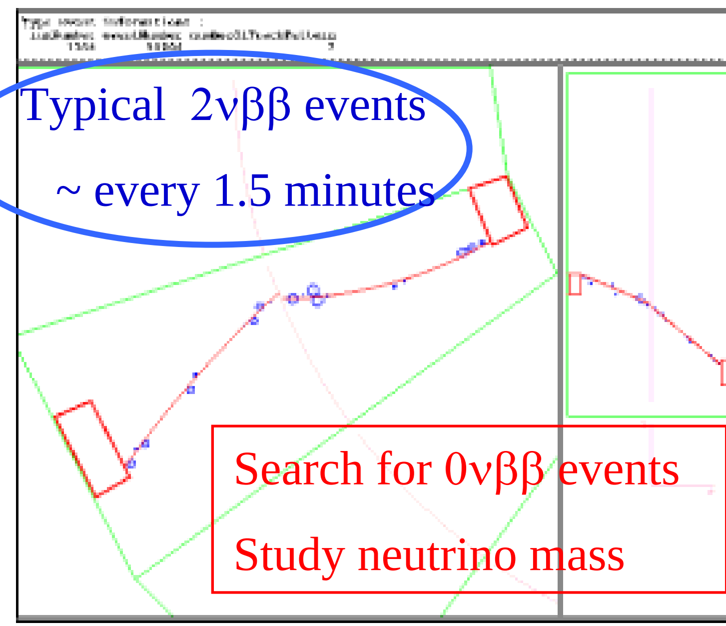
Recent Results from NEMO 3 Experiment



H. Ohsumi (Saga U.) @ US-Japan Seminar, September 16-20, 2005, Maui, Hawaii

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**
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LSCE, CNRS Gif sur Yvette, **France**
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Manchester University, Great-Britain
Mount Holyoke College, USA
RRC kurchatov Institute, Moscow, **Russia**
Saga university, Saga, **Japon**
UCL, London, **Great-Britain**

PLAN

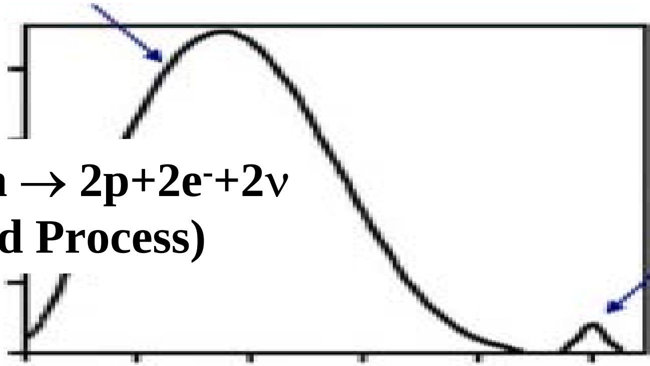
- Introduction
- NEMO3
  - description, performances
  - results $2\beta2\nu$
  - results $2\beta0\nu$: data phase 1 1.08 year
  - fight against radon
- SuperNEMO (if I have time …a little bit)
- Concluding Remarks

Philosophy of NEMO experiment

- **Neutrinoless Double Beta Decays (0νββ)**
  - **Majorana ν and effective mass $<m_\nu>$? or new physics (SUSY) ?**
- **Measure several isotopes (0νββ, 2νββ)**
  - **^{100}Mo(~7kg) , ^{82}Se(~1kg) , ^{130}Te , ^{116}Cd, ^{96}Zr , ^{48}Ca , ^{150}Nd**
- **Tag and measure all the BG events**
  - **e^-, e^+, γ, α, neutron**
  - **Tracking chamber+Calorimeter+$\vec{B}$-field+Shields**

"zero background" experiment

2νββ

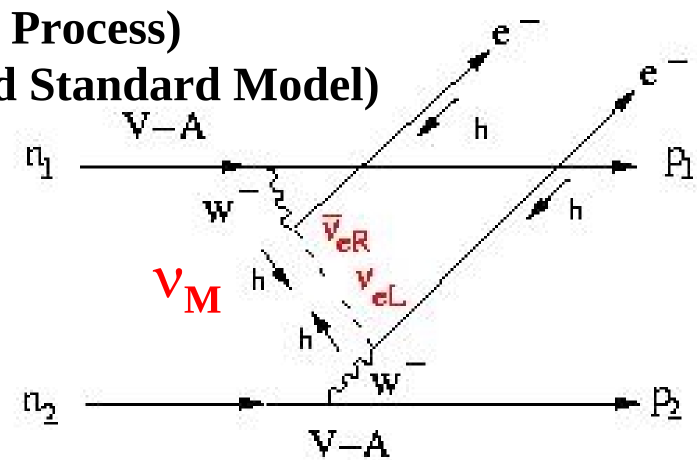


2νββ : 2n → 2p+2e⁻+2ν
(Standard Process)

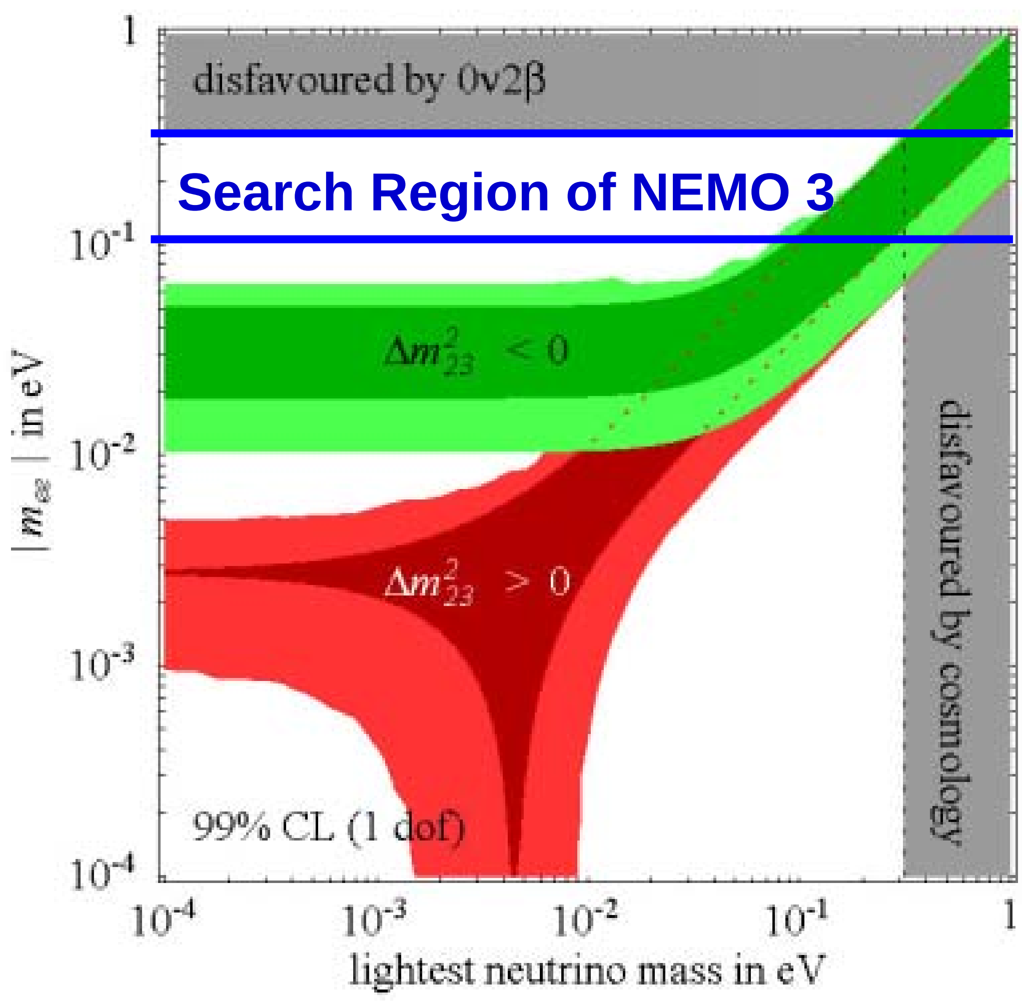
0νββ (?)

