PLAN

- Introduction to $2\beta0\nu$
- NEMO3
    - description, performances
    - results $2\beta2\nu$
    - results $2\beta0\nu$: data phase 1 1.08 year
    - fight against radon: result
- Prospects: SuperNEMO R&D
- Conclusion

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Why looking for $2\beta0\nu$

1. Proton decay experiments

   Super Kamiokande experiment

   $p \nrightarrow e^+\pi^o$ at a level of 1.6 10^{33} years (5.4 10^{33} y updated)

   $p \nrightarrow \nu\, K^+$ at a level of 6.7 10^{32} years

   robust consequence SU(5) is not the right GUT

2. Neutrino oscillation experiments

   ν_μ beam from accelerator K2K (≈ 1 GeV)

   ν_e, ν_μ atmospheric K and S.K (≈ GeV)

   ν_e from sun, reactors, Davis, Sage, Gallex, S. Kamioka, Chooz, SNO, Kamland (≈ MeV)

   ⇨ $m_\nu \neq 0$ but a tiny mass

   next soon OPERA $\nu_\mu \rightarrow \nu_\tau$?

   miniboone ν_s ?

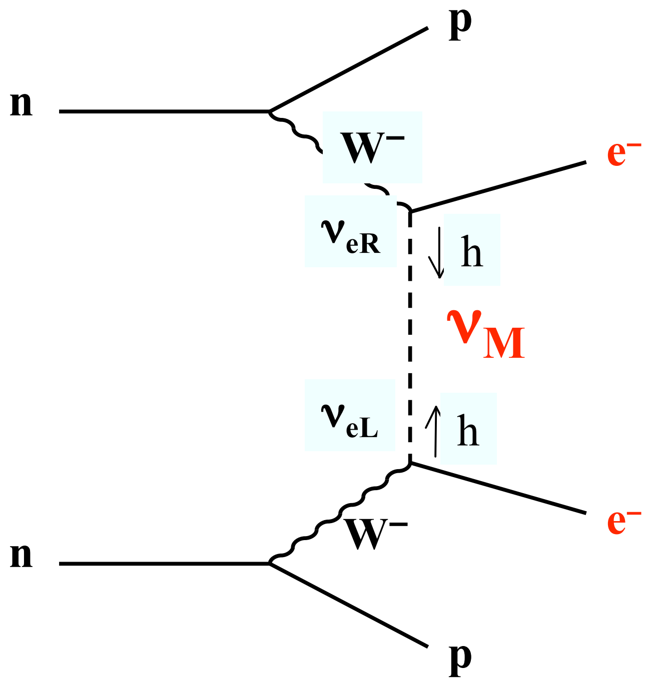
   MINOS ν_μ disappearance

3. If GUT is the line guide then beyond SU5 ν's are ν_M with a tiny mass

   ⇨ $2\beta0\nu$ mass mechanism ?

Double beta ββ(0ν) decay: Physics beyond the standard model

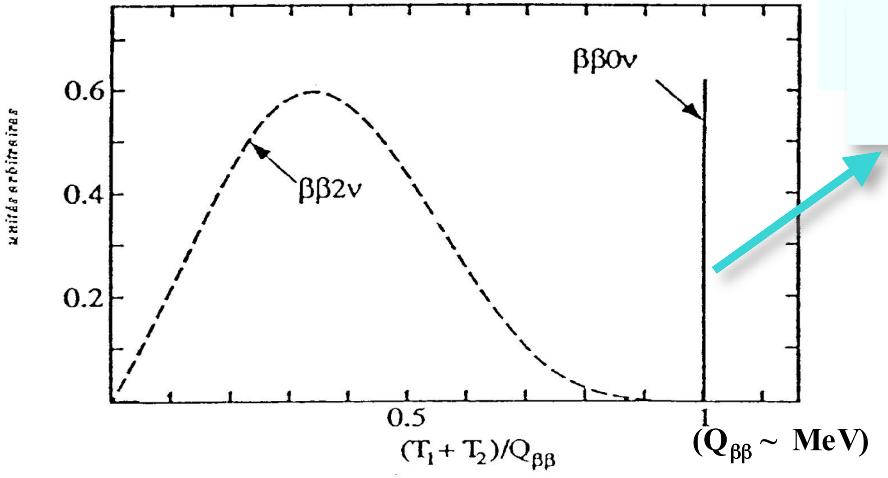
$\beta\beta(0\nu) : 2n \rightarrow 2p+2e^-$



$A=<m>^2 \text{xPSx} \, |M_{\text{Nuc.}}|^2$

ΔL = 2 Process

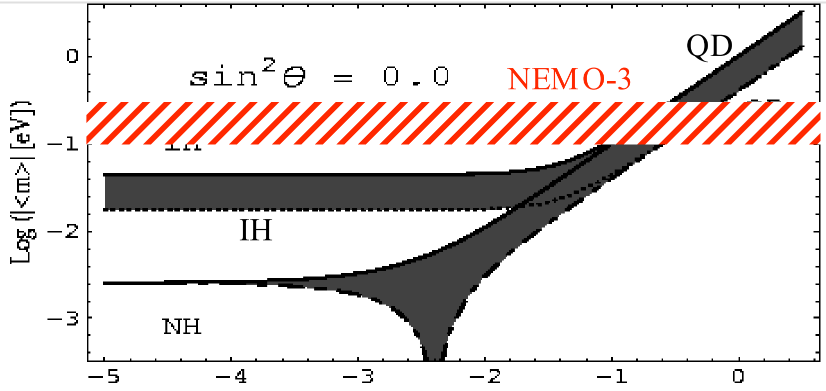
- Majorana Neutrino $\nu = \bar{\nu}$ and effective mass $<m_\nu>$
- Right-handed current in weak interaction
- Majoron emission
- SUSY particle exchange



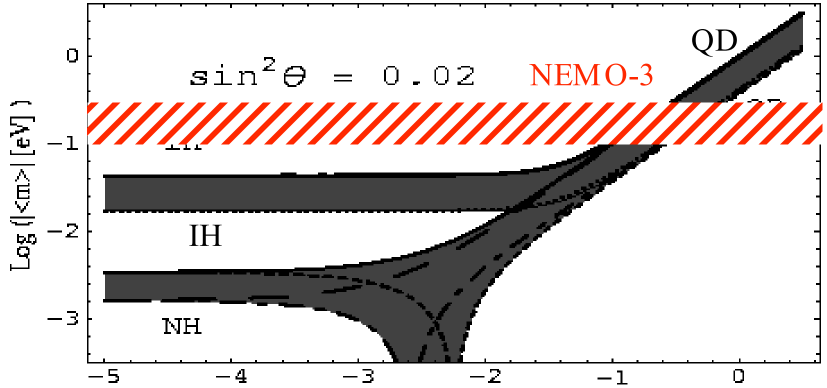
$(T^{0\nu}_{1/2})$

Expected values of $<m_\nu>$ from neutrinos oscillations parameters

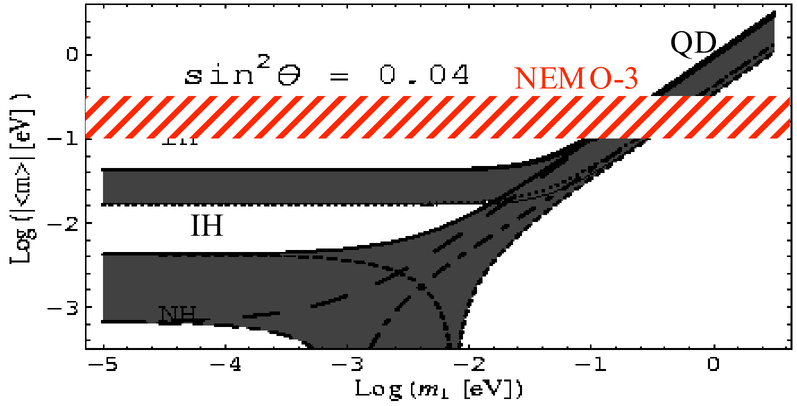
$\sin^2\theta_{13} = 0.0$



$\sin^2\theta_{13} = 0.02$



$\sin^2\theta_{13} = 0.04$



$$<m_\nu> = \sum_{1}^{3} m_i \, U^2_{ei} \, e^{i\alpha j}$$

Pascoli and Petcov, hep-ph/0310003
(best fit $\nu_{atm} + \nu_{sol}$)

Quasi-Degenerate (QD):

$<m_\nu> > 50$ meV

Inverted Hierarchy (IH):

15 meV $< \; <m_\nu> \; <$ 50 meV

Normal Hierarchy (NH):

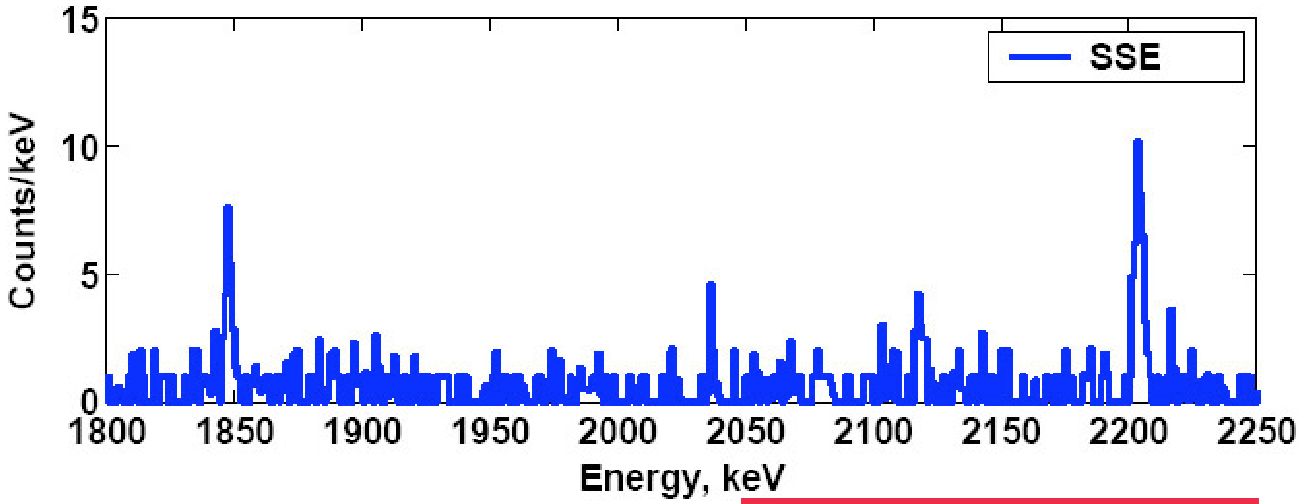
$<m_\nu> \; < 5$ meV

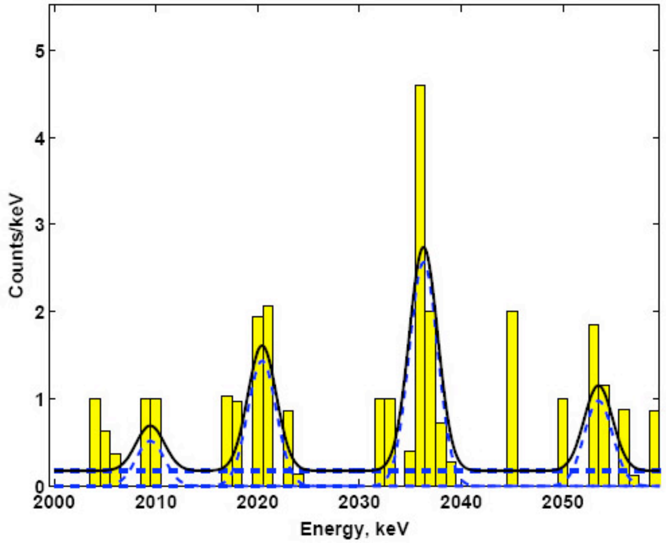
2β could give the absolute neutrino mass

Present limits for different isotopes: direct measurements

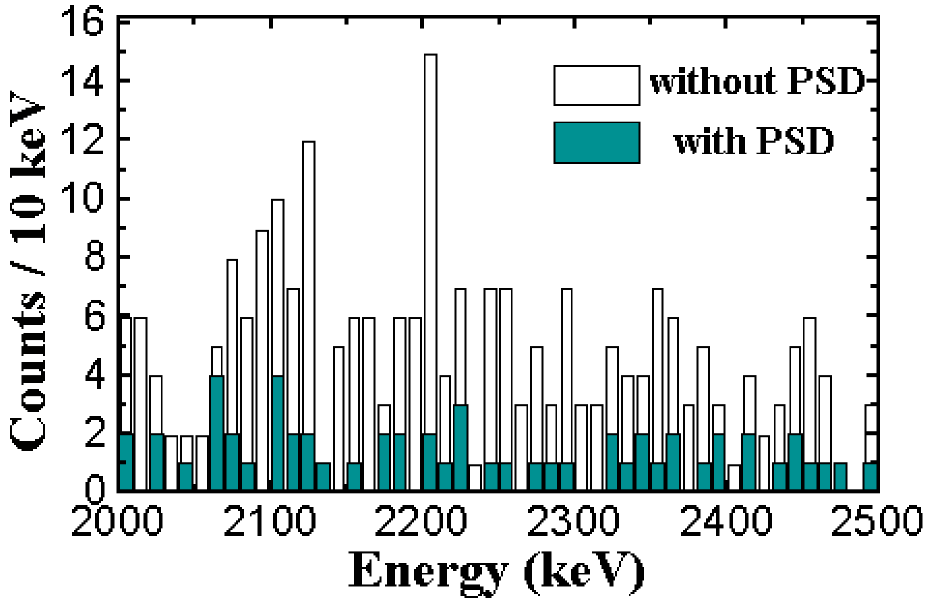
Isotope	$T_{1/2}$(90%CL)(y)	$<m_\nu>$(eV)	Mass (kg.y)	Experiment
^{48}Ca	$> 1.8\ 10^{22}$	< 6.3 - 39.4	0.005	Candle
^{76}Ge	$> 1.9\ 10^{25}$	< 0.35 - 1.05	35.5	Heidelberg-Moscou
^{76}Ge	$> 1.57\ 10^{25}$	< 0.3 - 1.1	8.9	IGEX
^{82}Se	$> 1.9\ 10^{23}$	< 1.3 - 3.6	0.9	NEMO3
^{96}Zr	$> 1.0\ 10^{21}$	< 2.3	0.008	NEMO2
^{100}Mo	$> 3.5\ 10^{23}$	< 0.7 - 1.2	7.5	NEMO3
^{116}Cd	$> 1.3\ 10^{23}$	< 1.7	0.16	Solotvina
^{130}Te	$> 1.8\ 10^{24}$	< 0.2 - 1.1	10.8	CUORICINO
^{136}Xe	$> 4.4\ 10^{23}$	< 2 - 3	2.3	Gotthard
^{150}Nd	$> 1.2\ 10^{21}$	< 3	0.009	TPC M.Moe

H.V. Klapdor-Kleingrothaus et al. I Nuclear Instruments and Methods in Physics Research A 522 (2004) 371-406



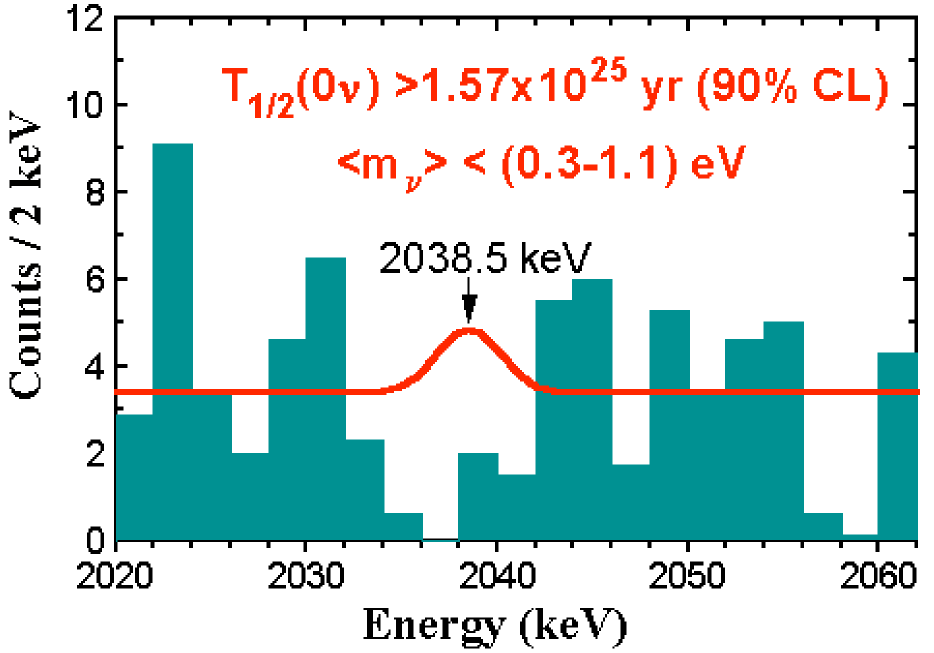


IGEX experiment



116.75 mole.years - 8.87 kg.y in ^{76}Ge

116.75 mole.years - 8.87 kg.y in ^{76}Ge



Running experiments
For mass ≈ 10 kg

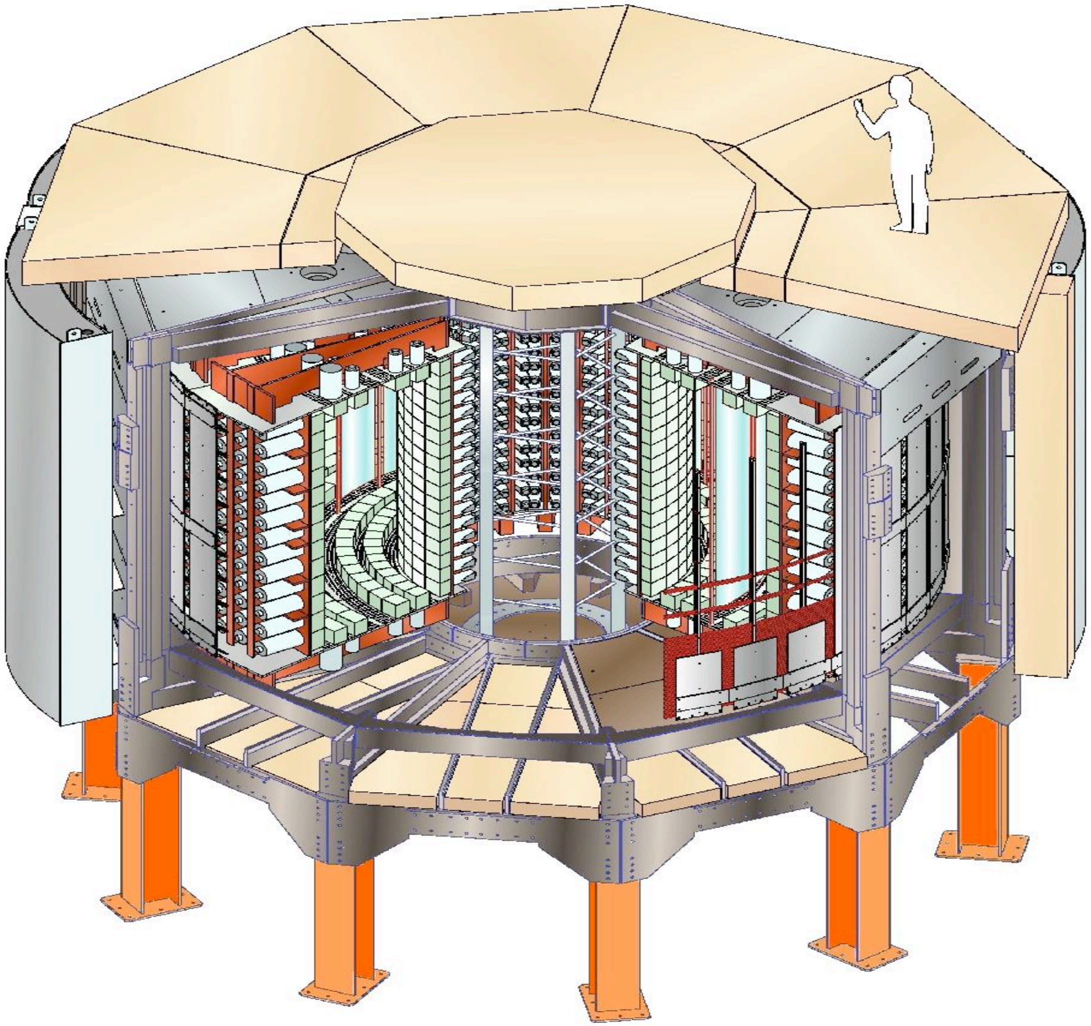
Experiment	isotope	Mass (kg)	Type of detector	Lab.	Expected back-ground (counts/ FWHM .kg.y)	Sensitivity $T_{1/2}$ (y)	Limit $<m_{\nu}>$ (eV)
CUORICINO	^{130}Te	11	Bolometer	Gran Sasso (Italie)	0.5	7×10^{24}	0.3
NEMO3	^{100}Mo ^{82}Se	6.9 0.93	Tracko-Calo	Modane (France)	0.3 0.1	4×10^{24} 8×10^{23}	0.20-0.35 0.65-1.8

