


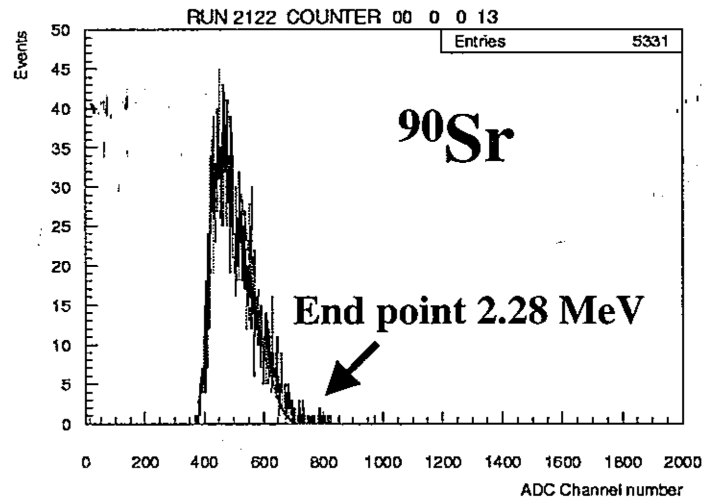


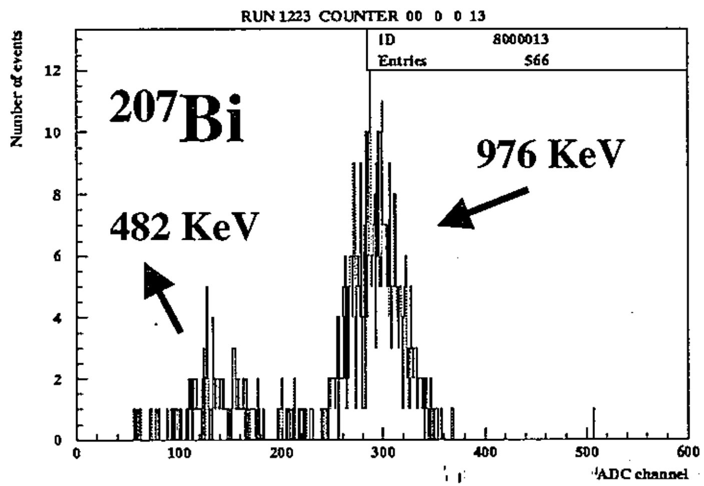
e⁻ + γ channel ⟶ Internal contaminations ⟵ e⁻ + γ γ channel

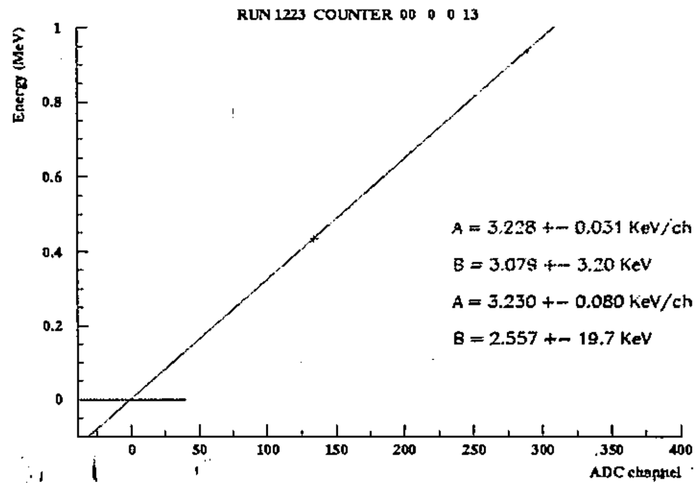
Energy calibration

[redacted]