E(β₁+β₂) $Q_{\beta\beta}$

0νββ : 2n → 2p+2e⁻
(ΔL = 2 Process)
(Beyond Standard Model)



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



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):

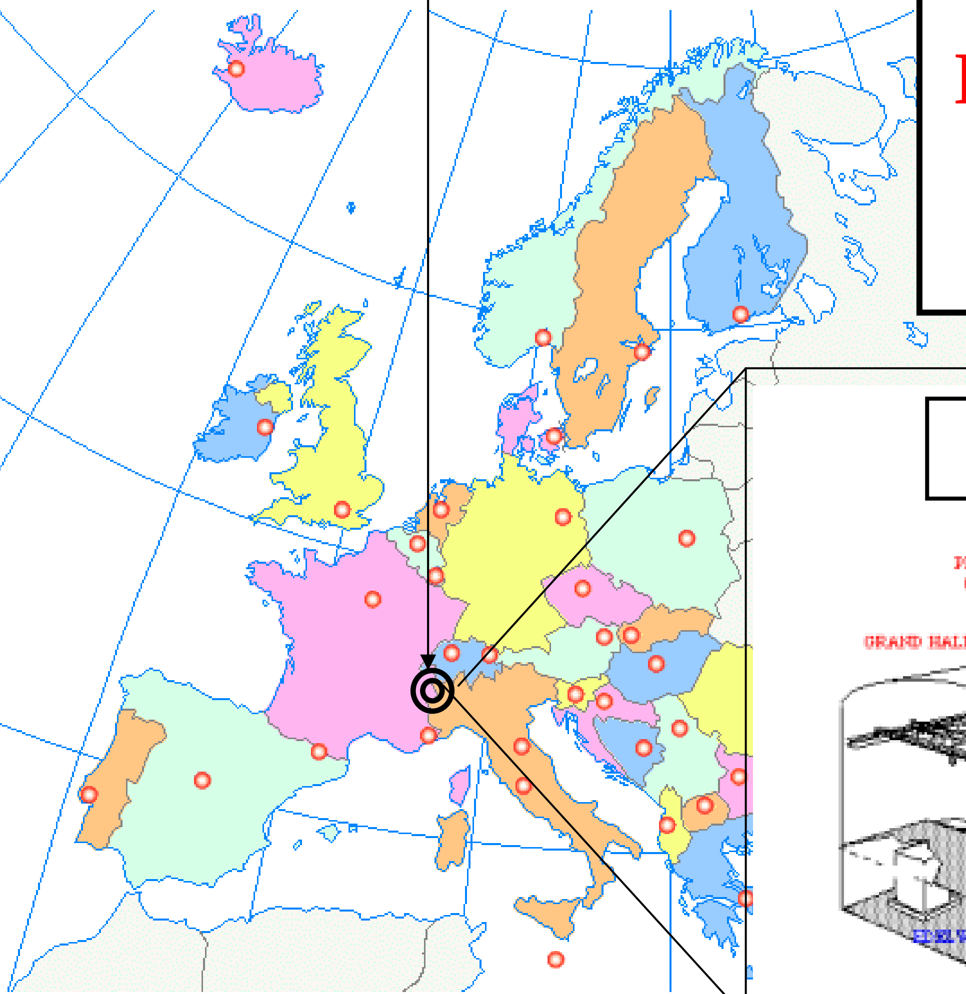
<m$_\nu$> < 5 meV

2β could give the absolute neutrino mass

(hep-ph/0503246 A.Strumia and F.Vissani)

The Location of the NEMO3

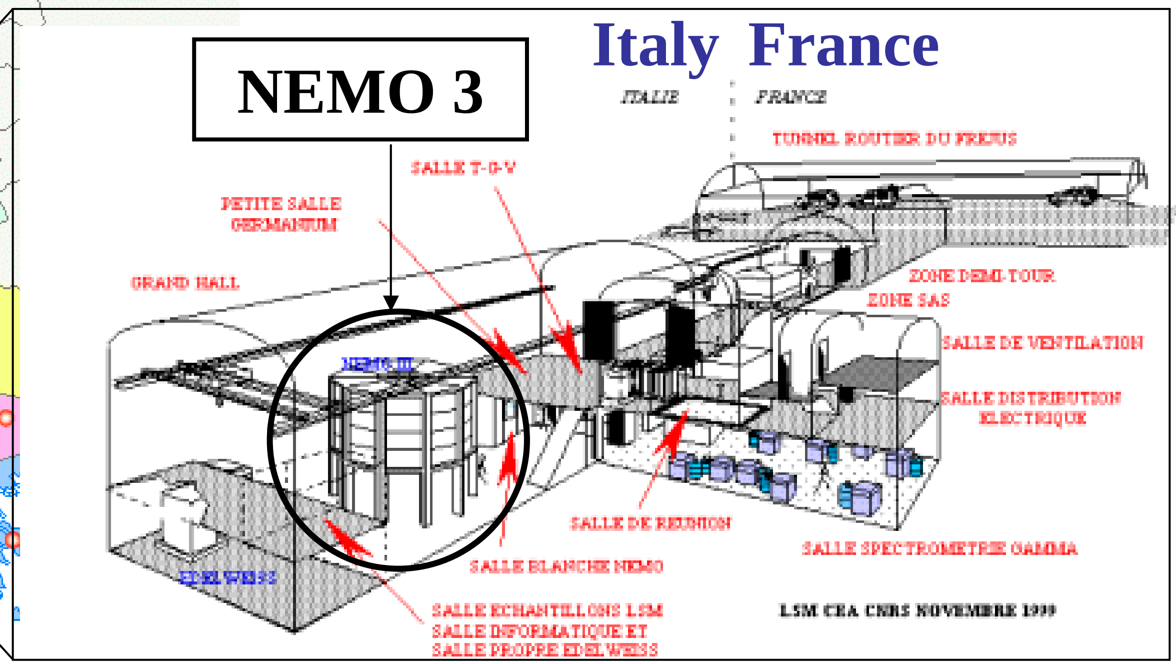
NEMO 3 is here !



Frejus Underground Laboratory

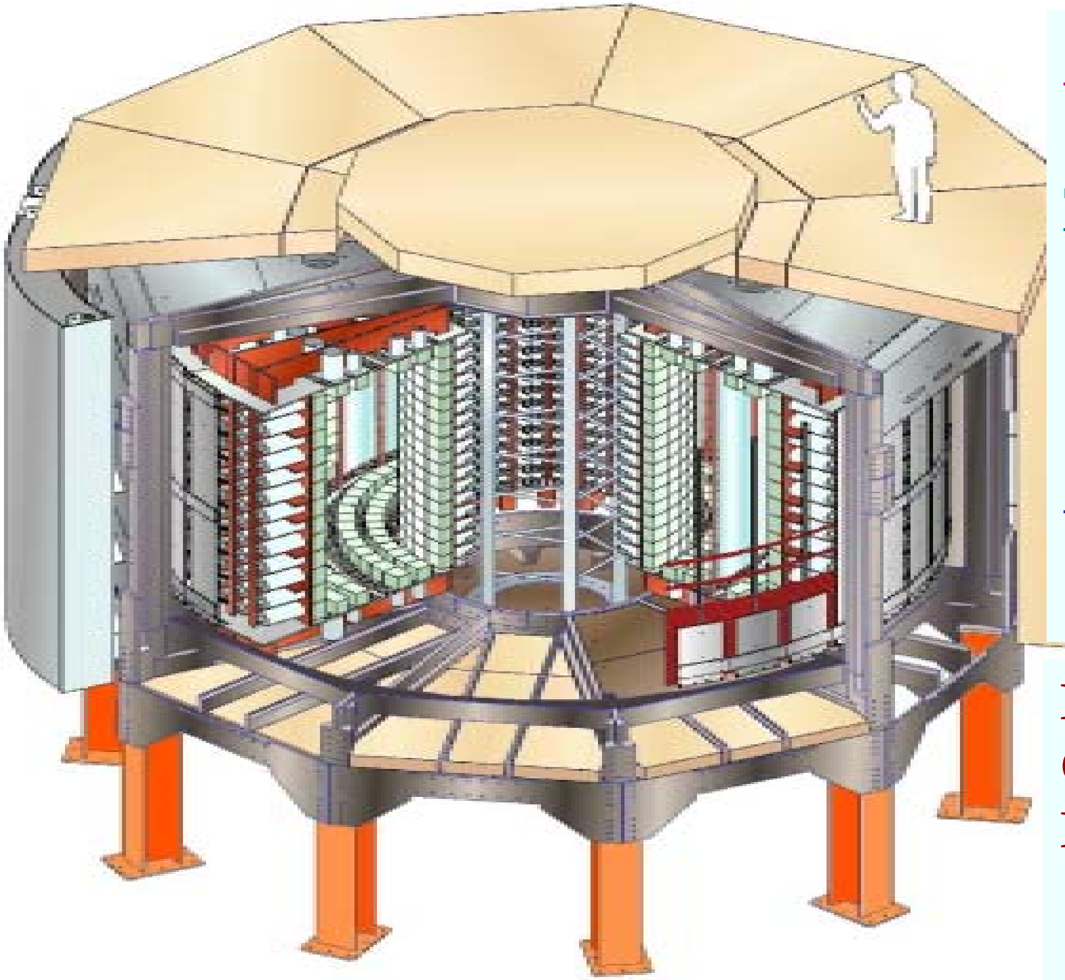
Laboratoire Souterraine de Modane(LSM)

(4800 m.w.e.)