NEMO3 Collaboration

CENBG, IN2P3-CNRS Bordeaux University, **France**
Charles University, Praha, **Czech Republic**
CTU, Praha, **Czech Republic**
INEL, Idaho Falls, **USA**
INR, Moscow, **Russia**
IReS, IN2P3-CNRS Strasbourg University, **France**
ITEP, Moscou, **Russia**
JINR, Dubna, **Russia**
Jyvaskyla University, Finland
LAL, IN2P3-CNRS Paris-Sud University, **France**
LSCE, CNRS Gif sur Yvette, **France**
LPC, IN2P3-CNRS Caen University, **France**
Manchester University, Great-Britain
Mount Holyoke College, USA
RRC kurchatov Institute, Moscow, **Russia**
Saga university, Saga, **Japon**
UCL, London, **Great-Britain**

The NEMO3 detector

Fréjus Underground Laboratory : 4800 m.w.e.



Source: 10 kg of ββ isotopes

cylindrical, S = 20 m^2, e ~ 60 mg/cm^2

Tracking detector:

drift wire chamber operating in Geiger mode (6180 cells)

Gas: He + 4% ethyl alcohol + 1% Ar + 0.1% H_2O

Calorimeter:

1940 plastic scintillators
coupled to low radioactivity PMTs

Magnetic field: 25 Gauss
Gamma shield: Pure Iron (e = 18 cm)
Neutron shield: 30 cm water (ext. wall)
40 cm wood (top and bottom)
(since march 2004: water + boron)

⇨ **Able to identify e$^-$, e$^+$, γ and α**

Cathodic rings
Wire chamber

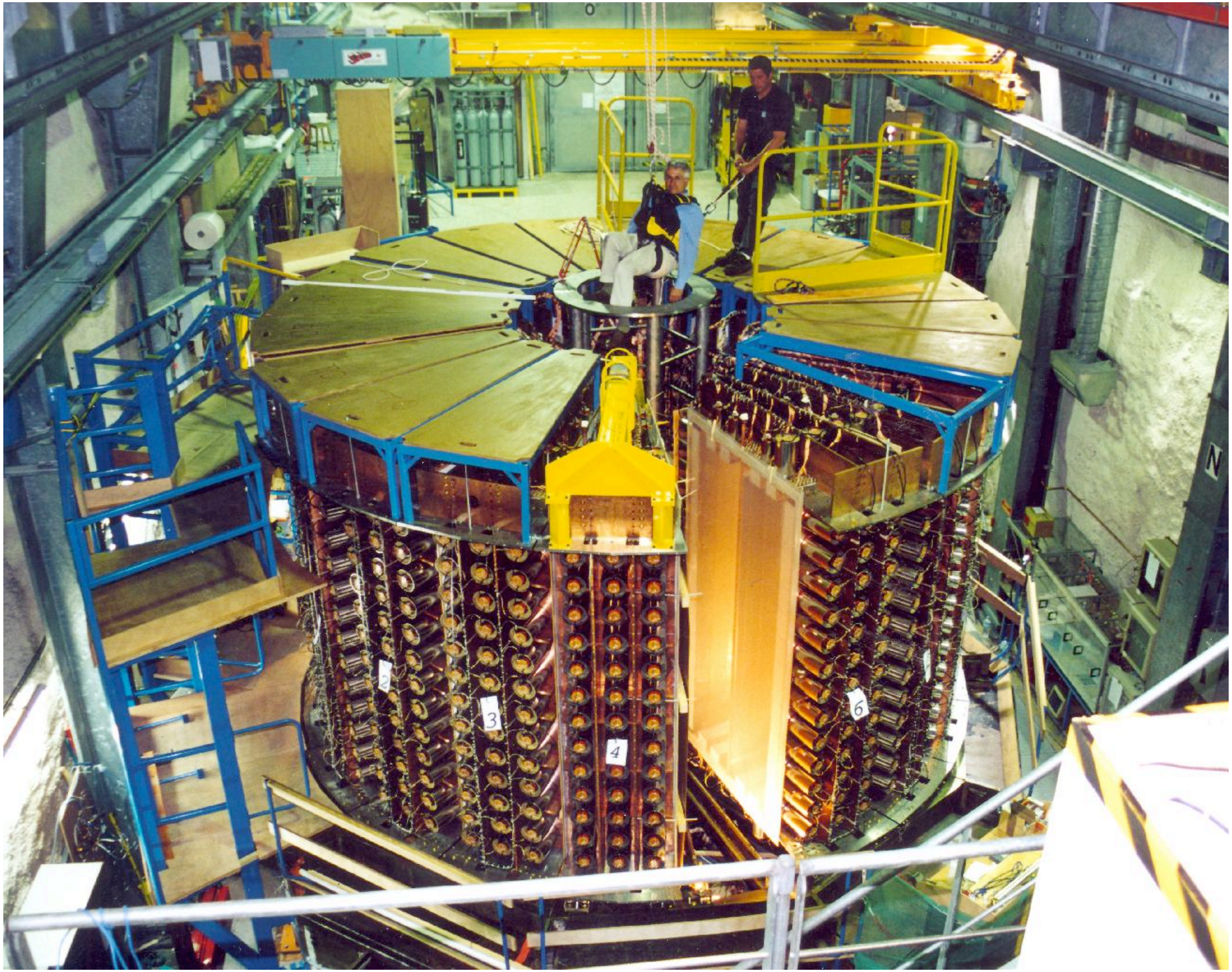
PMTs

Calibration tube

scintillators

ββ isotope foils

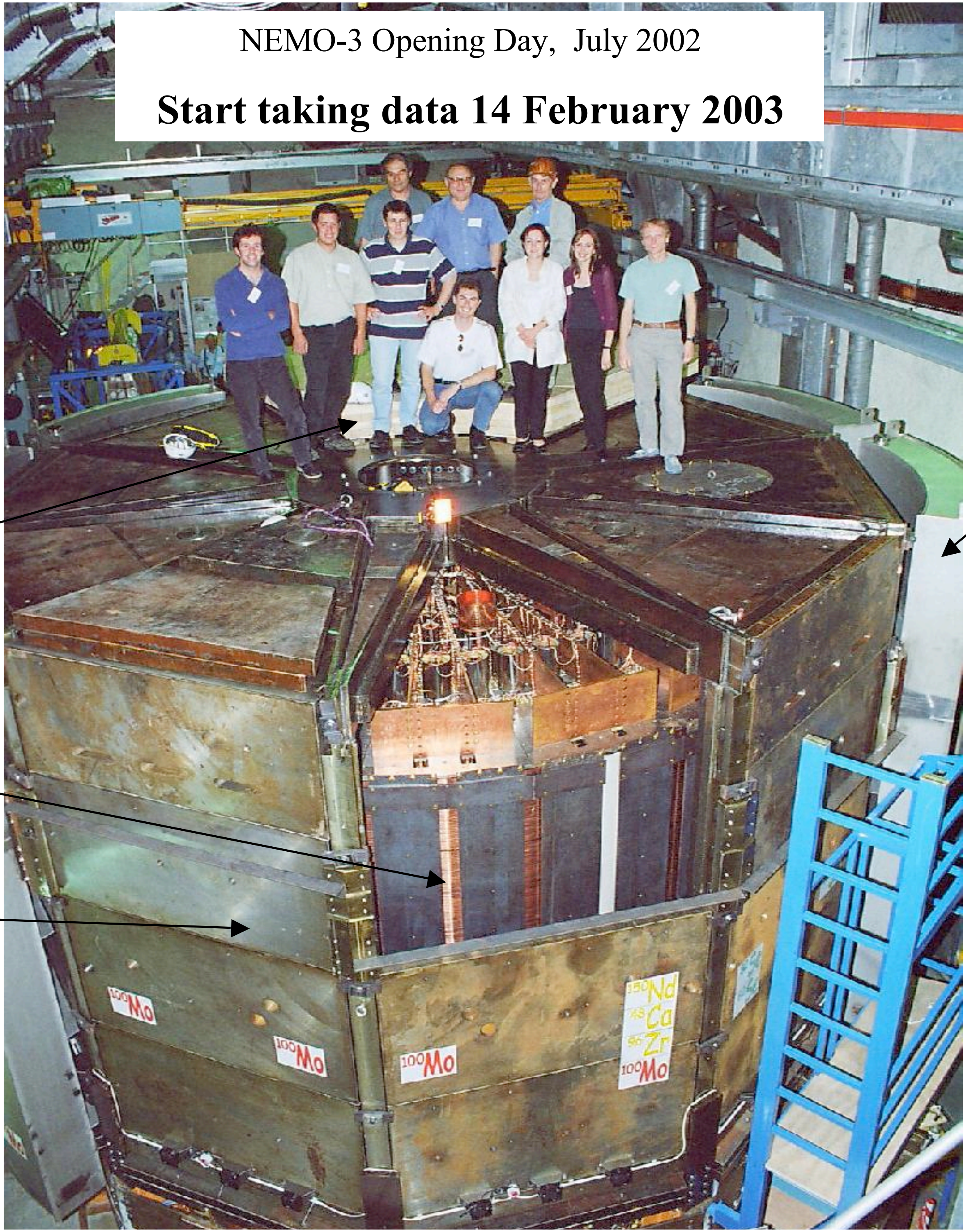
Sources preparation



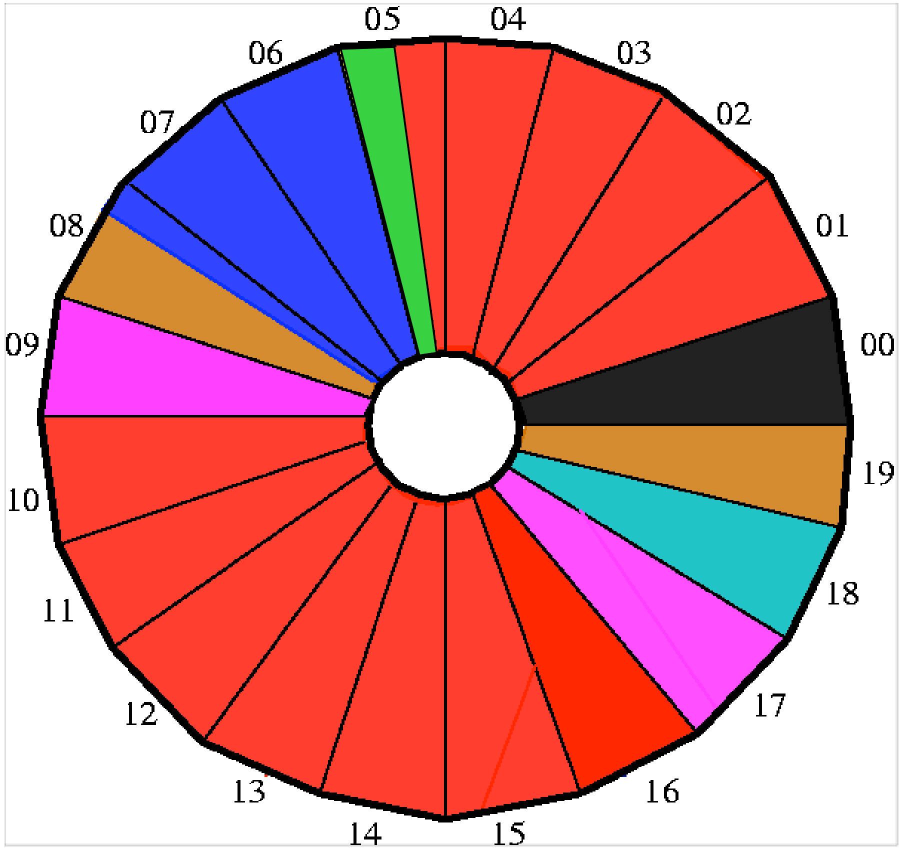
AUGUST 2001

NEMO-3 Opening Day, July 2002

Start taking data 14 February 2003



ββ decay isotopes in NEMO-3 detector



^{100}Mo 6.914 kg

$Q_{\beta\beta}$ = 3034 keV

^{82}Se 0.932 kg

$Q_{\beta\beta}$ = 2995 keV

ββ0ν search

ββ2ν measurement

^{116}Cd 405 g

$Q_{\beta\beta}$ = 2805 keV

^{96}Zr 9.4 g

$Q_{\beta\beta}$ = 3350 keV

^{150}Nd 37.0 g

$Q_{\beta\beta}$ = 3367 keV

^{48}Ca 7.0 g

$Q_{\beta\beta}$ = 4272 keV

^{130}Te 454 g

$Q_{\beta\beta}$ = 2529 keV

^{nat}Te 491 g

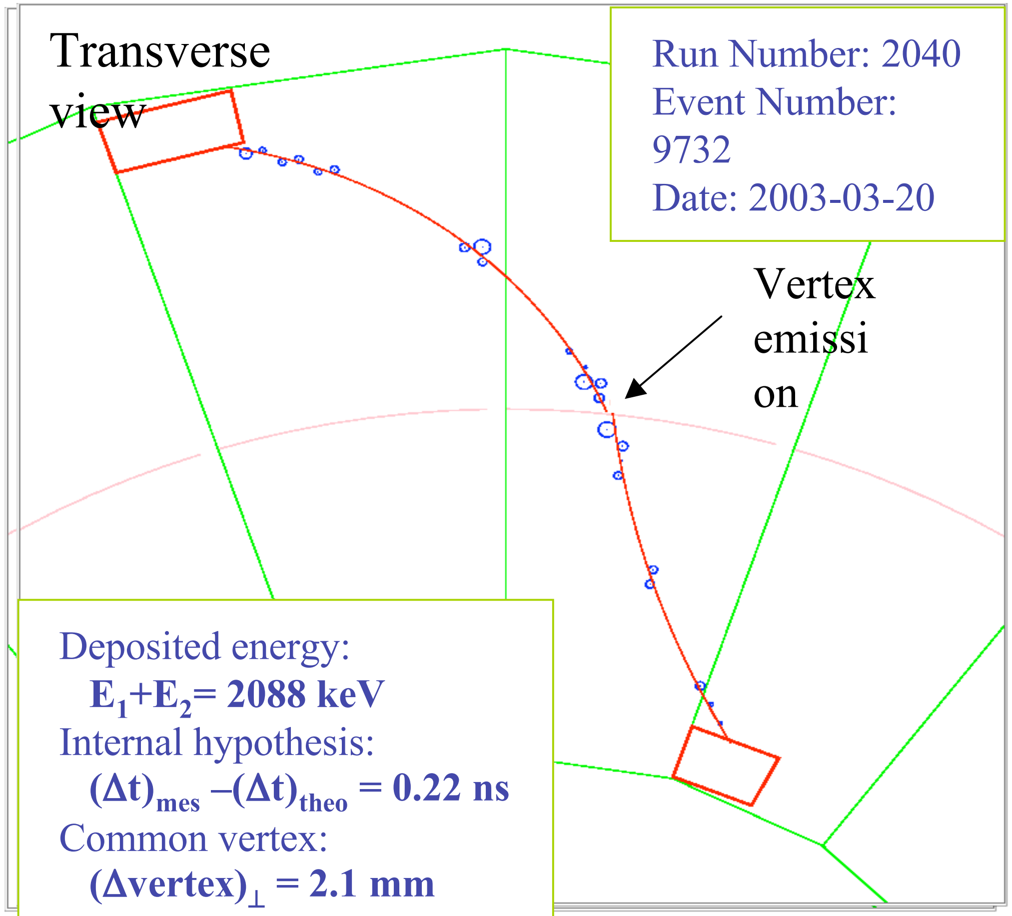
Cu 621 g

External bkg measurement

(All the enriched isotopes produced in Russia)