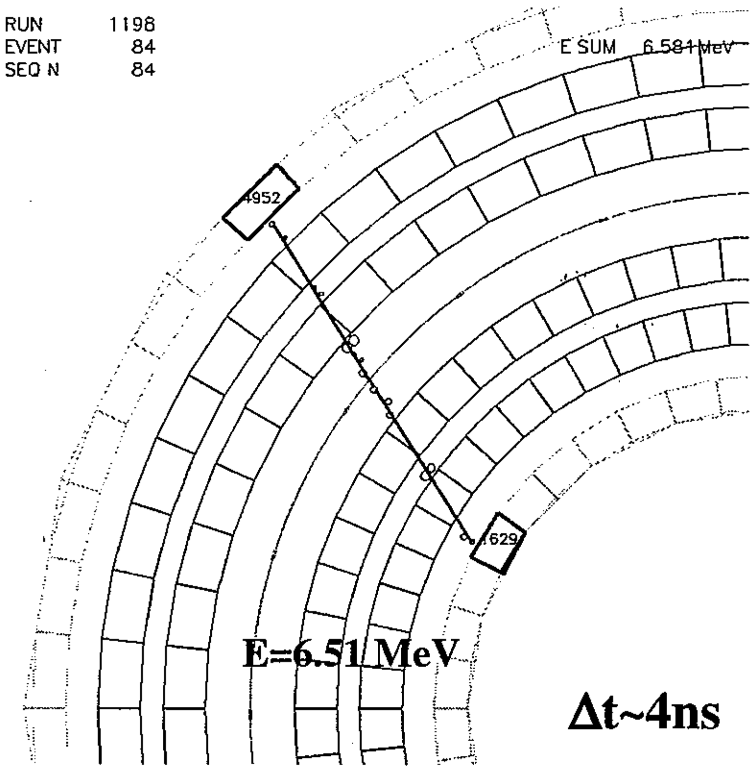






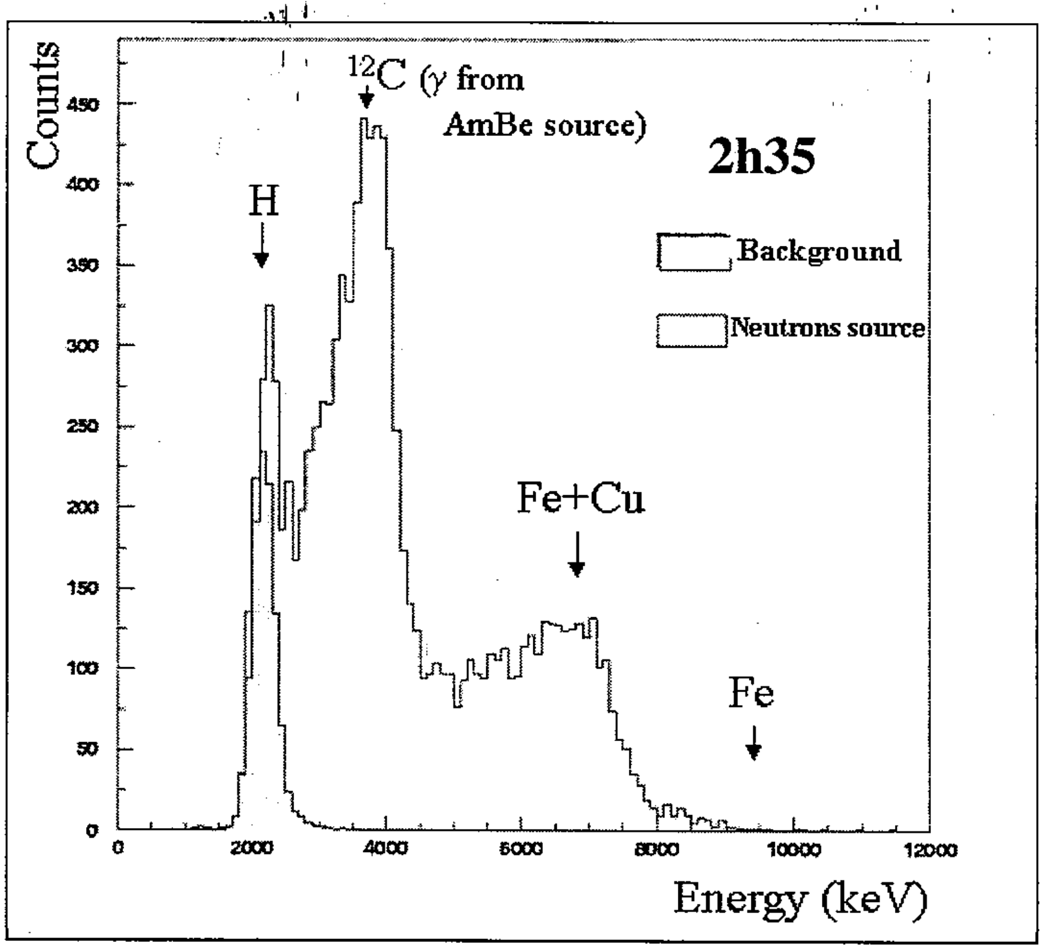


Data with Am-Be neutron source without shielding



Δt~4ns

One-crossing electron channel



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NEMO3 Status

Data taking with Iron shielding ⟶ June

Data taking with all shieldings in June 2002 ⟶ 2007

NEMO 3 sensitivities (few years)

^{208}Tl in source	0.002 mBq/kg (< 0.02 required)
^{214}Bi in source	0.002 mBq/kg (< 0.3 required)
Neutrons	$10^{[illegible]}$ n.cm^{-2}.s^{-1}
$\beta\beta(0\nu)$	few 10^{24} y
$\beta\beta(2\nu)$	few 10^{21} y
$\beta\beta(0\chi)$	few 10^{22} y

Study of the possibility to introduce 20 kg of ^{82}Se or ^{150}Nd in few years to reach ~ 0.1 eV