The NEMO3 detector

Fréjus Underground Laboratory : 4800 m.w.e.



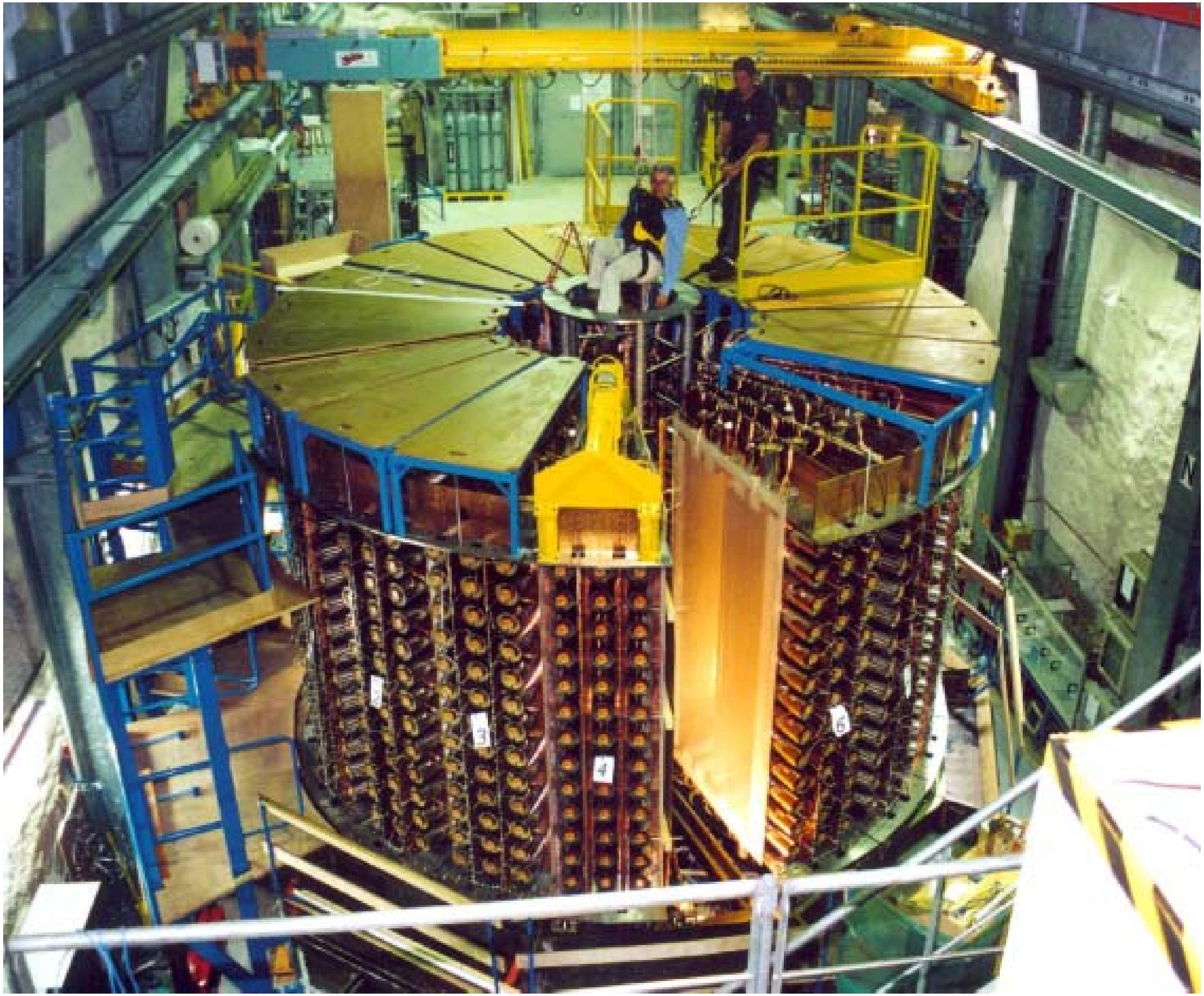
Source: 10 kg of ββ isotopes
cylindrical, S = 20 m^2, e ~ 60 mg/cm^2

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 = 18cm)
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



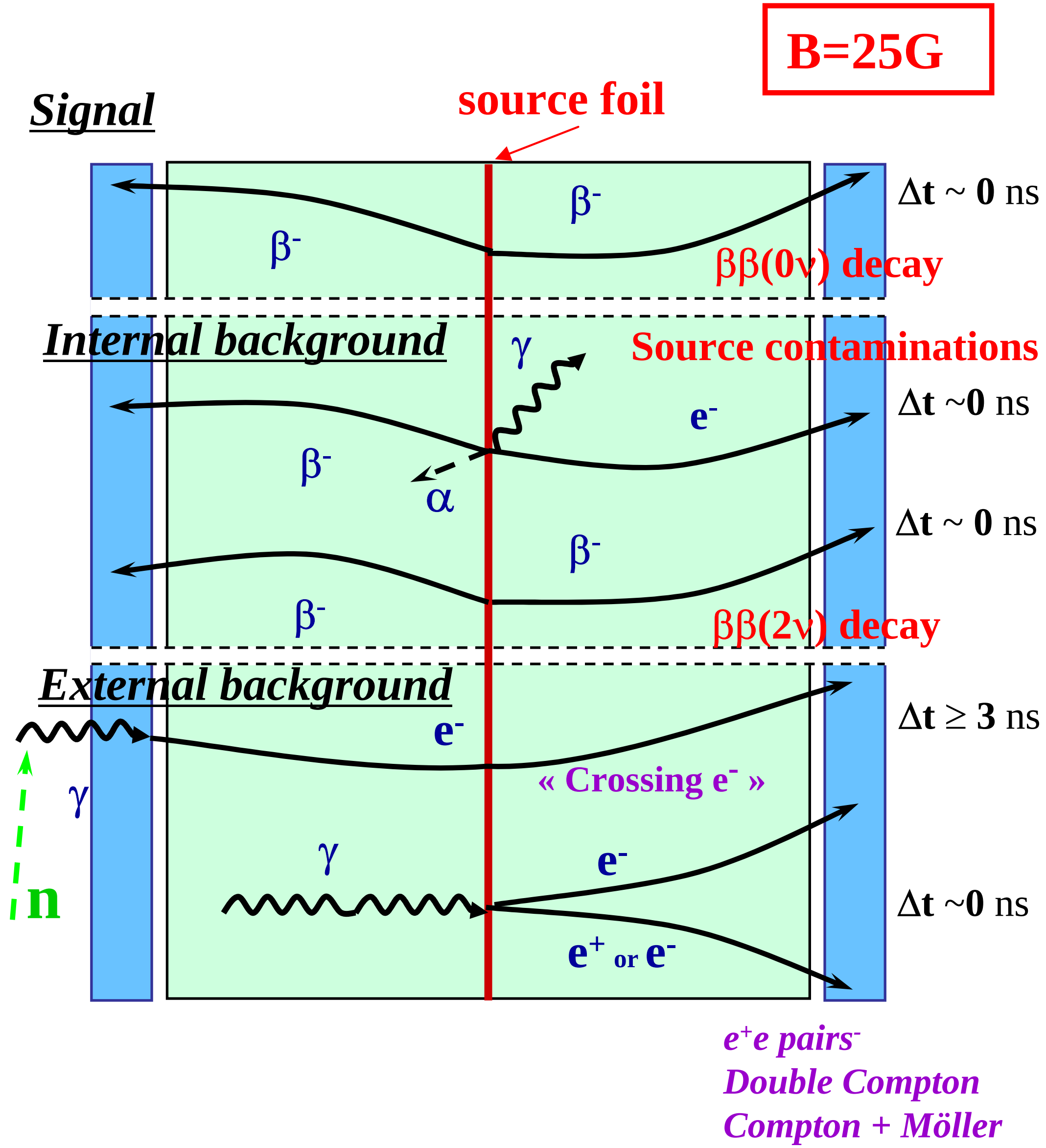
AUGUST 2001


PMTs
scintillators
ββ isotope foils
Cathodic rings
Wire chamber
Calibration tube
Calibration Source
^{207}Bi
2e^{-} (IC) lines
~0.5 ,~1 MeV
^{90}Sr
^{60}Co

How detect signals and tag the background ?