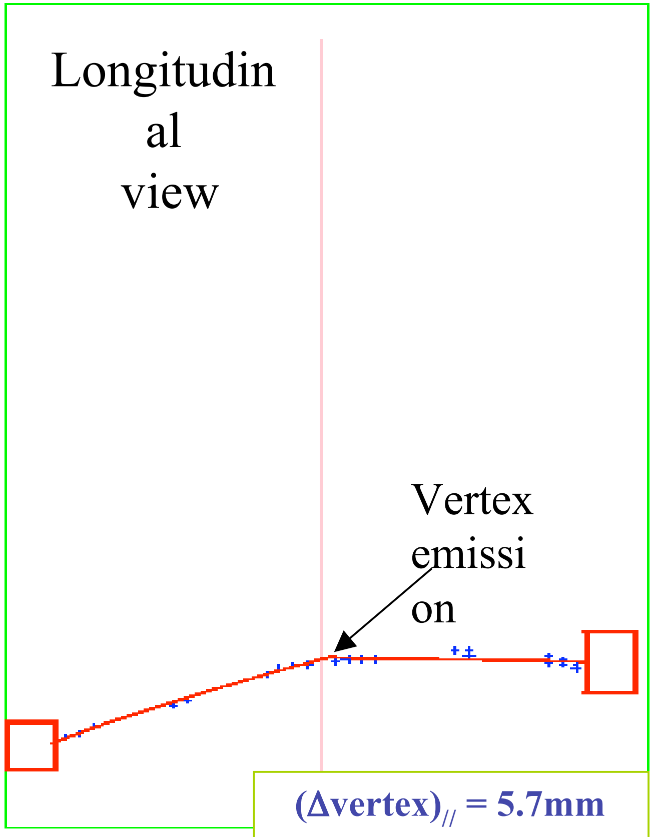
ββ events selection in NEMO-3

Typical ββ2ν event observed from ^{100}Mo



Run Number: 2040
Event Number: 9732
Date: 2003-03-20

Deposited energy:
E_1+E_2= 2088 keV
Internal hypothesis:
$(\Delta t)_{mes} - (\Delta t)_{theo}$ = 0.22 ns
Common vertex:
$(\Delta \text{vertex})_\perp$ = 2.1 mm



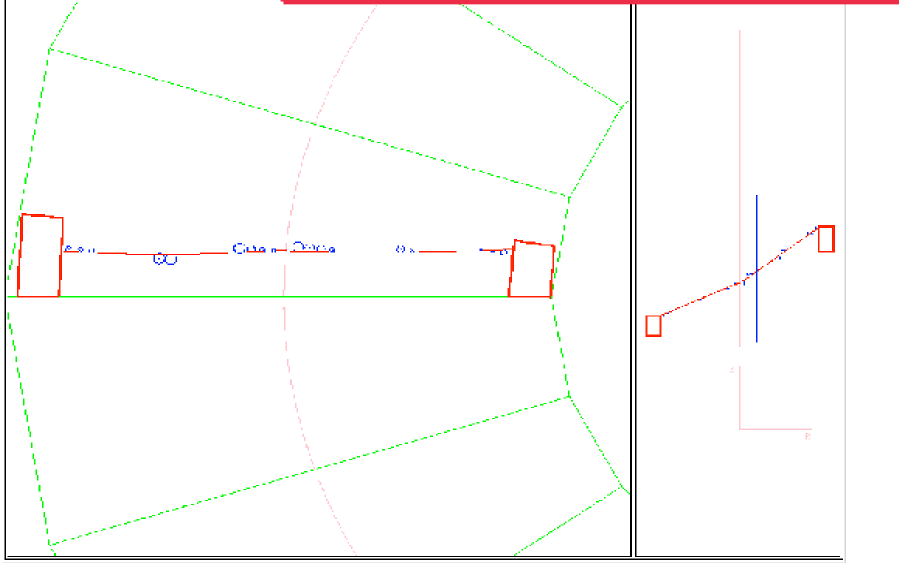
$(\Delta \text{vertex})_{//}$ = 5.7mm

Trigger: 1 PMT > 150 keV
3 Geiger hits (2 neighbour layers + 1)

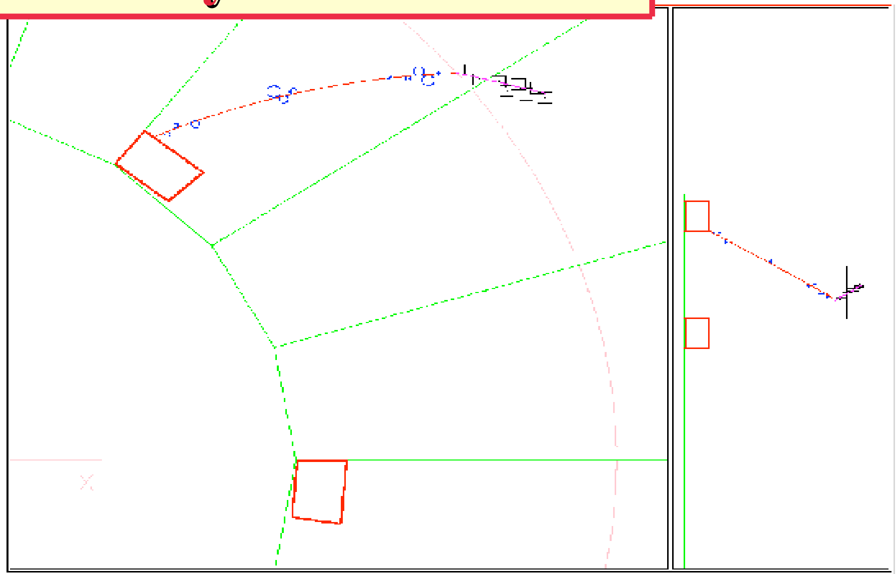
Trigger rate = 7 Hz

ββ events: 1 event every 1.5 minutes

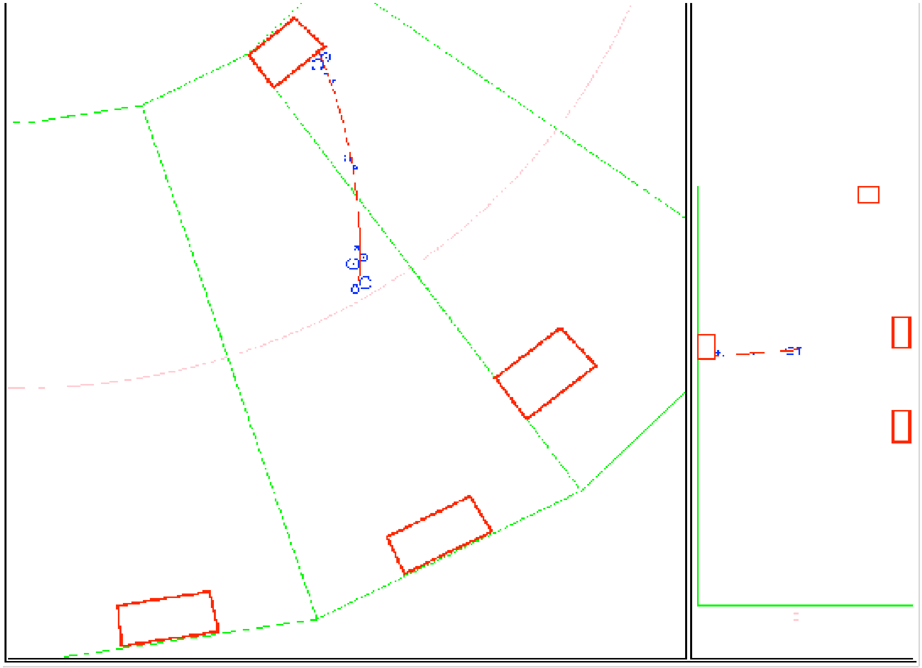
Background events observed by NEMO-3…



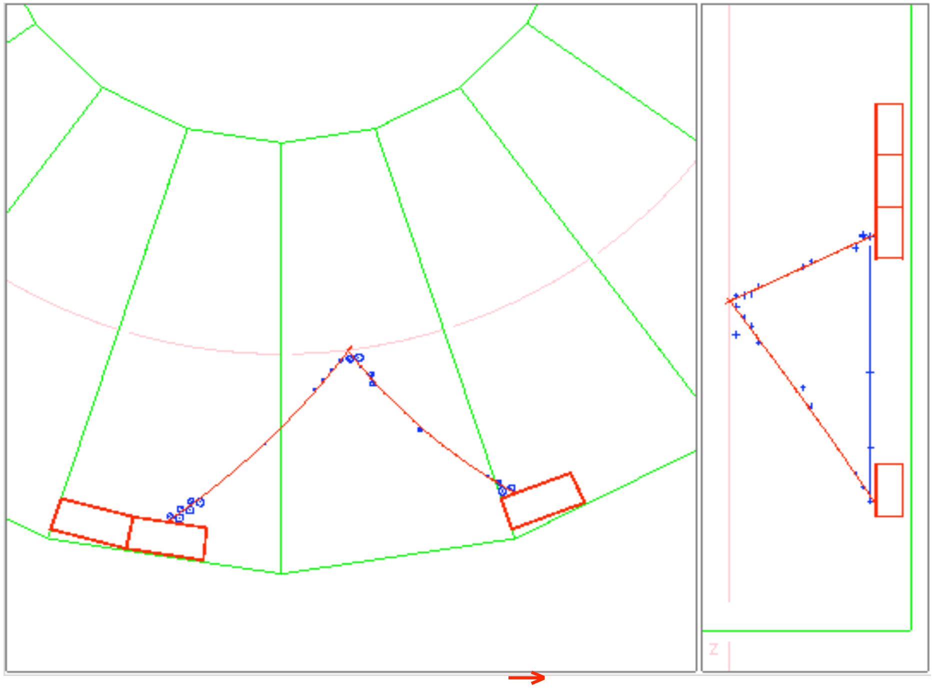
Electron crossing > 4 MeV **Neutron capture**



Electron + α delay track (164 μs) **^{214}Bi → ^{214}Po → ^{210}Pb**



Electron + N γ's **^{208}Tl (Eγ = 2.6 MeV)**



Electron – positron pair **$\vec{B}$ rejection**

NEMO3: detector performances
RUN with radioactive sources

- energy calibration : absolute

  ^{207}Bi $2e^-$ lines $\approx 0.5 \approx 1$ MeV

  ^{90}Sr β^- end point ≈ 2.2 MeV

- time of flight

  ^{60}Co γ_1, γ_2 2 lines ≈ 1.5 MeV

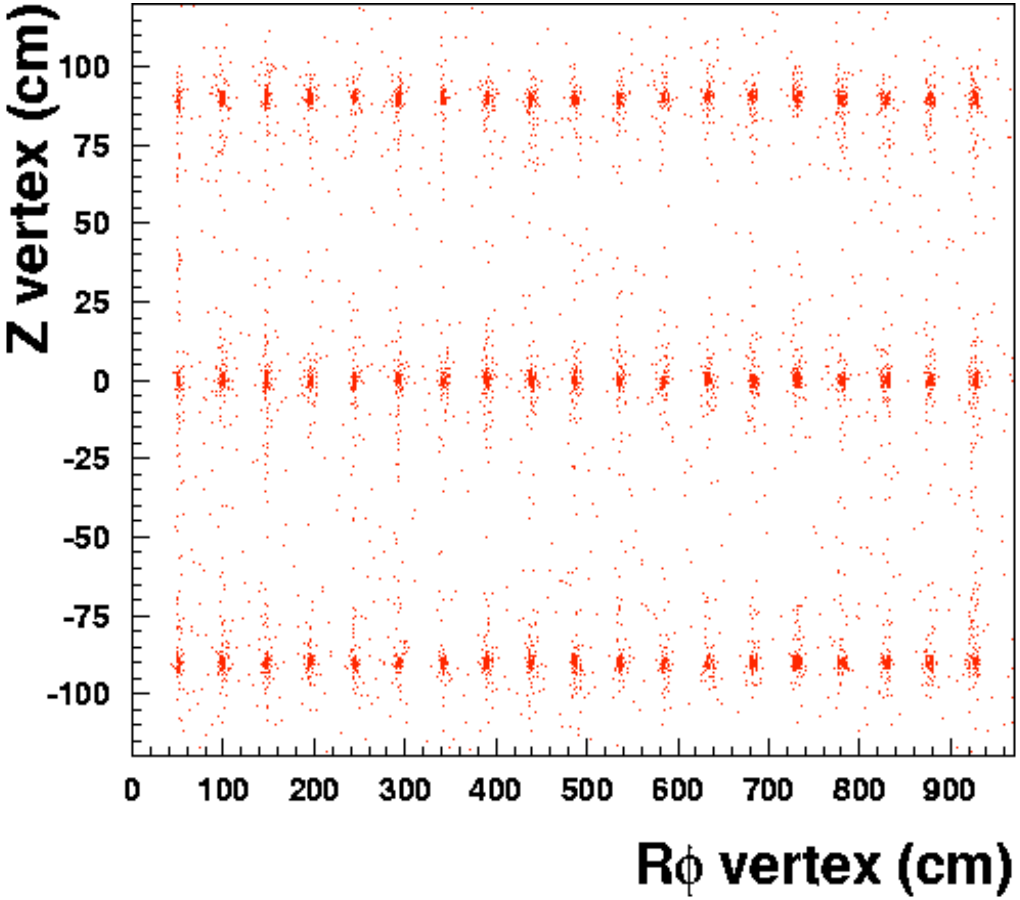
- tracking detector: $\sigma_T, \sigma_{//}$

  neutron source ⇒ (n,γ) ⇒ $e^- > 4.5$ MeV

- aging? absolute calibration ^{207}Bi during 2 years

Transversal and Longitudinal Resolution on the Vertex

^{207}Bi sources at 3 well known positions in each sector
(emission of two e- conversion at ≈ 1 and 0.5 MeV)

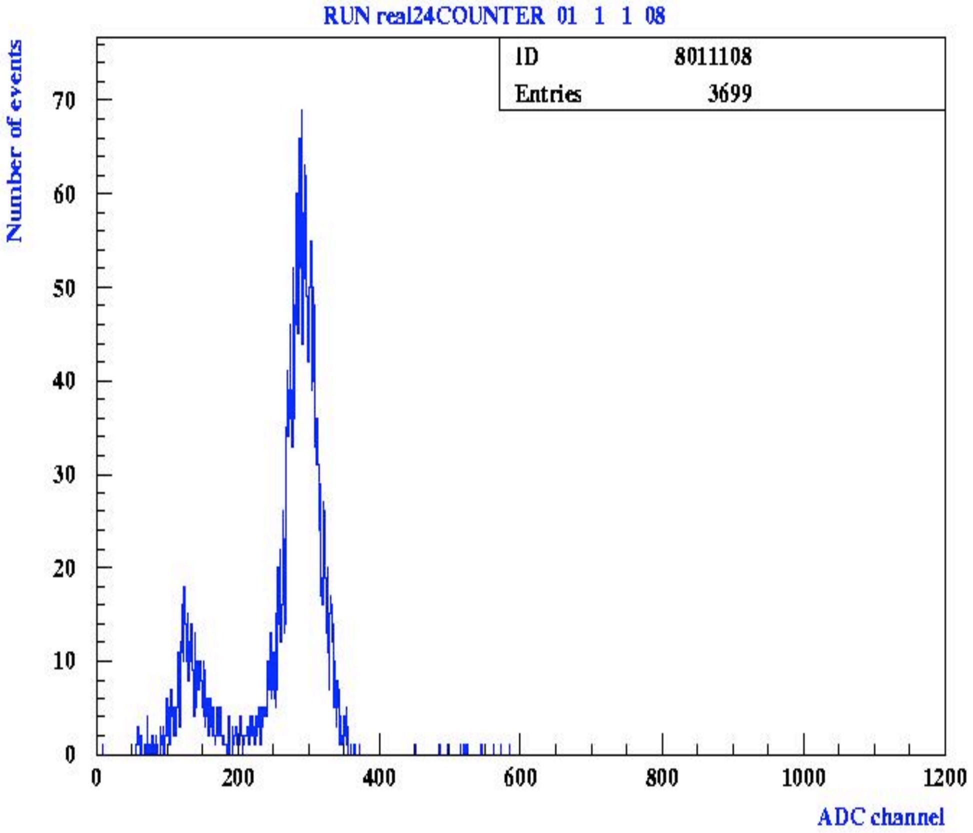


1 e^- channel at 1 Mev:
$\sigma_\perp$ (1 MeV) = 0.25 cm
$\sigma_{//}$ (1 MeV) = 0.95 cm (Z=0)

2e- channel (1 MeV+ 0.5 MeV)
$\sigma_\perp$ (1 MeV) = 0.6 cm
$\sigma_{//}$ (1 MeV) = 1.3 cm (Z=0)

Performances of the calorimeter

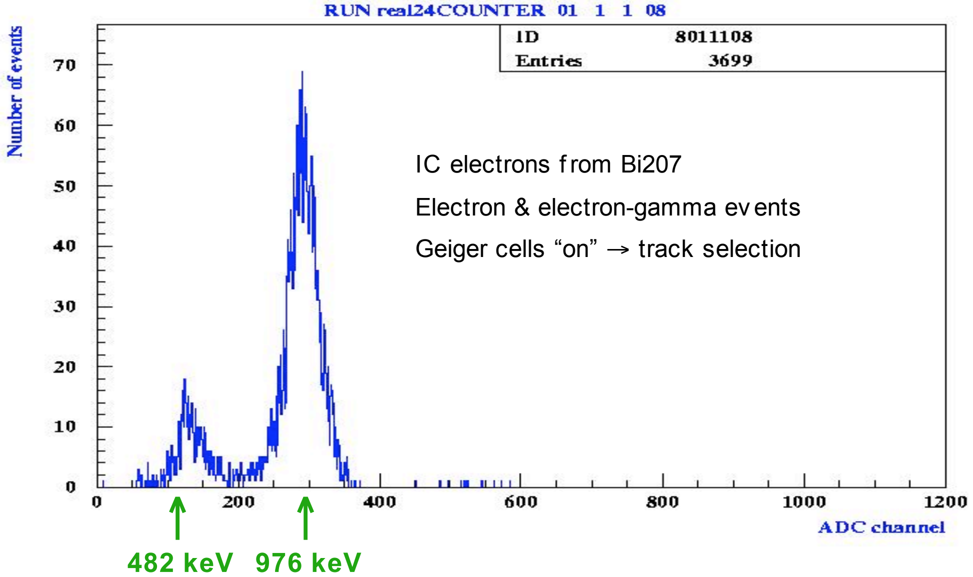
Tube in each sector where calibration sources are introduced (3 positions)
3 electron energies : 486 keV and 976 keV with ^{207}Bi, and 2.28 MeV with ^{90}Sr



At 1 MeV ($Q_{\beta\beta} \approx 3$ MeV for ^{100}Mo and ^{82}Se):

	FWHM	σ_E/E
Ext.Wall (PMTs 5")	14 %	5.8 % $/\sqrt{E(\text{MeV})}$
Int. Wall (PMTs 3")	17 %	7.1 % $/\sqrt{E(\text{MeV})}$

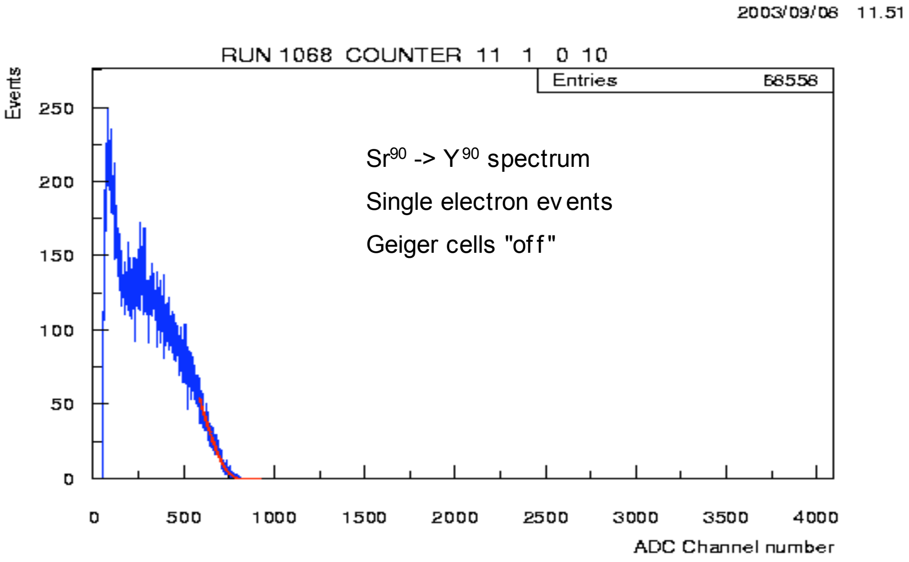
Absolute calibration: method



IC electrons from Bi207

Electron & electron-gamma events

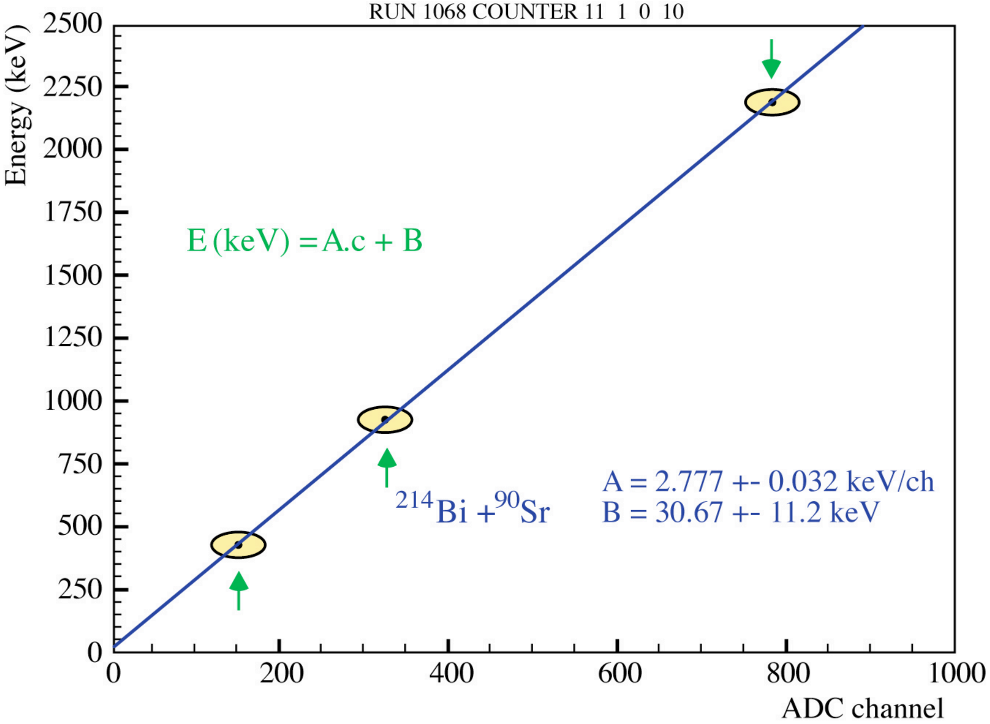
Geiger cells "on" → track selection



Sr^{90} -> Y^{90} spectrum

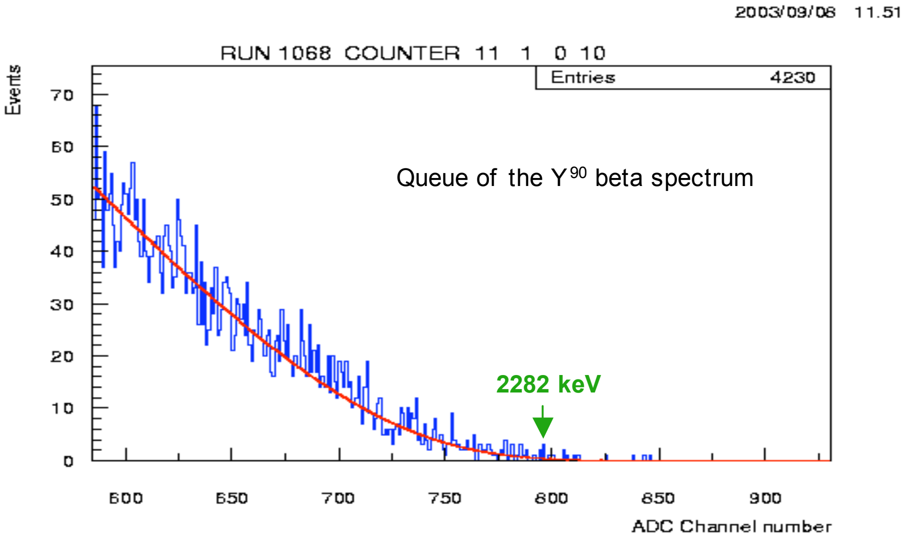
Single electron events

Geiger cells "off"



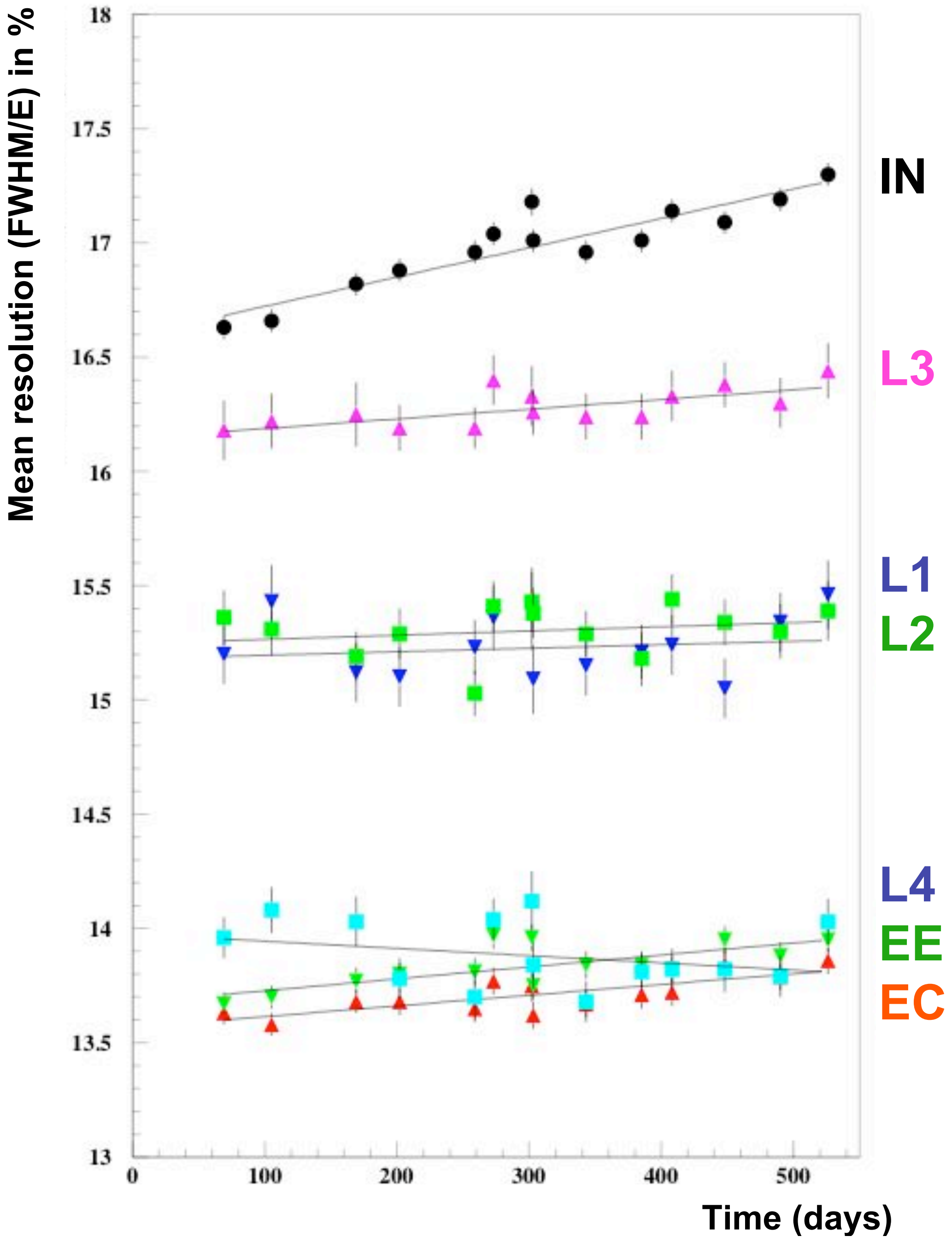
E (keV) = A.c + B

A = 2.777 +- 0.032 keV/ch
B = 30.67 +- 11.2 keV

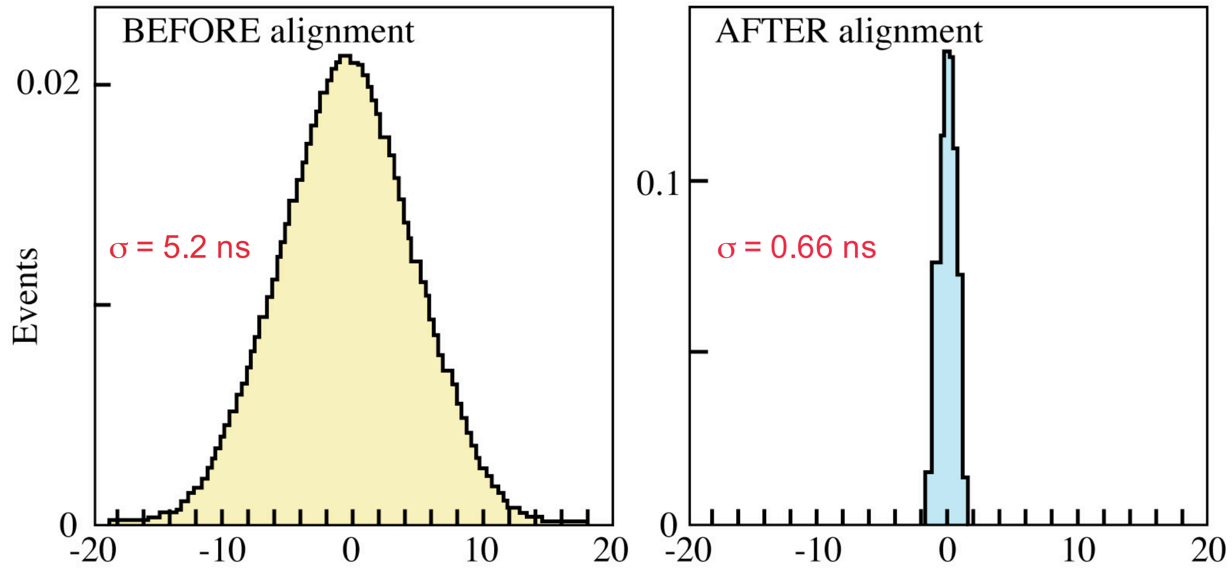


Queue of the Y^{90} beta spectrum

Aging measurements



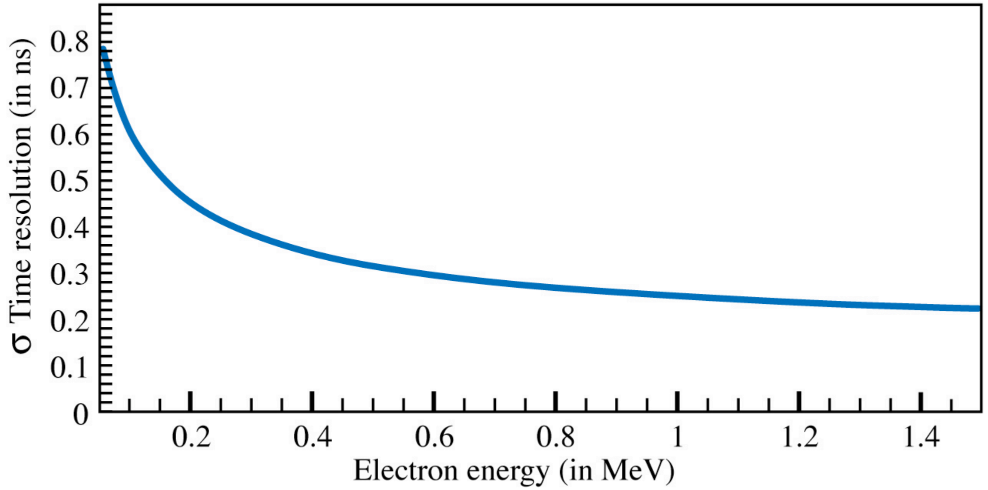
^{60}Co run: alignment of the 1940 units calo



Difference between measured and calculated times (in ns)

^{60}Co source

Υ_1 Υ_2



Time resolution (in ns) as a function of the electron energy (in MeV), obtained with two-electron events

Performance of the detector

Tracking Detector:

- **99.5 % Geiger cells ON**
- **Vertex resolution**:

2 e^- channels (482 and 976 keV) using ^{207}Bi sources at 3 well known positions in each sector

$\sigma_\perp$ **(ΔVertex) = 0.6 cm**

$\sigma_{//}$ **(ΔVertex) = 1.3 cm** (Z=0)

- **e^+/e^- separation** with a magnetic field of 25 G

~ 3% confusion at 1 MeV

Calorimeter:

- **97% of the PMTs+scintillators are ON**
- **Energy Resolution**:

calibration runs (every ~ 40 days) with ^{207}Bi sources

	Ext. Wall 5" PMTs	Int.Wall 3" PMTs
FWHM (1 MeV)	**14%**	**17%**

- **Daily Laser Survey** to control gain stability of each PM

Time Of Flight:

- **Time Resolution** ($\beta\beta$ channel) ≈ **250 ps at 1 MeV**

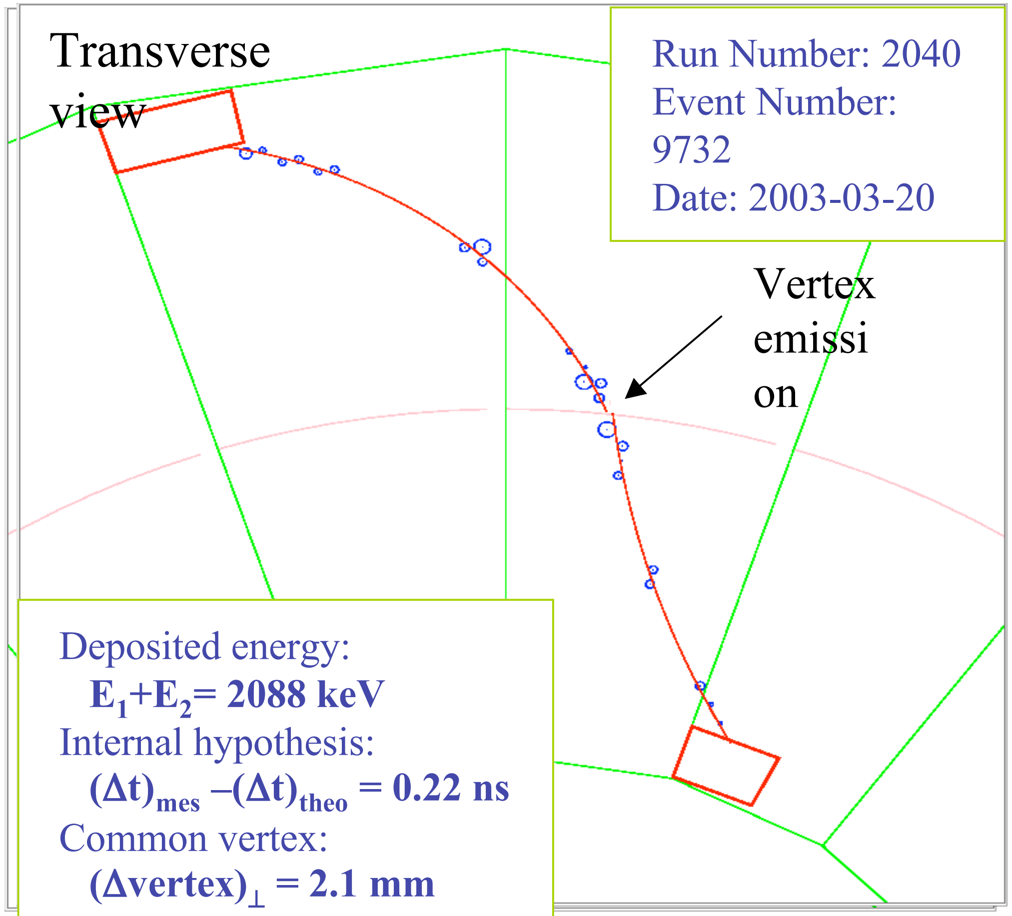
ToF (external crossing e^-) > 3 ns

external crossing e^- totaly rejected

Expected Performance of the detector has been reached

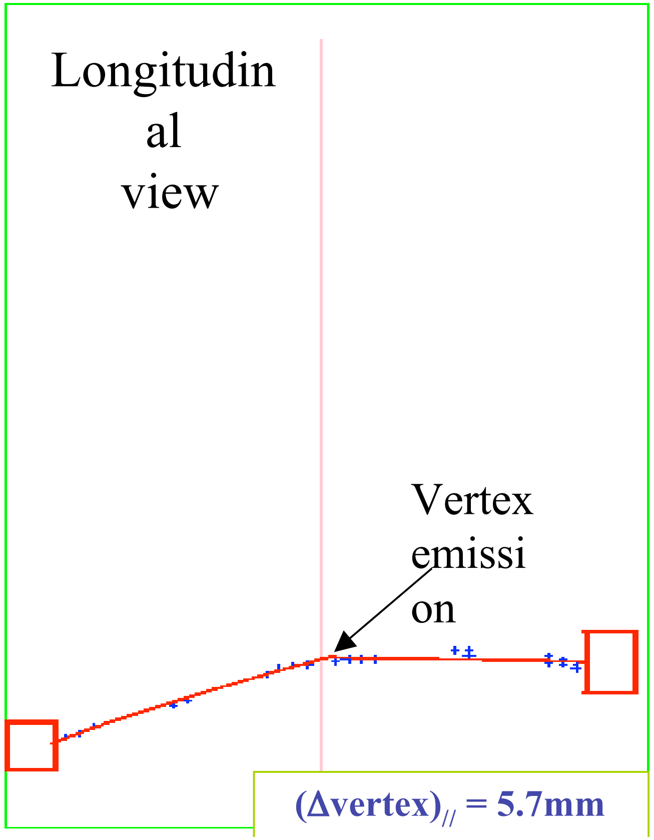
ββ events selection in NEMO-3

Typical ββ2ν event observed from ^{100}Mo



Run Number: 2040
Event Number: 9732
Date: 2003-03-20

Deposited energy:
E_1+E_2= 2088 keV
Internal hypothesis:
$(\Delta t)_{mes} - (\Delta t)_{theo}$ = 0.22 ns
Common vertex:
$(\Delta \text{vertex})_\perp$ = 2.1 mm