Identification of e, γ, α

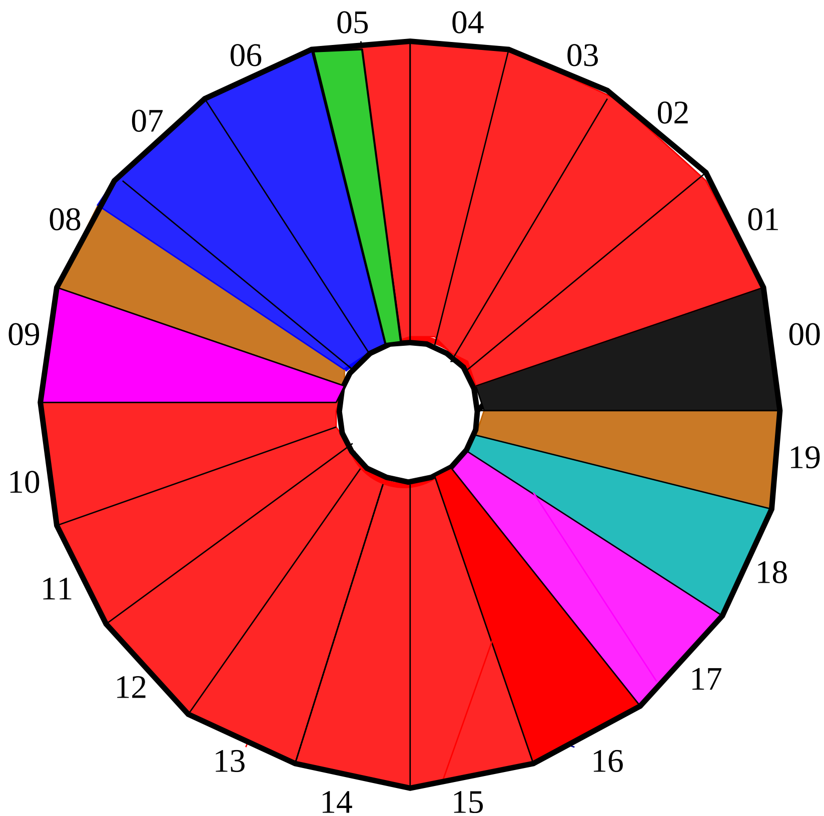
- **Tracking** (Identification e/others)
  - Delayed (<700μs) α track
- **Calorimeter** ε(γ)~50% (@0.5MeV)
  - Possible for tagging eγ, eγγ, eγγγ, …
- **Time of flight** σ_t~300ps(@1MeV)
  - External Background rejection
- **Magnetic Field** (Identification e^-/e^+)
  - 3~5% e^-/e^+ confusion @ 1~7MeV



Study of Background Process

- **^{214}Bi** Tagged by e(γ)α (~164μs)
  - (^{214}Bi->^{214}Po->^{210}Pb)
- **^{208}Tl** eγ, eγγ, eγγγ, with γ (2.6MeV)
  - or Taggd by e(γ) α (~300ns)
  - (^{212}Bi->^{212}Po->^{208}Pb)
- **Neutron** Crossing e (4~8MeV)

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)