$(\Delta \text{vertex})_{//}$ = 5.7mm

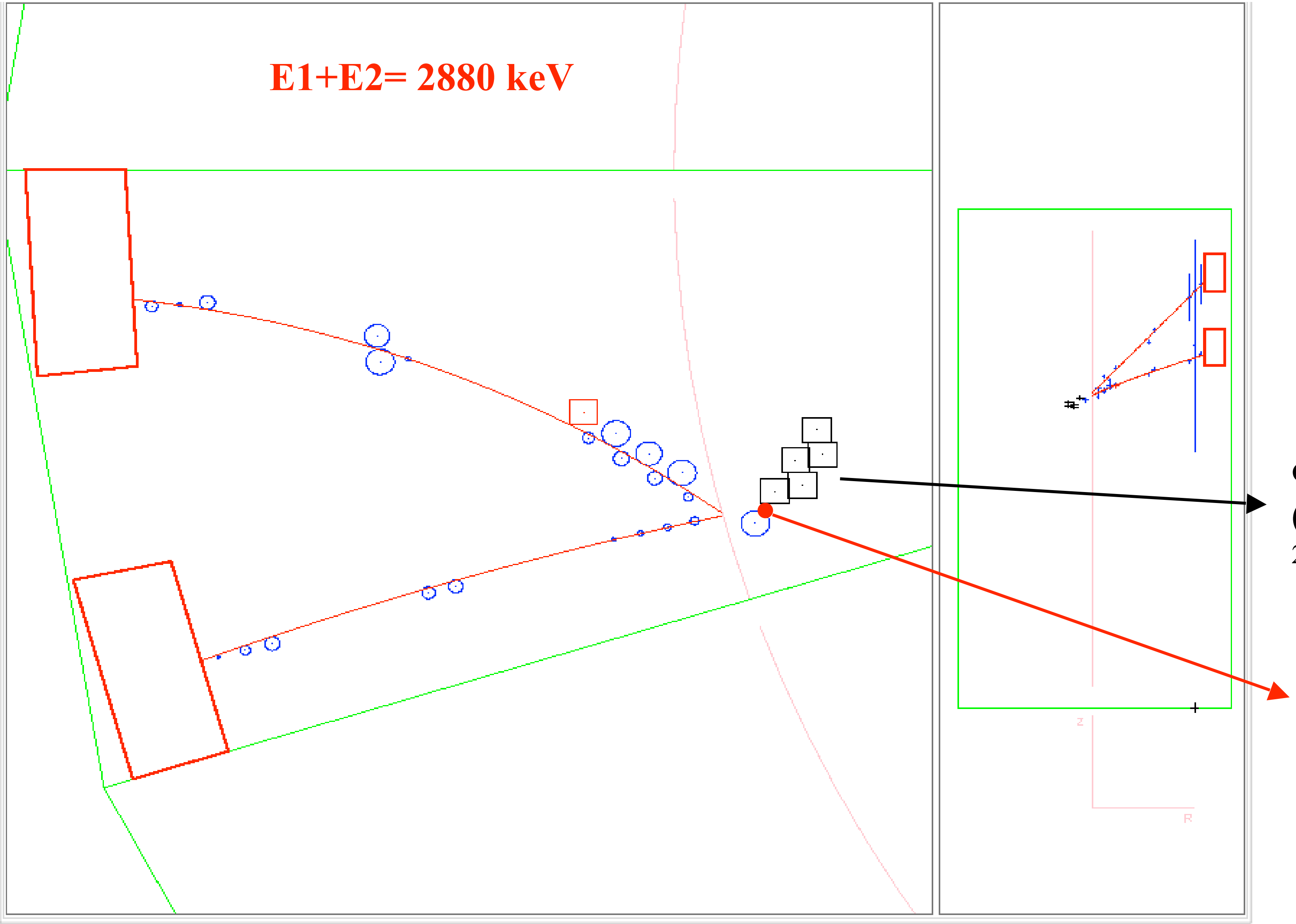
Trigger: 1 PMT > 150 keV
3 Geiger hits (2 neighbour layers + 1)

Trigger rate = 7 Hz

ββ events: 1 event every 1.5 minutes

a ββ0ν-like event due to Radon from the gas

Run 2220, event 136.604, May 11th 2003



E1+E2= 2880 keV

α track
(delay = 70 μs)
^{214}Po → ^{210}Pb

^{214}Bi → ^{214}Po
β decay
IN THE GAS

Event selection criteria

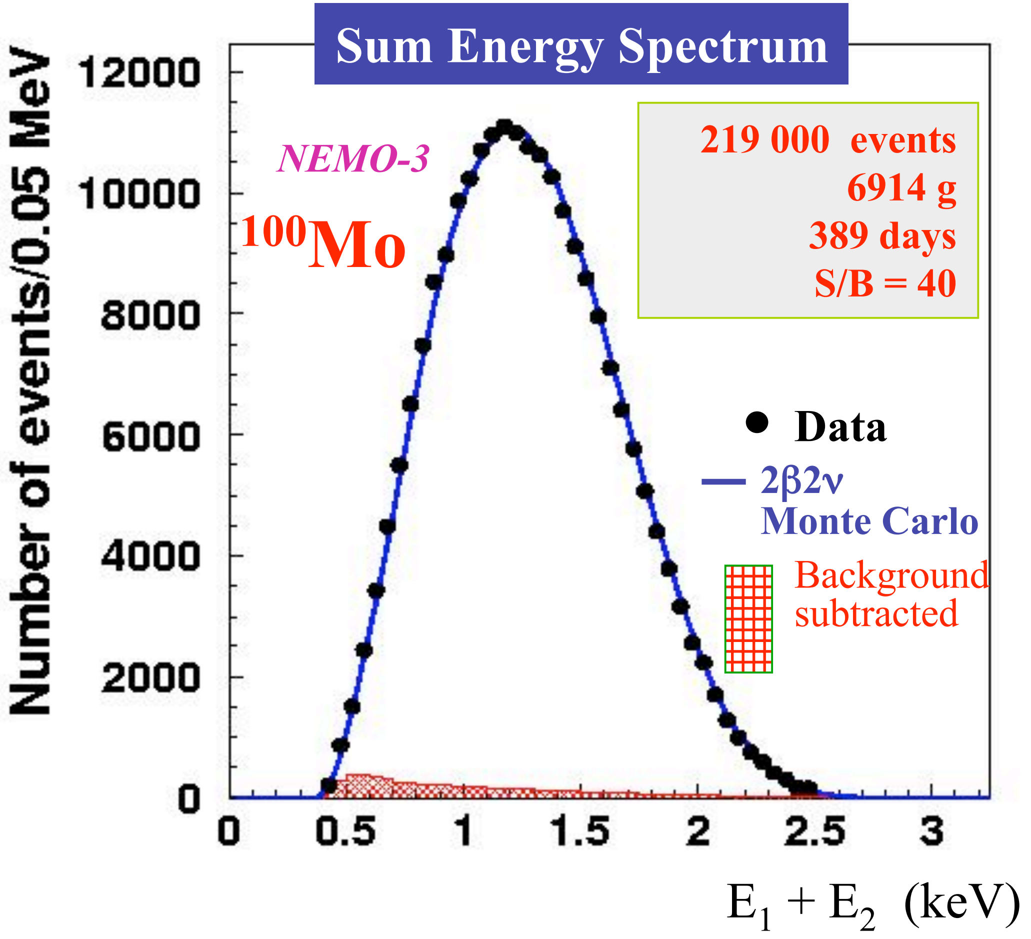
- Two tracks of negative charge associated to isolated PM
- Energy deposit in each scintillator E > 200 keV.
- Event vertex is inside the foil
- Distance track-to-vertex: $\Delta XY < 4$ cm, $\Delta Z<8$ cm;
- TOF cut: internal hypothesis probality > 4%, external hypothesis probability<1%;
- Reject events with the alpha particle found using ***alpha_search*** means:

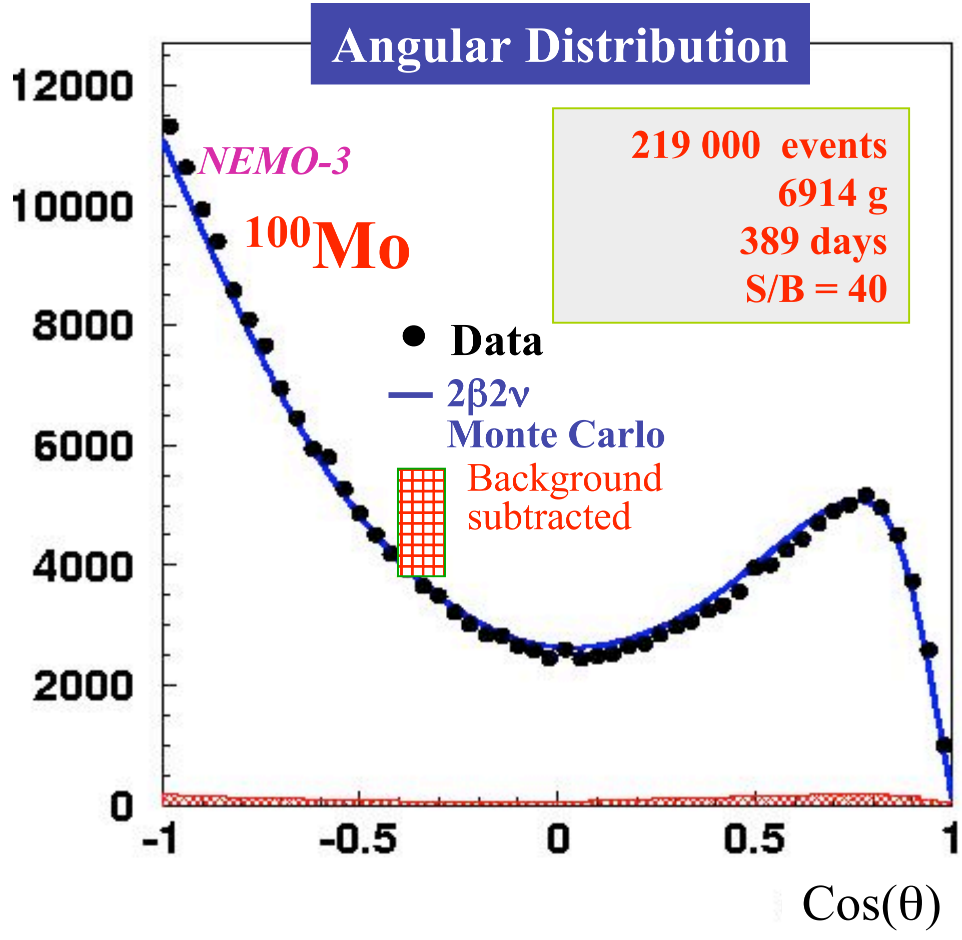
  - if only 1 extra hit in the tracking detector $\left\{ \begin{array}{l} \Delta t > 40\ \mu\text{sec} \\ \left. \begin{array}{l} \Delta xy < 4\ \text{cm} \\ \Delta Z < 10\ \text{cm} \end{array} \right\} \text{vertex} \end{array} \right.$
  - if at least 2 hits
    search for a short track
    $\Delta t > 2\ \mu$sec only but all hits on time

- Reject events with two tracks at one side of the foil and a geiger hit in time at the opposite side fo the foil close to the vertex: Möller scattering of β decay in gas (Radon).

^{100}Mo 2β2ν preliminary results

(Data Feb. 2003 – Dec. 2004)

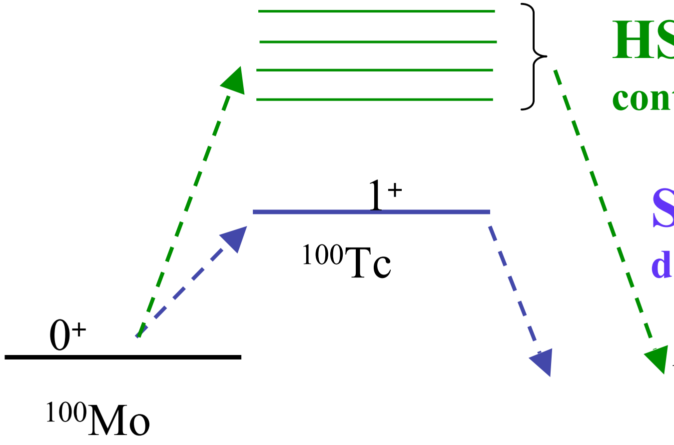




7.37 kg.y

$$T_{1/2} = 7.11 \pm 0.02\ (\text{stat}) \pm 0.54\ (\text{syst}) \times 10^{18}\ \text{y}$$

^{100}Mo 2β2ν Single Energy Distribution

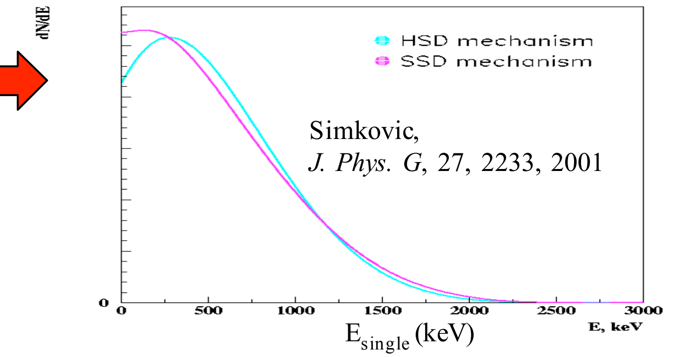


HSD, higher levels contribute to the decay

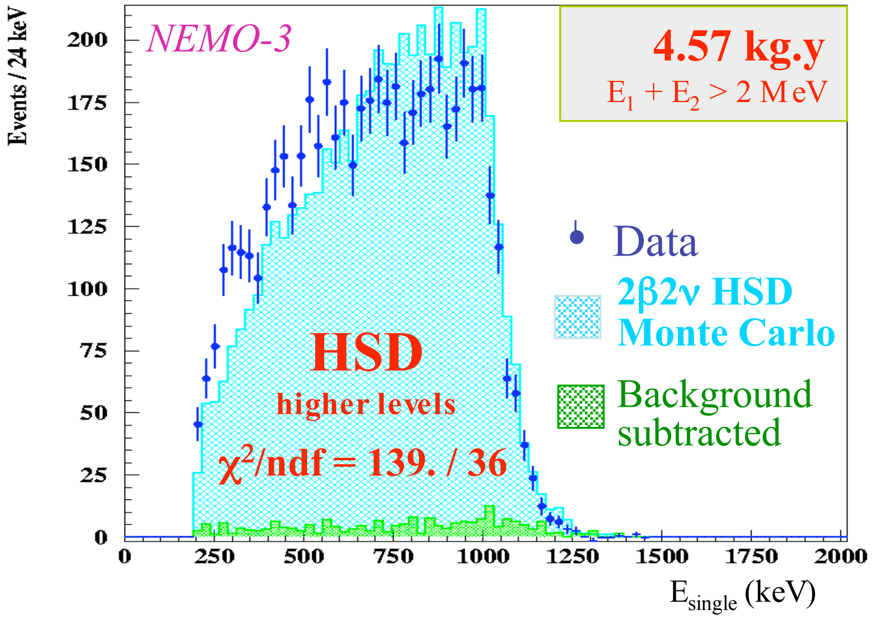
SSD, 1+ level dominates in the decay

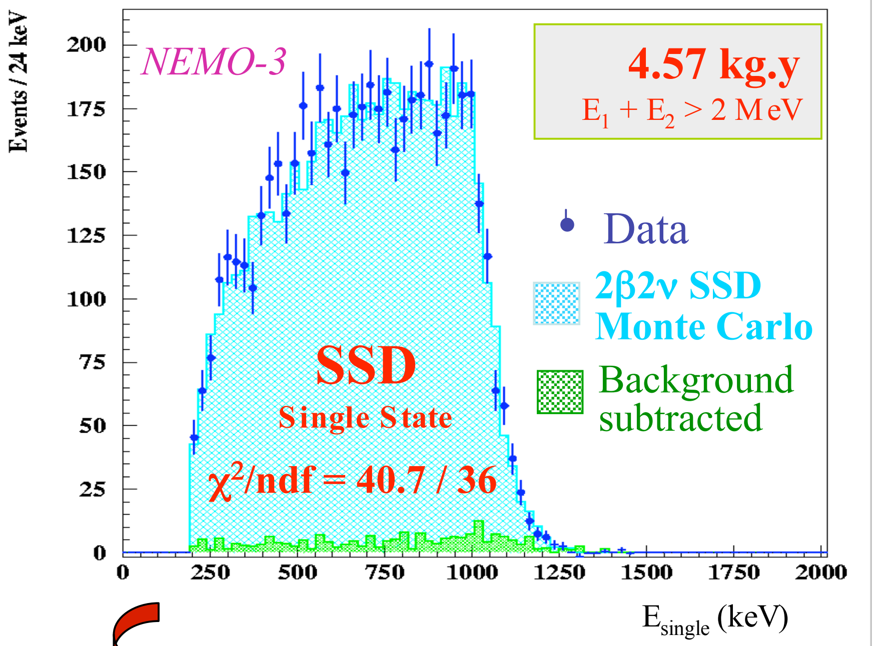
(Abad et al., 1984, *Ann. Fis*. A 80, 9)

Single electron spectrum different between SSD and HSD



Simkovic, *J. Phys. G*, 27, 2233, 2001



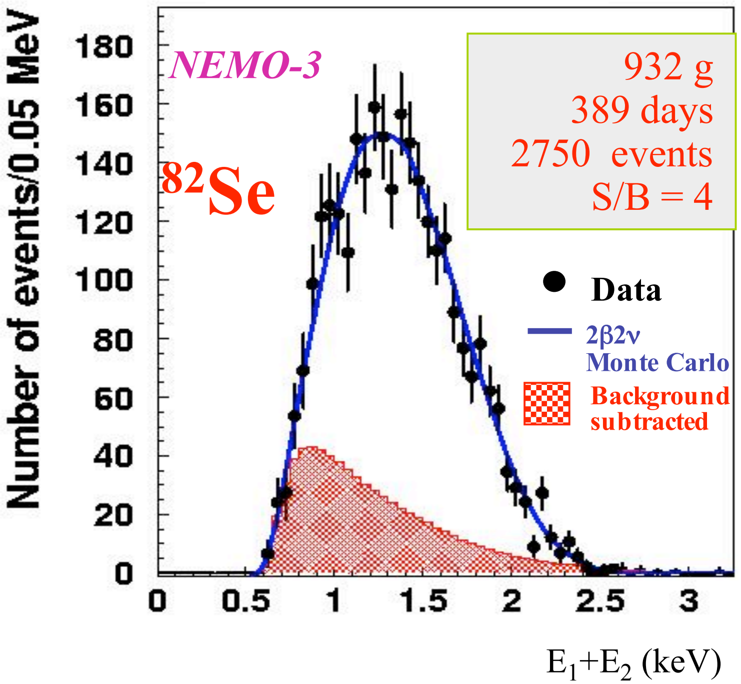


HSD: $T_{1/2} = 8.61 \pm 0.02\ (\text{stat}) \pm 0.60\ (\text{syst}) \times 10^{18}$ y

SSD: $T_{1/2} = 7.72 \pm 0.02\ (\text{stat}) \pm 0.54\ (\text{syst}) \times 10^{18}$ y

^{100}Mo 2β2ν single energy distribution in favour of Single State Dominant (SSD) decay

2β2ν preliminary results for other nuclei



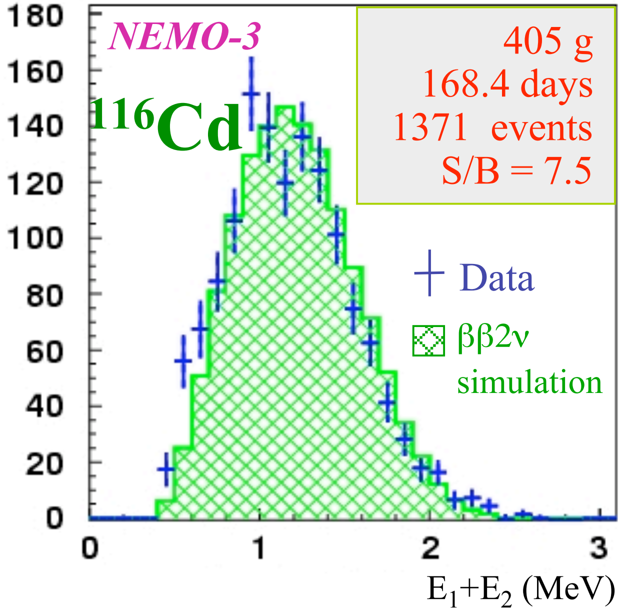
^{82}Se $T_{1/2}$ = 9.6 ± 0.3 (stat) ± 1.0 (syst) × 10^{19} y

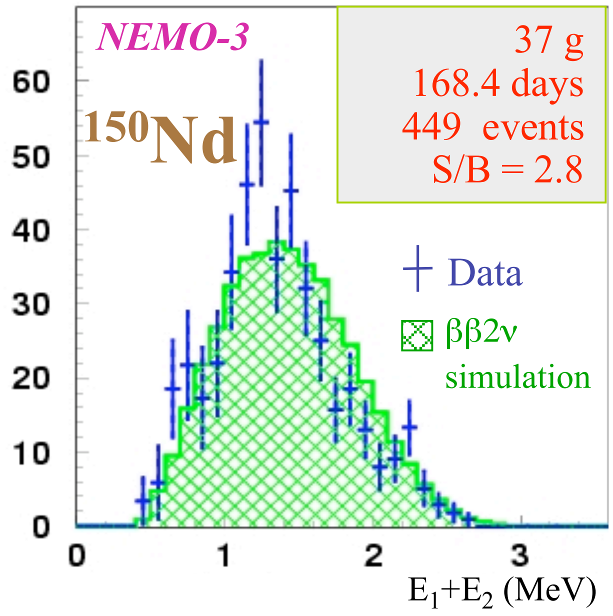
^{116}Cd $T_{1/2}$ = 2.8 ± 0.1 (stat) ± 0.3 (syst) × 10^{19} y

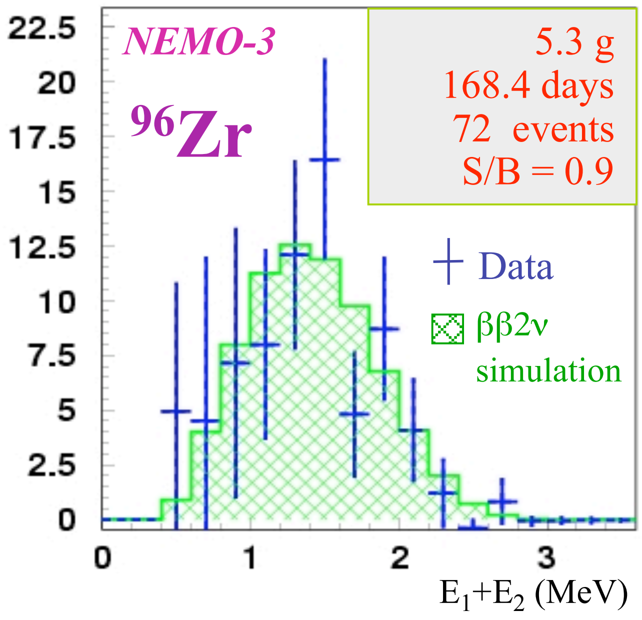
^{150}Nd $T_{1/2}$ = 9.7 ± 0.7 (stat) ± 1.0 (syst) × 10^{18} y

^{96}Zr $T_{1/2}$ = 2.0 ± 0.3 (stat) ± 0.2 (syst) × 10^{19} y

Background subtracted







Ca48 analysis 1st preliminary result

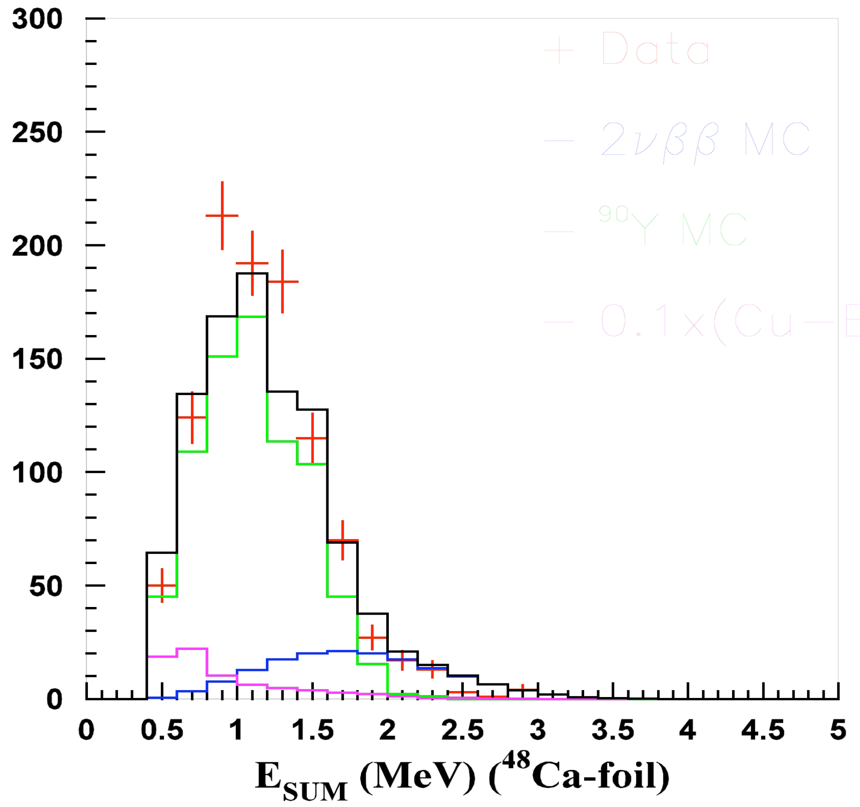
Hideaki Ohsumi analysis

- why 2β2ν ^{48}Ca: test of the shell model calculation
- 7g of ^{48}Ca enough radiopure after chemistry ^{214}Bi, ^{208}Tl but 30m Bq of ^{90}Sr!
  pure beta emitter criteria to remove Möller scattering E1 and E1 > 0.7 MeV
  cosθ < 0 back to back

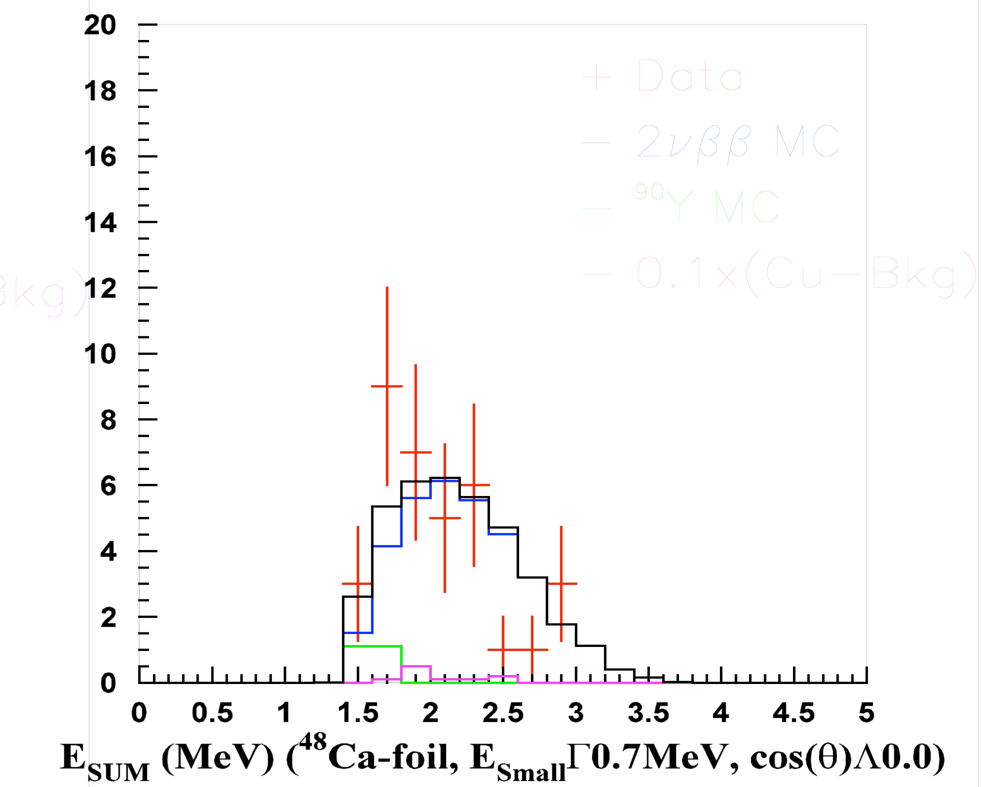
+ Data
– 2νββ MC
– ^{90}Y MC
– 0.1× (Cu – Bkg)

$T_{1/2} = 3.4 \pm 1.2\ 10^{19}$ years

result 35 events background 2



Esmall > 0.2 MeV



Esmall > 0.7 MeV cos(θ)<0.0

Search for 2β0ν decay in NEMO-3

Origin of Background at high energy

➡ Two natural isotopes which have the greatest Q_β values > 3 MeV:

^{214}Bi : $Q_\beta \approx 3.27$ MeV
^{208}Tl : $Q_\beta \approx 4.99$ MeV

Design NEMO-3 detector for 10 kg:

^{214}Bi in source foils < 0.3 mBq/kg
^{208}Tl in source foils < 0.02 mBq/kg

Total activity of the detector (30 tons) ≈ 1120 Bq

^{40}K = 800
^{214}Bi = 300
^{208}Tl = 20

➡ In the Modane Underground Laboratory:

Fast neutron flux (> 1 MeV):	3.5 ± 1.5	10^{-6}	n.cm^{-2}s^{-1}
Thermal neutron flux (~0.025 eV):	1.6 ± 0.1	10^{-6}	n.cm^{-2}s^{-1}

How NEMO-3 tags the background

- Electron and positron
- Gamma : 50% efficiency at 1 MeV
  Energy Threshold = 30 keV
- Time of Flight : Time Resolution ≈ 250 ps at 1 MeV
- e^+/e^- separation with a magnetic field of 25 G
  3% confusion at 1 MeV
- Delayed tracks (<700 μs) to tag delayed α from Bi^{207}
  $^{214}Bi \rightarrow {}^{214}Po\ (164\ \mu s) \rightarrow {}^{210}Pb$

ββ0ν Analysis: Background Measurement

NEMO-3 can measure each component of its background !

- **External Background ^{208}Tl (PMTs)**

Measured with (e^-, γ) external events

~ 10^{-3} ββ0ν-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV

- **External Neutrons and High Energy gamma**

Measured with $(e^-,e^-)_{int}$ events with $E_1+E_2 > 4$ MeV

≲ 0.02 ββ0ν-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV

Only 2 $(e^-,e^-)_{int}$ events with $E_1+E_2 > 4$ MeV observed after 260 days of data (without boron)

$$\begin{cases} \text{4253 keV (26 Mar. 2003)} \\ \text{6361 keV (8 Nov. 2003)} \end{cases}$$

In agreement with expected background

- **^{208}Tl impurities inside the foils**

Measured with (e^-,2γ), (e^-,3γ) events coming from the foil

~ 0.1 ββ0ν-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV

sources	A (μBq/k) from(e^-,Nγ)	A (μBq/k) HPGe meas.
^{100}Mo metal.	92 ± 18	< 110
^{100}Mo comp.	115 ± 13	< 100
^{82}Se	316 ± 46	400 ±100

In agreement with HPGe measurements

- **^{100}Mo ββ2ν decay** $T_{1/2} = 7.7\ 10^{18}$ y (SSD)

~ 0.3 ββ0ν-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV

ββ0ν Analysis: Background Measurement

Radon in the NEMO-3 gas of the wire chamber

Due to a tiny diffusion of the radon of the laboratory inside the detector

A(Radon) in the lab ~15 Bq/m^3

Two independant measurements of radon in NEMO-3 gas

- **Radon detector at the input/output of the NEMO-3 gas**

  ~ 20 counts/day for 20 mBq/ m^3

- **(1e$^-$ + 1 α) channel in the NEMO-3 data**:

  Delayed tracks (<700 μs) to tag delayed α from ^{214}Po

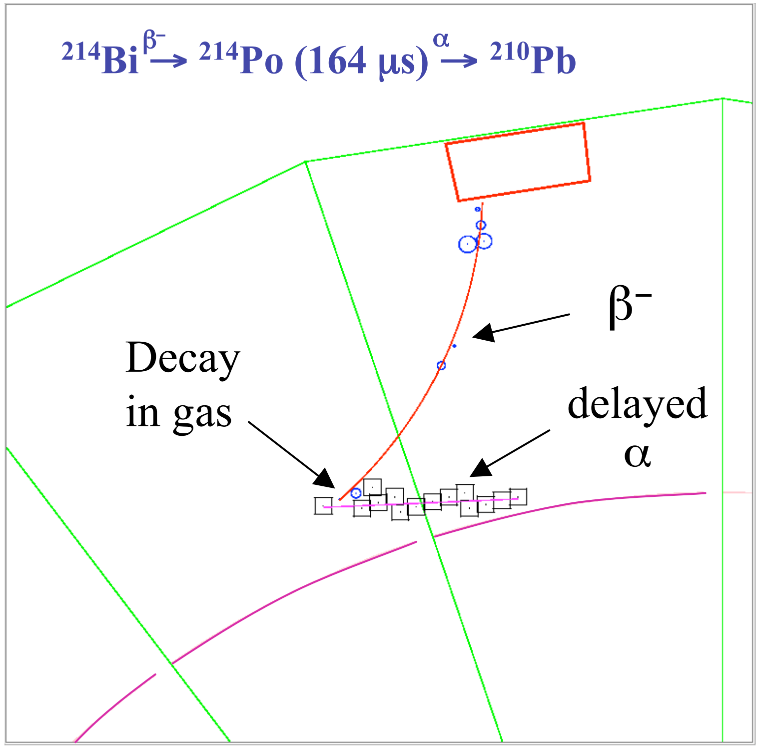
  ^{214}Bi → ^{214}Po (164 μs) → ^{210}Pb

  ~ 200 counts/hour for 20 mBq/m^3

Good agreement between the two measurements

A(Radon) in NEMO-3 ≈ 20-30 mBq/m^3

$^{214}\mathrm{Bi} \xrightarrow{\beta^-} {}^{214}\mathrm{Po}$ (164 μs) $\xrightarrow{\alpha} {}^{210}\mathrm{Pb}$



~ 1 ββ0ν-like events/year/kg with $2.8 < E_1+E_2 < 3.2$ MeV

Radon is the dominant background today for ββ0ν search in NEMO-3 !!!