Sources preparation

NEMO-3 Opening Day, July 2002

Start taking data 14 February 2003

wood

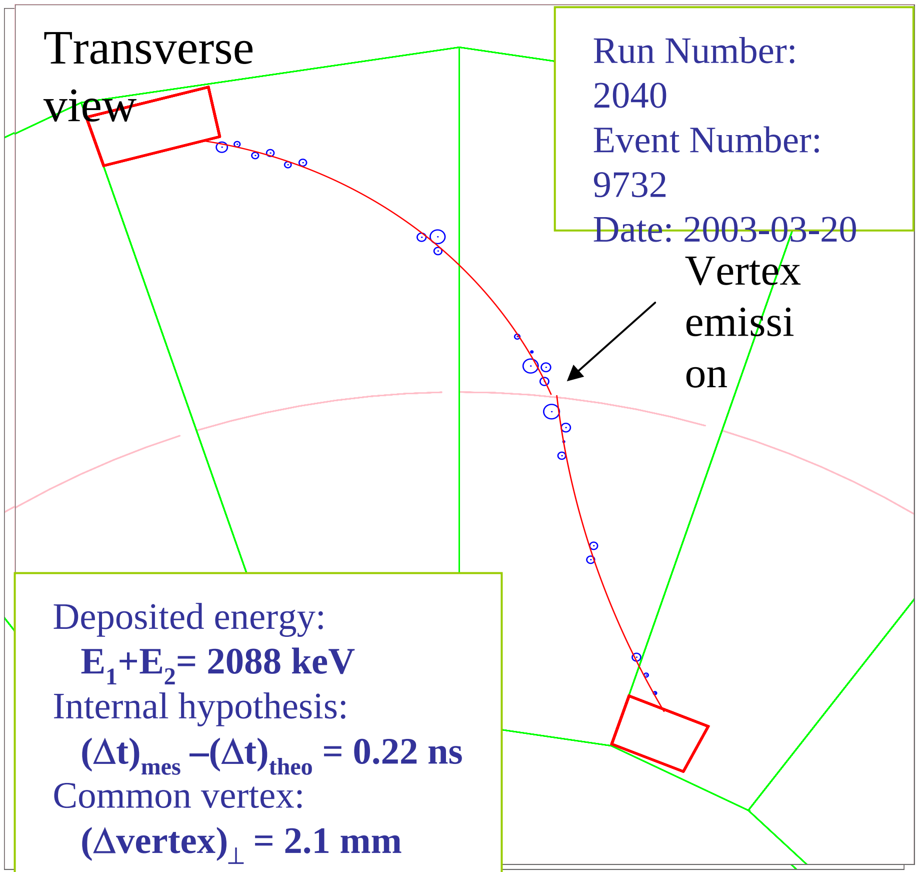
coil

Iron shield

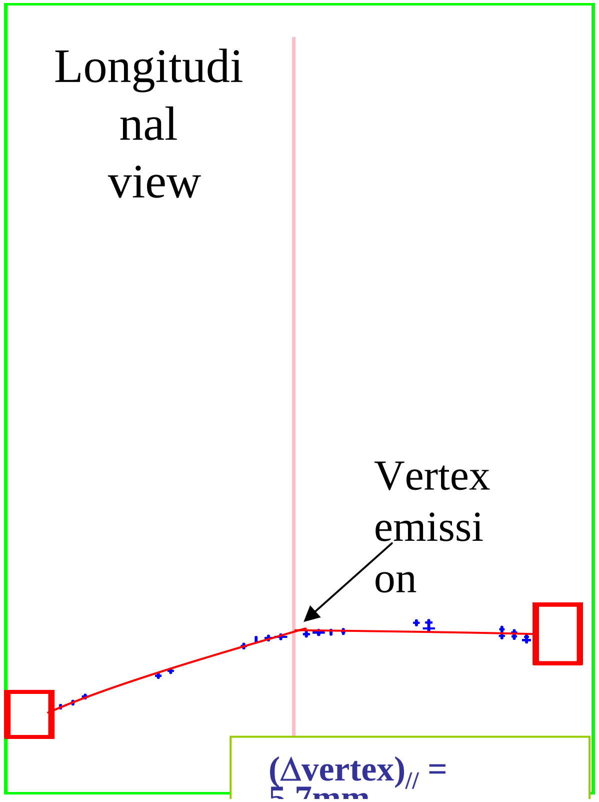
Water tank

ββ events selection in NEMO-3

Typical ββ2ν event observed from ^{100}Mo



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



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

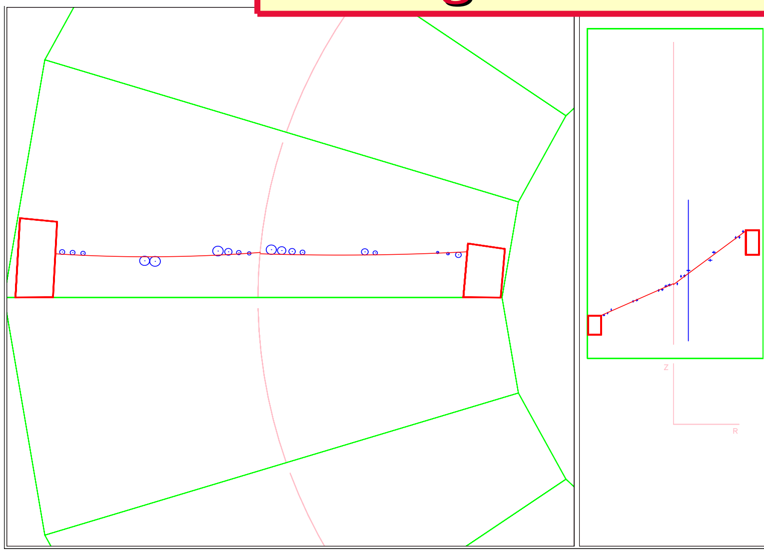
Trigger: 1 PMT > 150 keV

3 Geiger hits (2 neighbour layers + 1)

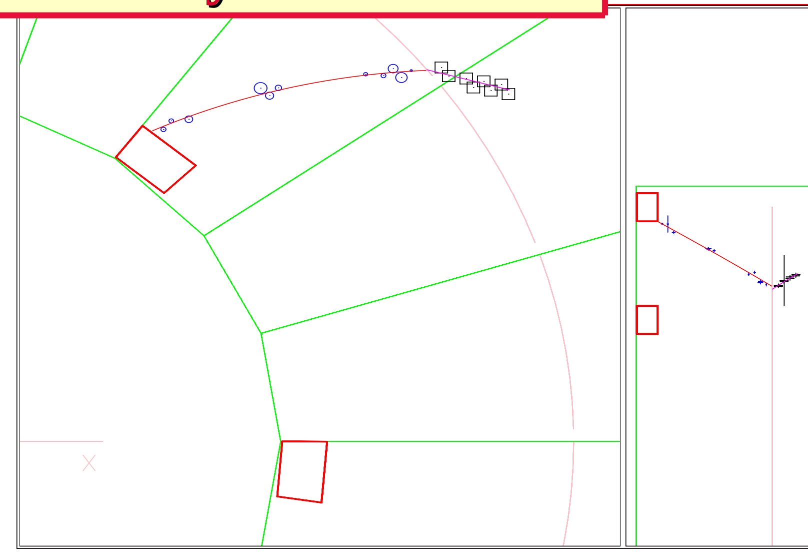
Trigger rate = 7 Hz

ββ events: 1 event every 1.5 minutes

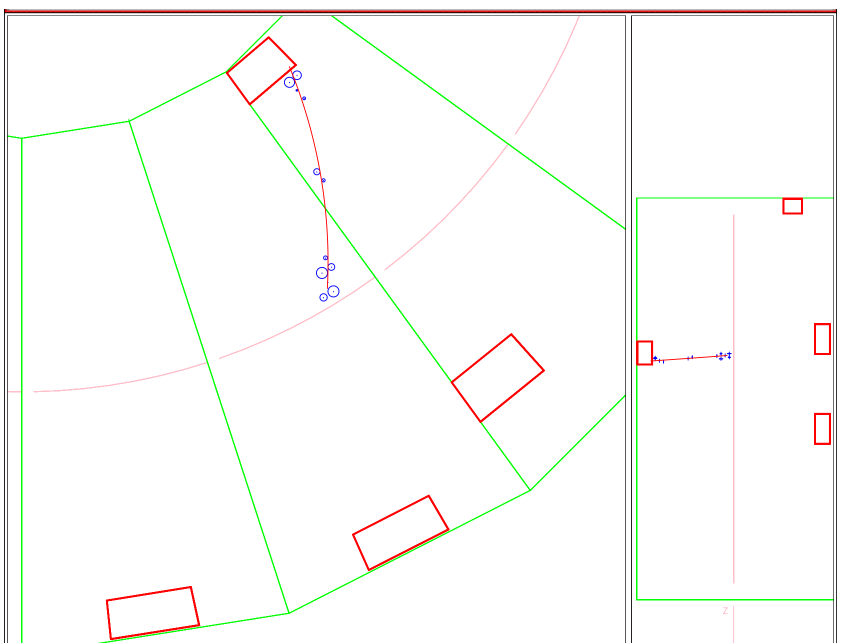
Background events observed by NEMO-3…



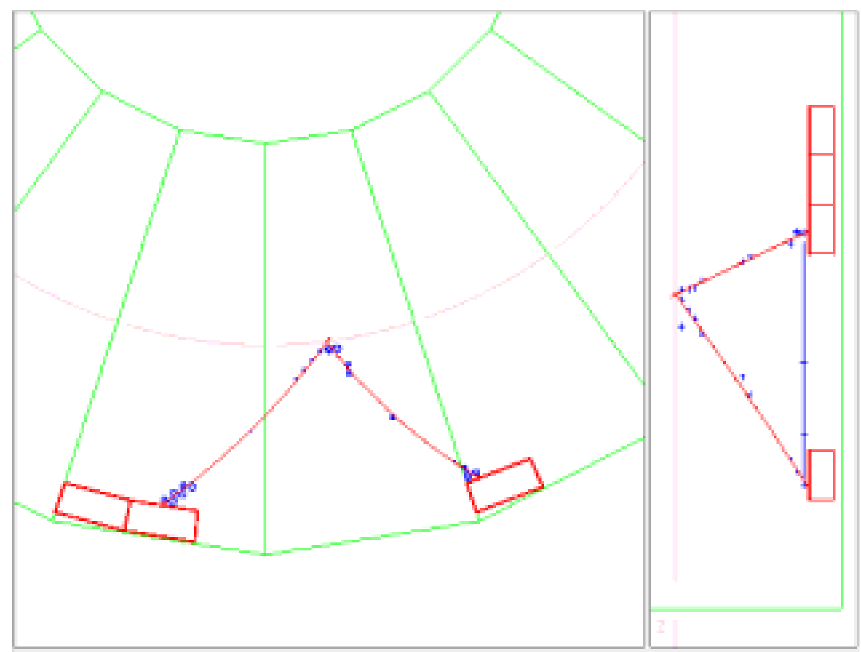
Electron crossing > 4 MeV **Neutron capture**



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**

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** (ββ channel) ≈ **250 ps at 1 MeV**