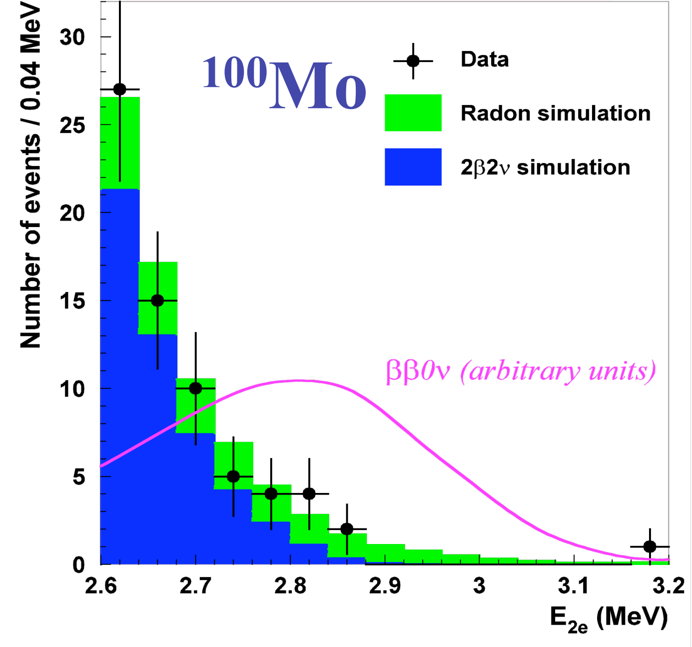
Limit on the effective mass of the Majorana neutrino

Phase 1 (Feb. 2003 – Sept. 2004: 1.08 y of data) with radon bkg
(limits @ 90% CL)

^{100}**Mo** (6.914 kg)

$T_{1/2}(\beta\beta0\nu) > 4.6\ 10^{23}$ y

$\langle m_\nu \rangle < 0.66 - 2.81$ eV



[2.8-3.2] MeV: $\varepsilon(\beta\beta0\nu) = 8$ %

Expected bkg = 8.1 ± 1.3

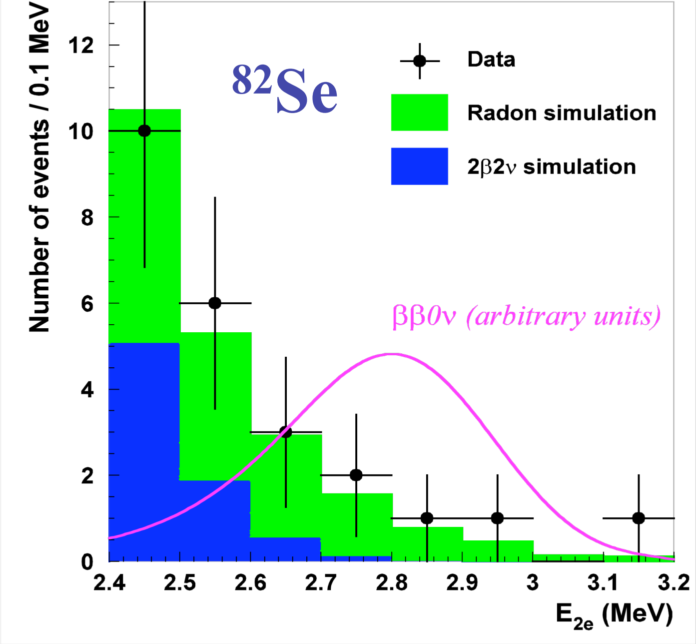
$N_{observed} = 7$ events

Previous limits: $T_{1/2}(\beta\beta0\nu) > 5.5\ 10^{22}$ y
Ejiri et al. (2001)

^{82}**Se** (0.932 kg)

$T_{1/2}(\beta\beta0\nu) > 1.0\ 10^{23}$ y

$\langle m_\nu \rangle < 1.75 - 4.86$ eV



[2.7-3.2] MeV: $\varepsilon(\beta\beta0\nu) = 13$ %

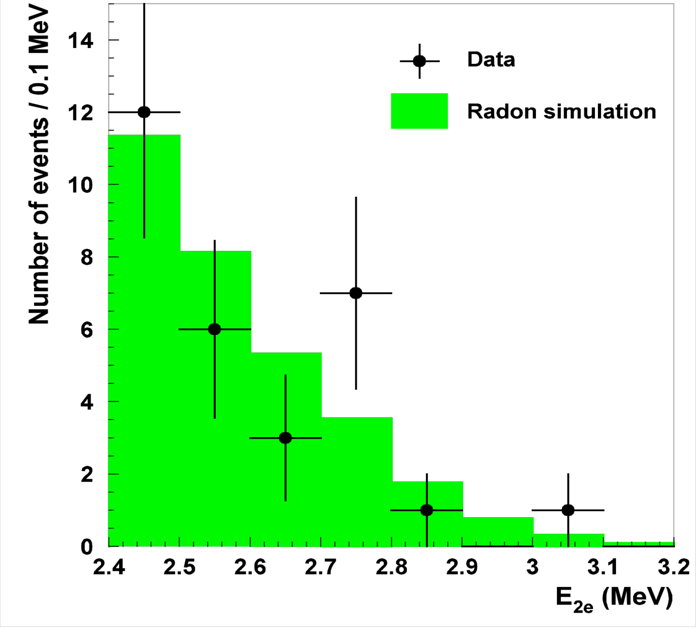
Expected bkg = 3.1 ± 0.6

$N_{observed} = 5$ events

Previous limits: $T_{1/2}(\beta\beta0\nu) > 9.5\ 10^{21}$ y
Arnold et al. (1992)

Cu+^{nat}Te+^{130}Te

In agreement with only Radon bkg expected



Nuclear Matrice Elements Ref. Simkovic (1999), Stoica (2001), Suhonen (1998,2003), Rodin (2005), Caurier (1996)

Limit on Majoron and V+A

Phase 1 (Feb. 2003 – Sept. 2004: 1.08 y of data) with radon bkg

(limits @ 90% CL)

Limit on Majoron

^{100}Mo: $T_{1/2}(\beta\beta0\nu M) > 1.8\ 10^{22}$ y

$g_M < (5.3 - 8.5)\ 10^{-5}$ (best limit)

Simkovic (1999), Stoica (1999)

^{82}Se: $T_{1/2}(\beta\beta0\nu M) > 1.5\ 10^{22}$ y

$g_M < (0.7 - 1.6)\ 10^{-4}$

Simkovic (1999), Stoica (2001)

Limit on V+A

^{100}Mo: $T_{1/2}(\beta\beta0\nu\ V{+}A) > 2.3\ 10^{23}$ y

$\lambda < (1.5 - 2.0)\ 10^{-6}$

Tomoda (1991), Suhonen (1994)

^{82}Se: $T_{1/2}(\beta\beta0\nu\ V{+}A) > 1.0\ 10^{23}$ y

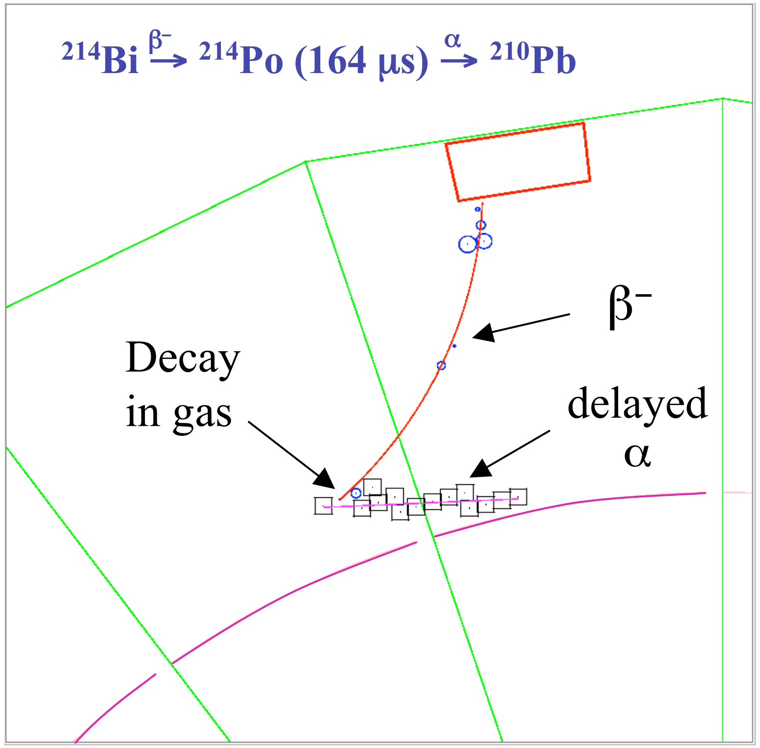
$\lambda < 3.2\ 10^{-6}$

Tomoda (1991)

Radon was the dominant background for ββ0ν search in NEMO-3

Radon in the NEMO-3 gas of the wire chamber

Due to a tiny diffusion of the radon of the laboratory inside the detector
A(Radon) in the lab ~15 Bq/m³



<u>Two independent measurements</u> of radon in NEMO-3 gas

- **Radon detector at the input/output of the NEMO-3 gas**

  ~ 20 counts/day for 20 mBq/ m³

- **($1e^- + 1\,\alpha$) channel in the NEMO-3 data:**

  Delayed tracks (<700 μs) to tag delayed α from ^{214}Po

  ^{214}Bi → ^{214}Po (164 μs) → ^{210}Pb

  ~ 200 counts/hour for 20 mBq/m³

Good agreement between the two measurements

A(Radon) in NEMO-3 ≈ 20-30 mBq/m³

~ 1 ββ0ν-like events/year/kg with $2.8 < E_1+E_2 < 3.2$ MeV

Free-Radon Purification System 1/2

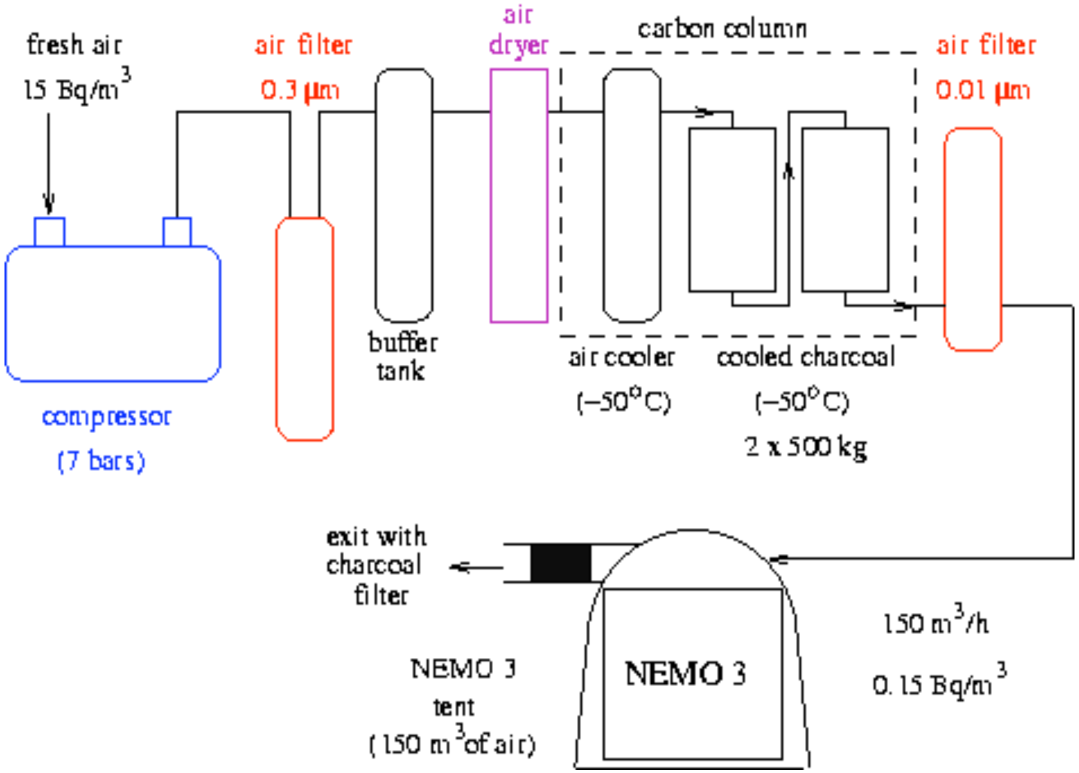
May 2004 : Tent surrounding the detector

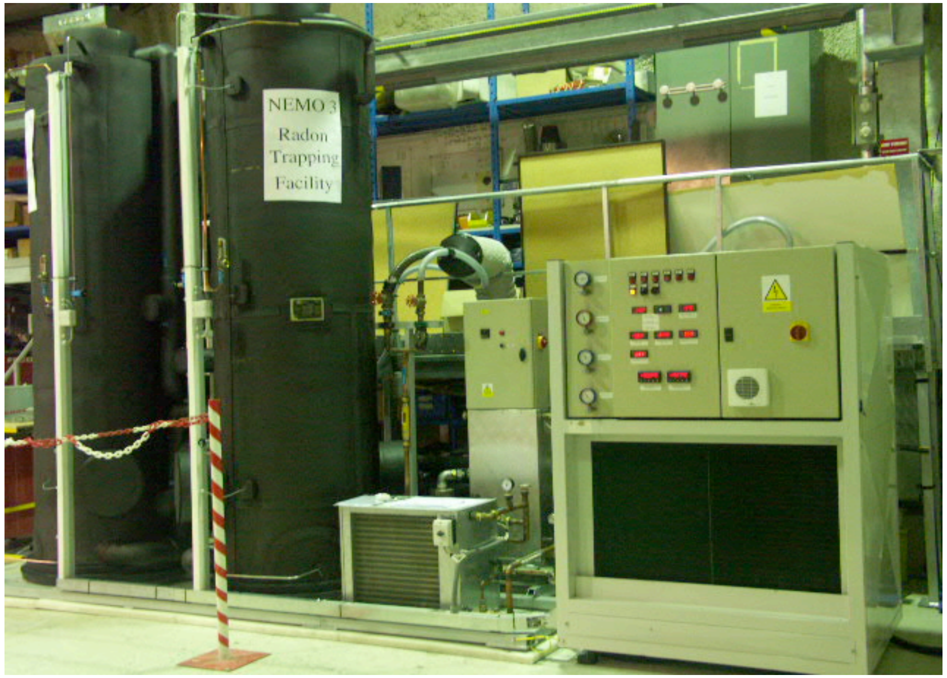
Free-Radon Air factory

Starts running Oct. 4th 2004
in Modane Underground Lab.

1 ton charcoal @ -50°C, 7 bars

Activity: A(^{222}Rn) < 15 mBq/m^3 !!!
Flux: 125 m^3/h a factor 1000






NEMO 3
Radon
Trapping
Facility

Radon purification of the air surronding the detector

- Results -

- A(Radon) in the lab………………………………….. **~15 Bq/m^3**
- A(Radon) in the tent after flushing free-radon air…… **~ 5 Bq/m^3**

⇓

- source of radon inside the tent
- ground and electronics degasing
- 20-21 oct. 2004: the detector has been roughly isolated from the ground and electronics

⇓

- A(Radon) in the upper part, surrounding the detector... **~ 0.15 Bq/m^3**

air flux: 125 m^3/h

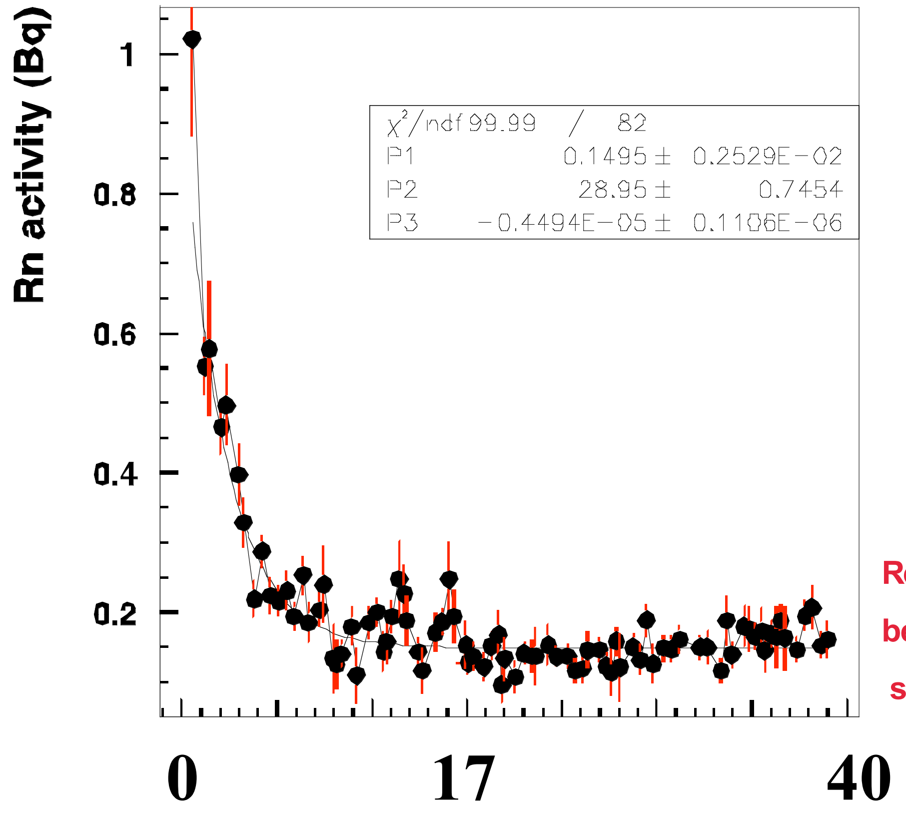
Activity of Radon surrounding the detector has been reduced by a factor ~ 100

Radon level inside the detector
- Results -

Level of radon measured inside the wire chamber,
by analysing ($1e^- + 1\ \alpha$) channel in the NEMO-3 data

Without tent: A ~ 1.5 Bq

After flushing radon-free air
inside the tent: A ~ 0.15 Bq



Residual level to
be understood
sources ?