ToF (external crossing e⁻) > 3 ns

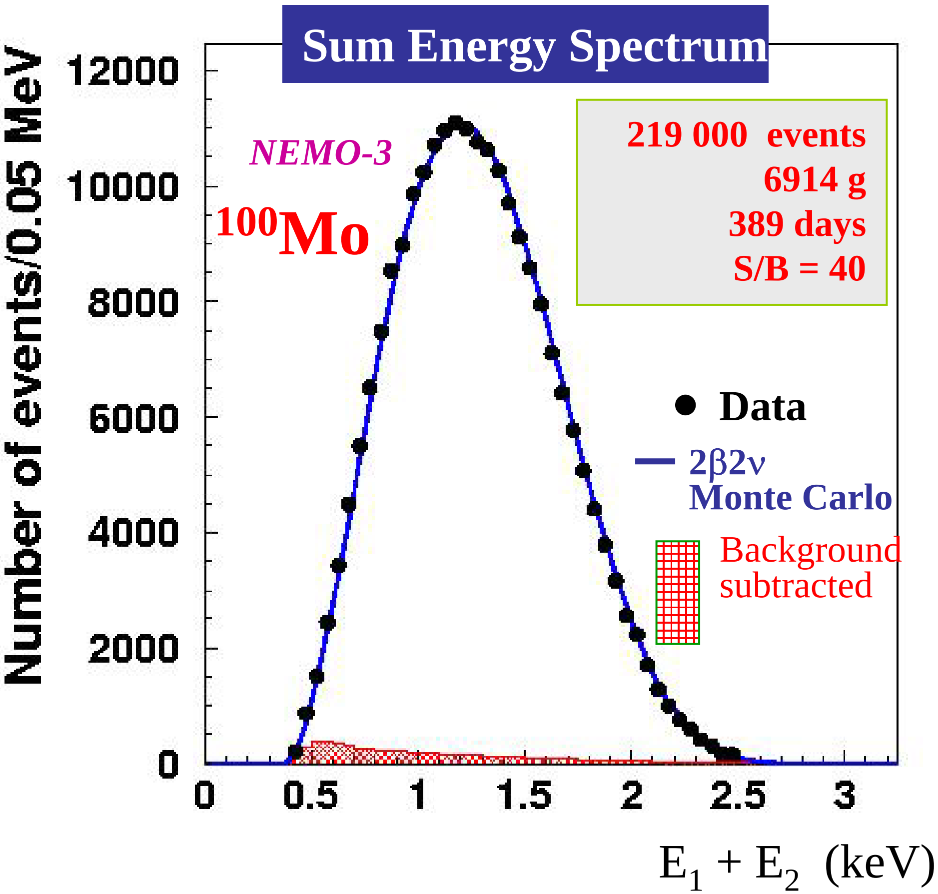
external crossing e⁻ totaly rejected

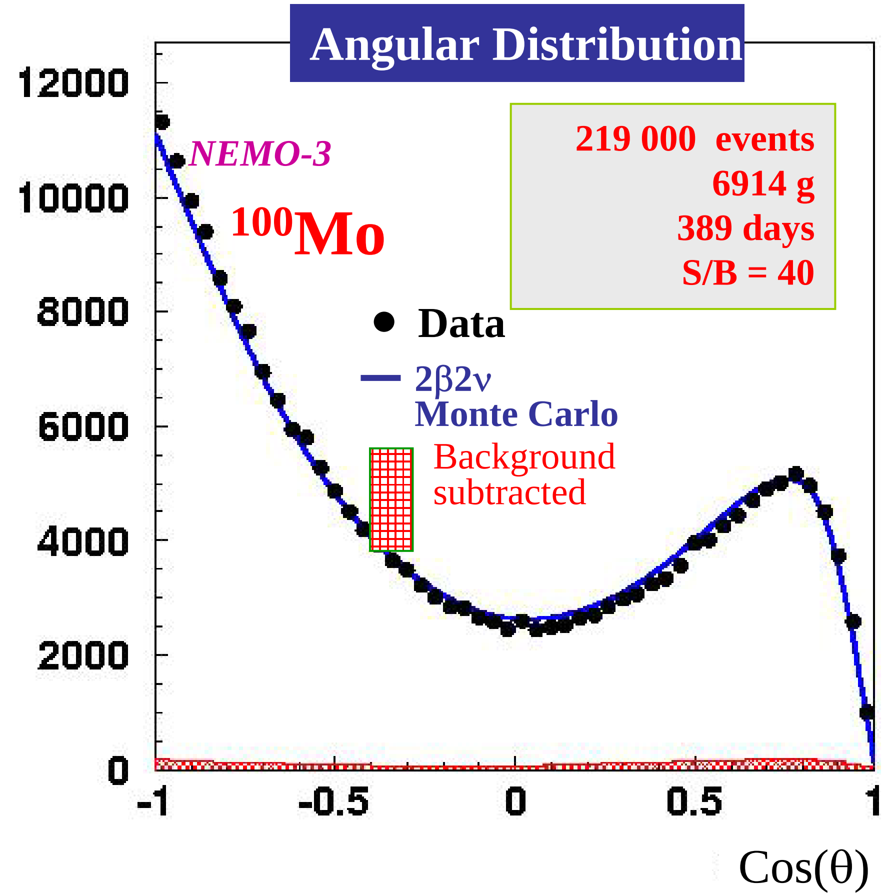
Expected Performance of the detector has been reached

$2\beta2\nu$ decay results in NEMO-3

^{100}Mo 2β2ν preliminary results

(Data Feb. 2003 – Dec. 2004)

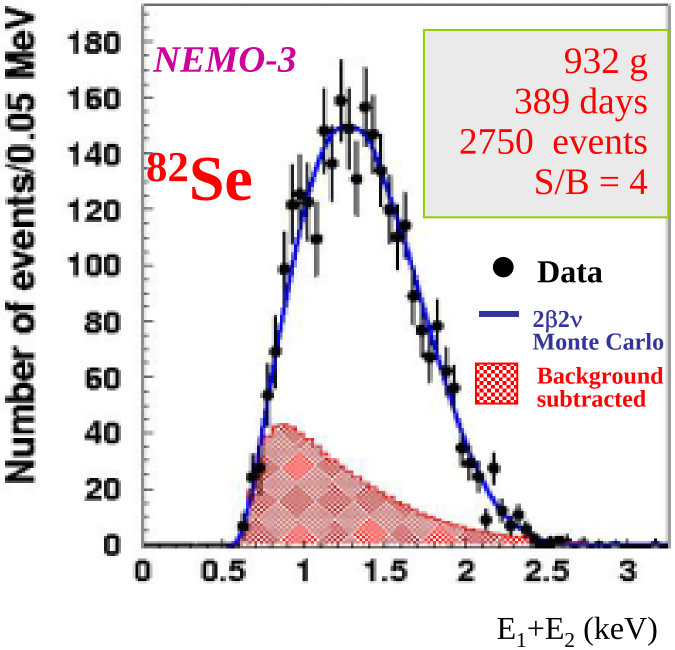




7.37 kg.y

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

$2\beta2\nu$ preliminary results for other nuclei



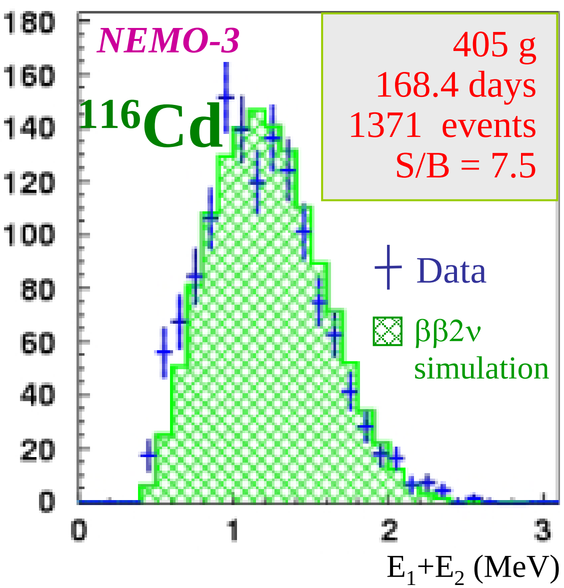
^{82}Se $T_{1/2} = 9.6 \pm 0.3\ (\text{stat}) \pm 1.0\ (\text{syst}) \times 10^{19}$ y

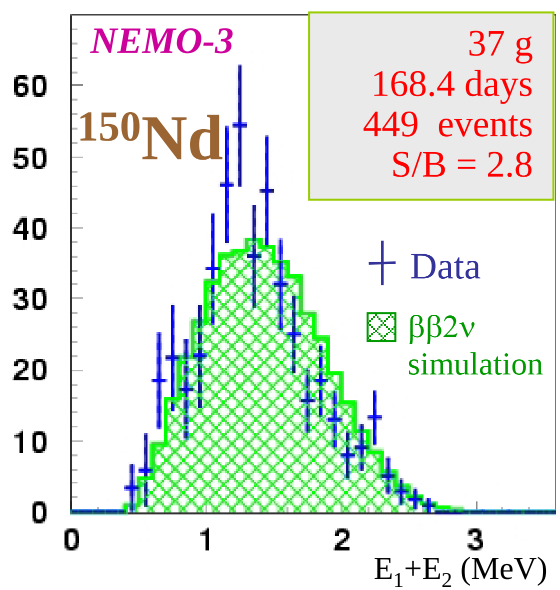
^{116}Cd $T_{1/2} = 2.8 \pm 0.1\ (\text{stat}) \pm 0.3\ (\text{syst}) \times 10^{19}$ y

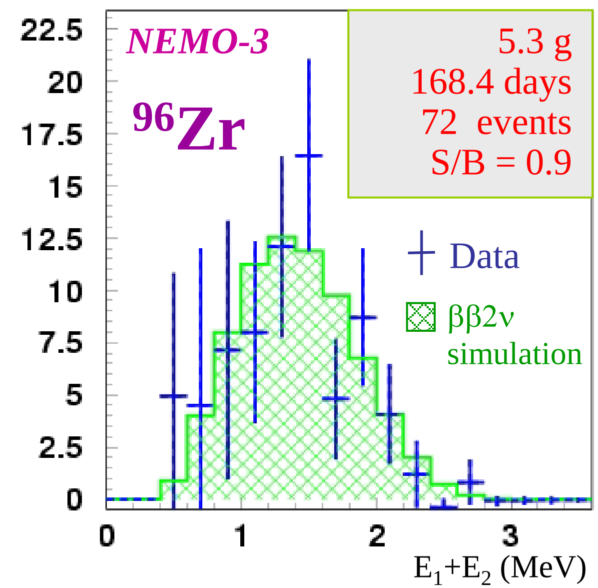
^{150}Nd $T_{1/2} = 9.7 \pm 0.7\ (\text{stat}) \pm 1.0\ (\text{syst}) \times 10^{18}$ y

^{96}Zr $T_{1/2} = 2.0 \pm 0.3\ (\text{stat}) \pm 0.2\ (\text{syst}) \times 10^{19}$ y

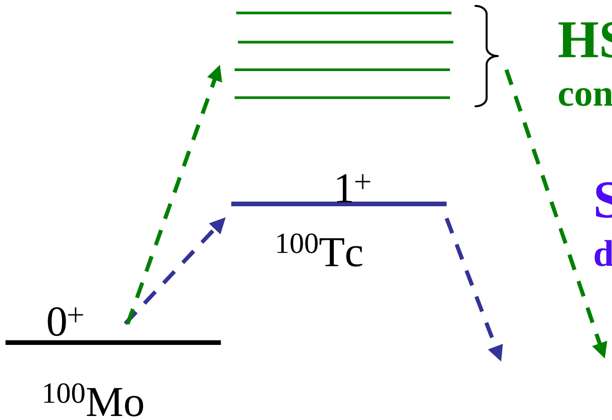
Background subtracted







^{100}Mo 2β2ν Single Energy Distribution

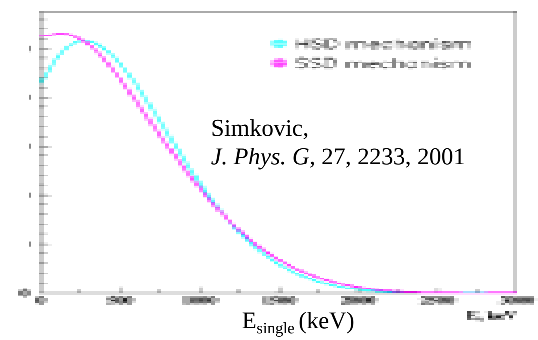


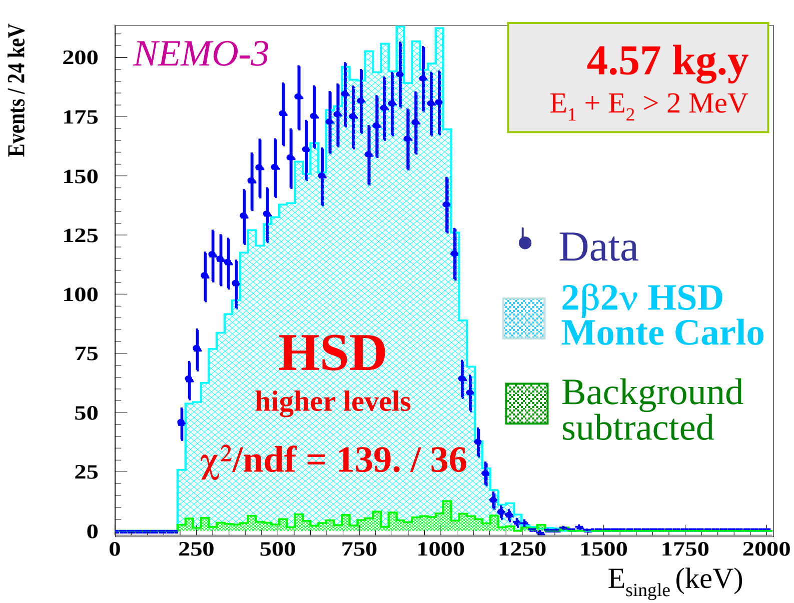
HSD, higher levels contribute to the decay

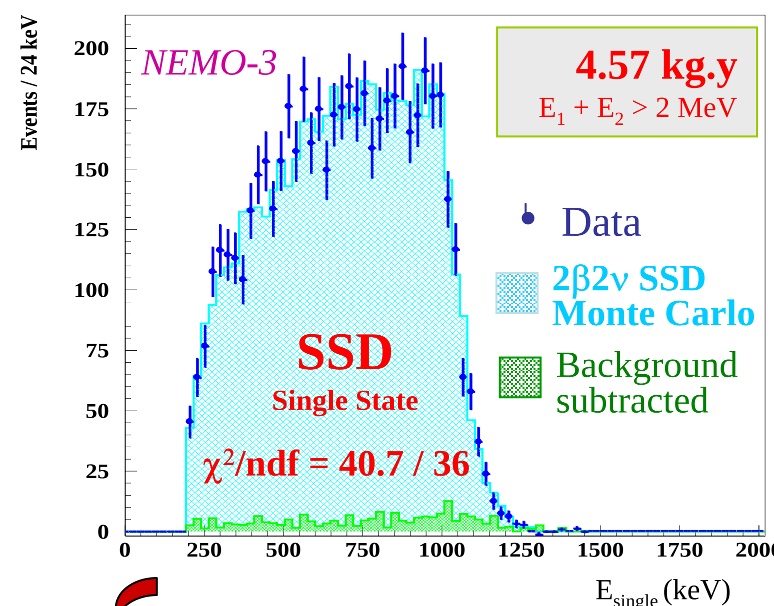
SSD, 1^+ level dominates in the decay

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

Single electron spectrum different between SSD and HSD







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

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

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

Search for 2β0ν decay in NEMO-3

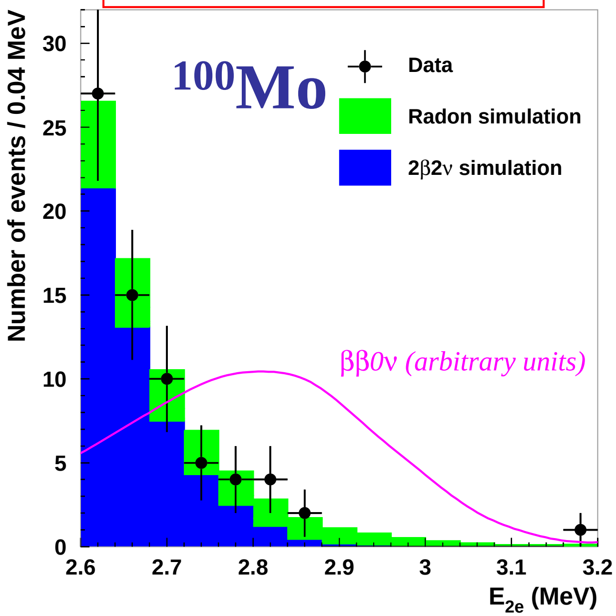
Limit on the effective mass of the Majorana neutrino

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



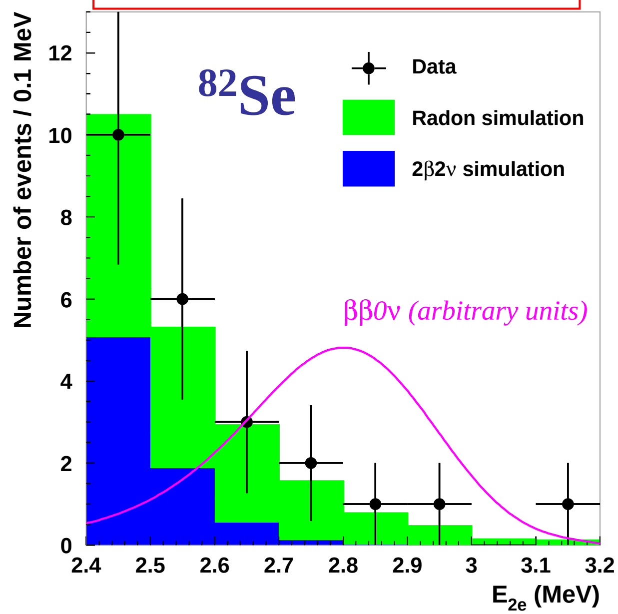
[2.8-3.2] MeV: $\varepsilon(\beta\beta0\nu)$ = 8 %
Expected bkg = 8.1 ± 1.3
$N_{observed}$ = 7 events

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

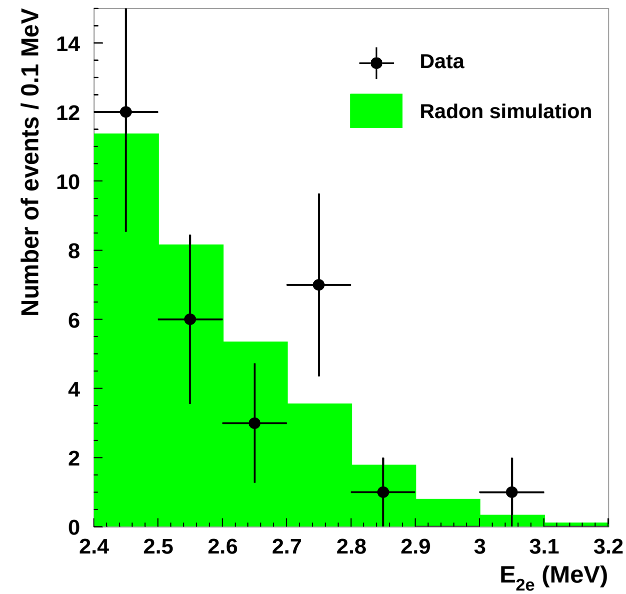


[2.7-3.2] MeV: $\varepsilon(\beta\beta0\nu)$ = 13 %
Expected bkg = 3.1 ± 0.6
$N_{observed}$ = 5 events

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)

$\beta\beta 0\nu$ 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} $\beta\beta 0\nu$-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

$\lesssim$ 0.02 $\beta\beta 0\nu$-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)

- 4253 keV (26 Mar. 2003)
- 6361 keV (8 Nov. 2003)