Radon level reduced by a factor of 10

Thanks a lot to S.K especially **M.Nakahata,S.Tasaka**

NEMO-3 Expected sensitivity

Background

External Background: negligible

Internal Background: **^{208}Tl** : 60 μBq/kg for ^{100}Mo
300 μBq/kg for ^{82}Se
^{214}Bi : < 300 μBq/kg

~ 0.1 count kg^{-1} y^{-1} with $2.8<E_1+E_2<3.2$ MeV

ββ2ν ^{100}Mo: $T_{1/2} = 7.14\ 10^{18}$ y
~ 0.3 count kg^{-1} y^{-1} with $2.8<E_1+E_2<3.2$ MeV

in 2009 after 5 years of data

6914 g of ^{100}Mo **$T_{1/2}(\beta\beta0\nu) > 4\ 10^{24}$ y (90% C.L.)**
$<m_\nu> < 0.2 – 1.3$ eV

932 g of ^{82}Se **$T_{1/2}(\beta\beta0\nu) > 8\ .10^{23}$ y (90% C.L.)**
$<m_\nu> < 0.6 – 1.7$ eV

Nuclear Matrice Elements Ref. Simkovic (1999), Stoica (2001), Suhonen (1998,2003), Rodin (2005), Caurier (1996)

Prospects

- We live a « prenatal period » for the double beta decay experiments ≈ 10 kg of isotopes NEMO3 ≈ 0.2 eV ^{100}Mo with a small background

  CUORECINO ≈ 0.2 eV ^{130}Te, the background would be improved soon

  ^{76}Ge ≈ 0.3 eV with backgrounds
- NEMO3 phase 2 : a zero background exp. with 10 kg ^{82}Se or a dream 10 kg of ^{150}Nd
- ^{76}Ge experiment : a 10 kg exp. backgrounds would be improved: GERDA
- then experiments with at least 100 kg of isotope to reach

  $<m_\nu> \approx$ a few 10 meV

Projects near future: 10 years

Experiment	isotope	Mass kg	Type of detector	Lab.	Background (counts FWHM Kg.y)	Sensitivity $T_{1/2}$(y)	Limit	Comment
CUORE	^{130}Te	200	Bolometer	Gran Sasso	0.001	3×10^{26}	0.015-0.090	R&D start
GERDA phase I	^{76}Ge	15	Ge Detector	Gran Sasso	0.01	3×10^{25}	0.3-0.9	2006
GERDA phase II	^{76}Ge	100	Ge Detector	Gran Sasso	0.001	2×10^{26}	0.09-0.29	2009
Super NEMO	^{82}Se ou ^{150}Nd	100	Tracko-Calo	?	0.002	2×10^{26}	0.03-0.06	R&D 2005 → 2007
Majorana	^{76}Ge	500	Ge Detector	?	0.01	$4\ 10^{27}$	0.034-0.039	for 10 years of running
EXO	^{136}Xe	200 1000	TPC	WIPP (US)	0.015 0-0.0018	210^{26} 8.3×10^{26}	0.39-1.2 0.0510.14	Start 2005 ?
MOON	^{100}Mo	10 1000	Tracko-calo	?		10^{27}	0.2-0.3 0.03	R&D in progress
CANDLES	^{48}Ca	0.180	CaF_2 (200kg)	Otho (Japon)	0.3		0.5	start
COBRA	^{130}Te ^{116}Cd	10	CdZnTe	Boulby U.K	0.2, 0.03	1×10^{24}	0.7	R&D in progress
DCBA	^{150}Nd	20	TPC	?			0.05	R&D in progress
XMASS	Xe	800	Calo.	Kamioka				R&D in Progress 100 kg

What we learnt with NEMO3

- to identify and measure all the sources of background
- to build a very low-background detector
- to prove the reliability of the chosen techniques
- to purify ββ isotopes by removing parents of ^{214}Bi, ^{208}Tl
- to remove background due to Radon (recently)
- to develop ultra low background H P Ge detectors

→ technique can be extrapolated

R&D program approved recently in France

3 years: 2005, 2006, 2007

From NEMO to SuperNEMO

Factor 100 on the ββ(0ν) period $T_{1/2}$, reach few 10^{26} years

Light Majorana neutrino exchange: $<m_\nu>$ ~50 meV

Detection efficiency

Mass of isotope ββ (g)

$$T^{0\nu}_{1/2}\,(y) > \frac{\ln 2\;.\;N}{k_{C.L.}}\;\frac{\varepsilon}{A}\;\sqrt{\frac{m\;.\;t}{N_{BDF}\;.\;R}}$$

Background (y^{-1}. g^{-1}. keV^{-1})

FWHM (keV)

N : Avogadro Number
$k_{C.L.}$ =1,6 à 90% C.L.
A : Mass number
t : measurement time (y)

Mass

~100 kg

Resolution

(FWHM): ~ 7 % at 3 MeV (will be dominated by source foil)
instead of ~ 11 % at 3 MeV for NEMO 3 (dominated by calorimeter)

Efficiency

improvement by a factor 2

Background

internal contaminations in ^{208}Tl and ^{214}Bi to be improved by a factor of 10

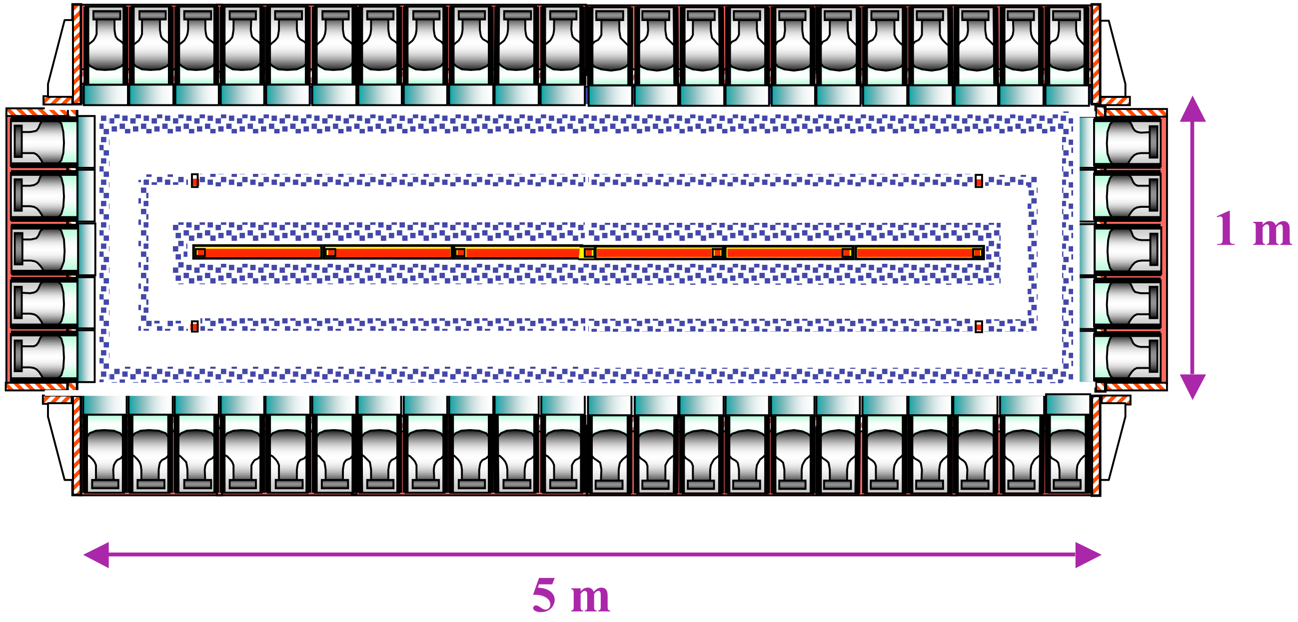
SuperNEMO preliminary design

Plane geometry

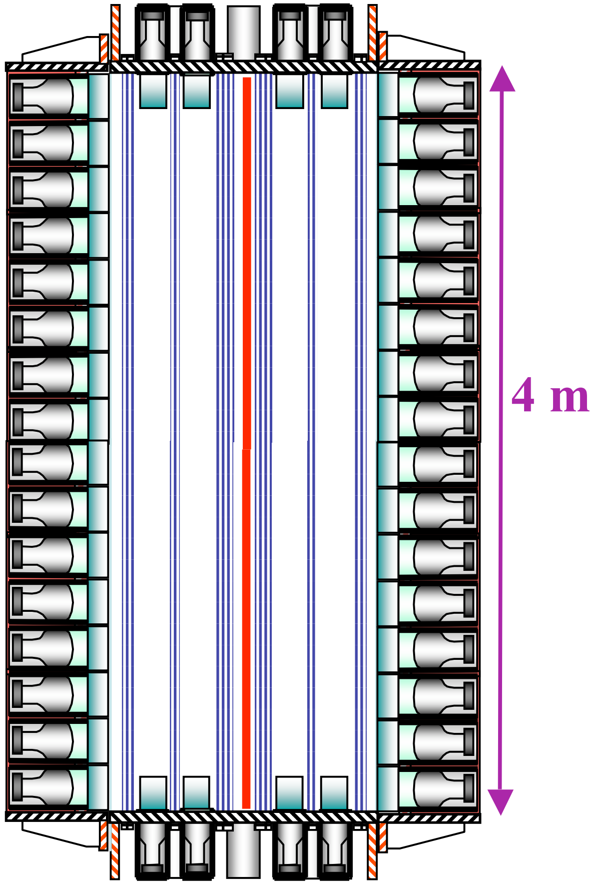
Source (40 mg/cm^2) 12m^2 , tracking volume (~3000 channels) and calorimeter (~1000 PMT)

Modular (~ 5 kg of enriched isotope/module)

100 kg: 20 modules
~ 60 000 channels for drift chamber
~ 20 000 PMT

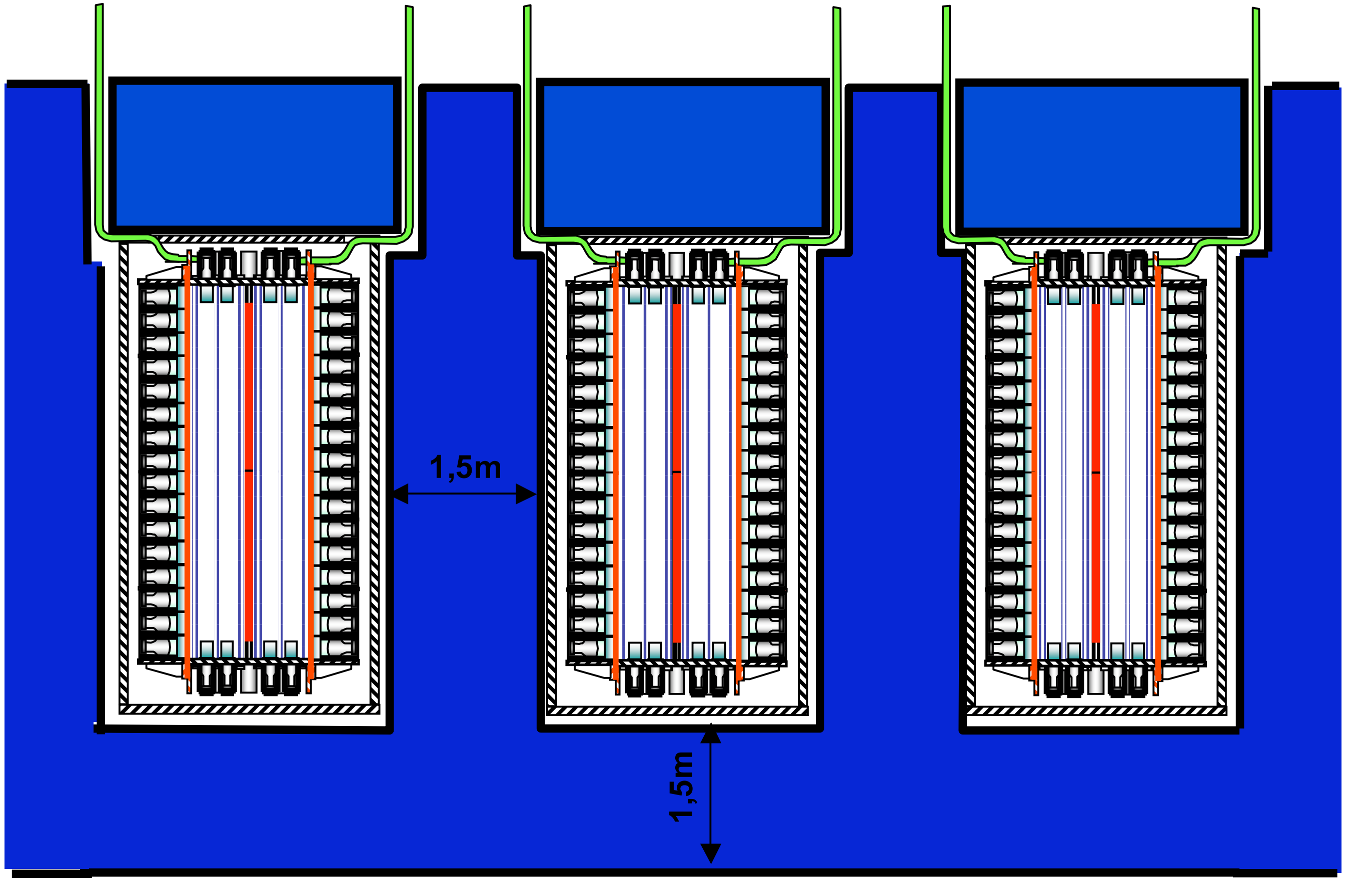


Top view



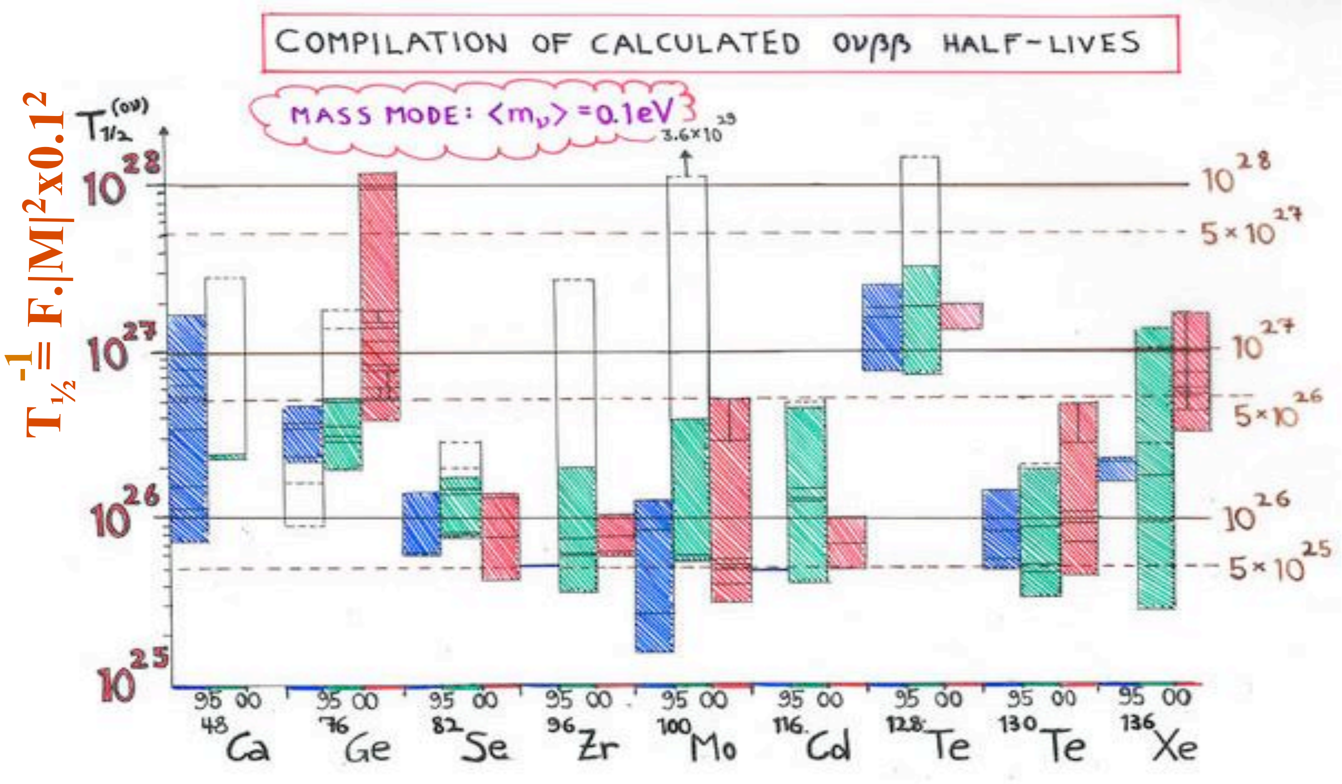
Side view

Water shield



Need of cavity of ~ 60m x 15m x15m
Possible in Gran Sasso or in Modane if a new cavity

Choice of the nucleus



Suhonen Neutrino 2004

CONCLUSIONS

- The ranges of values of the ββNME is still an open problem
- Need more coherent efforts in computation of ββNME
- Need new spectroscopic probes

No strong theoritical criteria. Nucleus choice depends on:

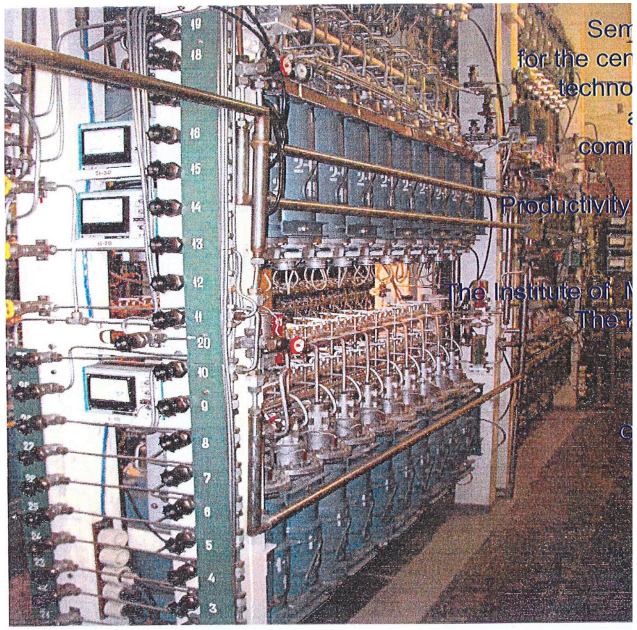
- enrichment possibilities
- experimental technics
- $Q_{\beta\beta}$ value (phase space factor, background)

	$Q_{\beta\beta}$ (MeV)	Isotopic Abundance
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
$^{82}Se \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
$^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

R&D for the source of ^{82}Se

Goal: To be able to produce 100 kg of ^{82}Se with internal contaminations less than 2 μBq/kg in ^{208}Tl and 10 μBq/kg in ^{214}Bi (60 decays/year)

Production: 5kg of ^{82}Se funded by ILIAS
100 kg possible
Development of ICR for enrichment ?



Purification: 2x100 g ^{nat}Se already processed at INEEL
5kg of ^{82}Se funded by ILIAS
1kg of ^{82}Se 2005
2kg of ^{82}Se 2006
5kg of ^{82}Se 2007

then radiopurety measurements to qualify the process
1) H P Ge
2) device "à la NEMO"

Thickness: ~250 m^2 with 40 mg/cm^2 thickness
(6% (FWHM) at 3 MeV)

Participants: CENBG, LAL, LSCE (France)
ITEP, Kurchatov, JINR (Russia)
INEEL, MHC (USA)

Conclusion

- NEMO3 is running for ≈ 5 years
- R&D program for SuperNEMO 2005, 2006, 2007 a real challenge !
- Coordination started at the European level (ILIAS)
- Neutrinoless double beta decay can be one of the experimental key for understanding neutrino physics: a long way but promising ?

Thank you

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