In agreement with expected background

➢ ^{208}Tl impurities inside the foils

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

~ 0.1 $\beta\beta 0\nu$-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 $\beta\beta 2\nu$ decay

$T_{1/2} = 7.7\ 10^{18}$ y (SSD)

~ 0.3 $\beta\beta 0\nu$-like events year^{-1} kg^{-1} with $2.8 < E_1 + E_2 < 3.2$ MeV

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

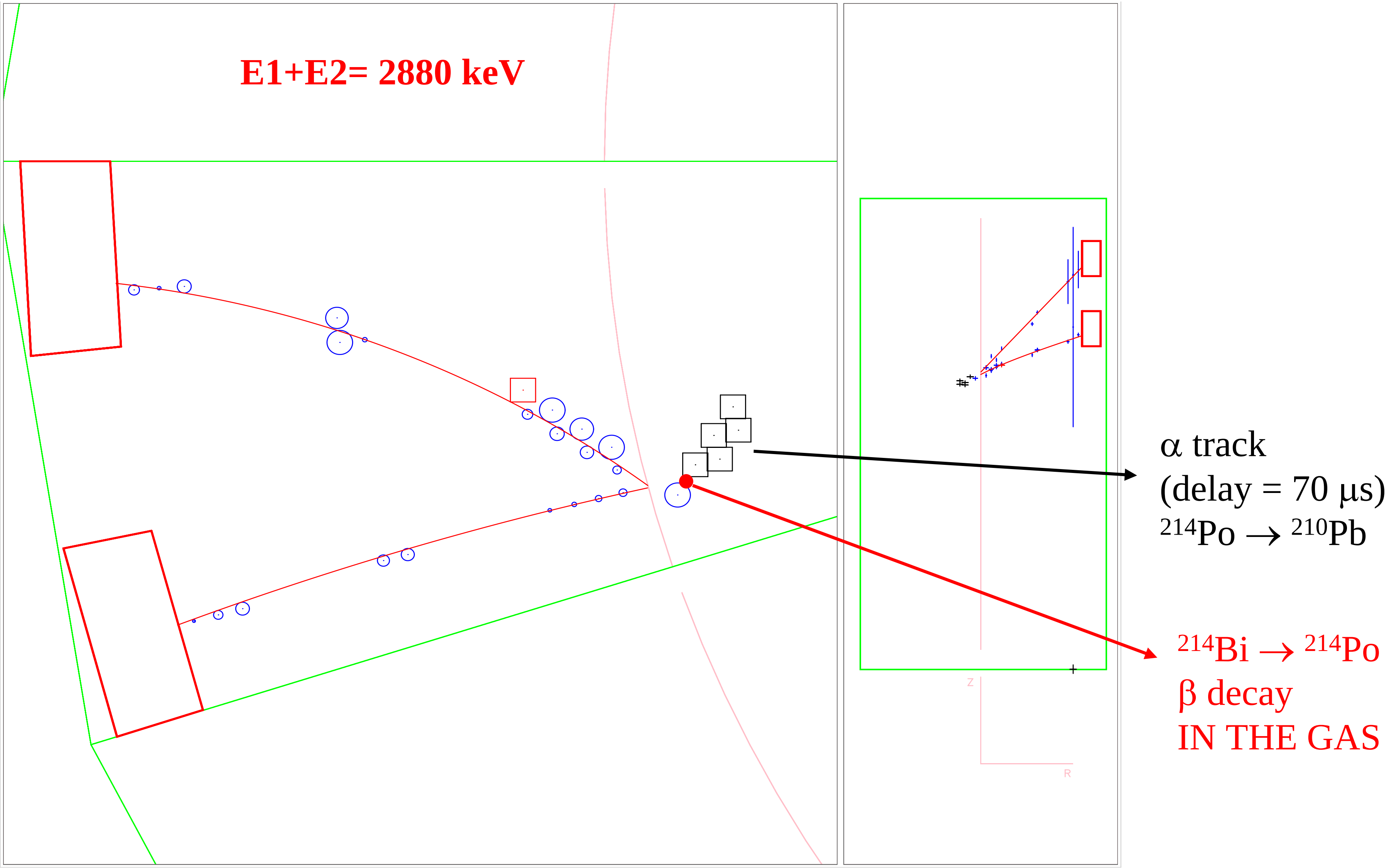
$\lambda < 3.2\ 10^{-6}$

Tomoda (1991)

Radon effect and fight against radon

a ββ0ν-like event due to Radon from the gas

Run 2220, event 136.604, May 11th 2003



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**

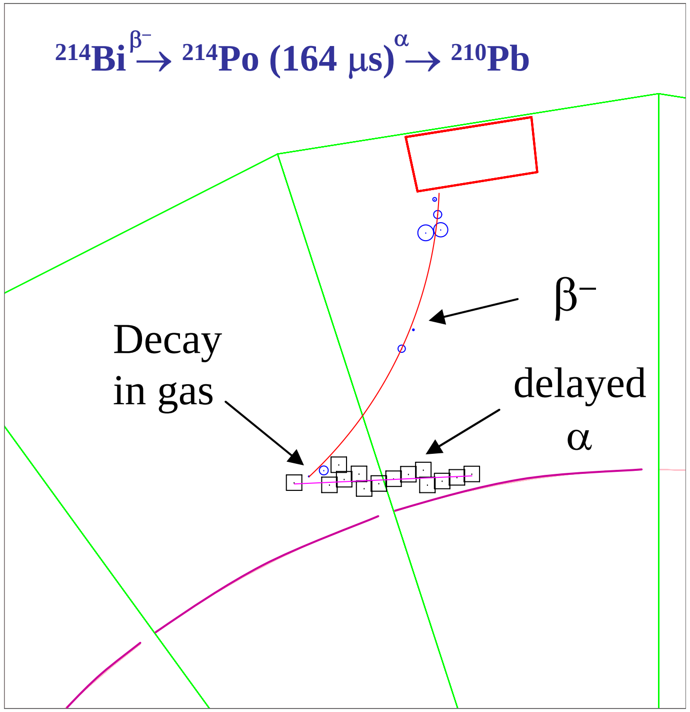
  ~ 20 counts/day for 20 mBq/ m^3

- **(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

~ 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 !!!

NEMO Tent for Free-Radon air Installation

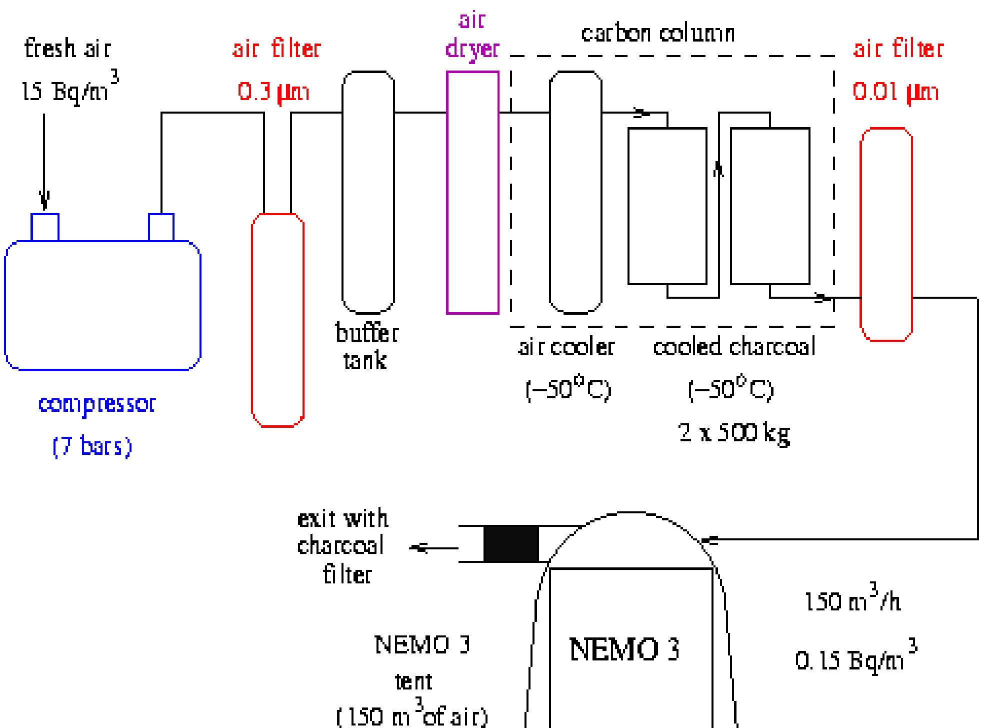
May 2004 : Tent surrounding the detector

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

(Without Radon)

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.)**
$\langle m_\nu \rangle < 0.2 – 1.3$ eV

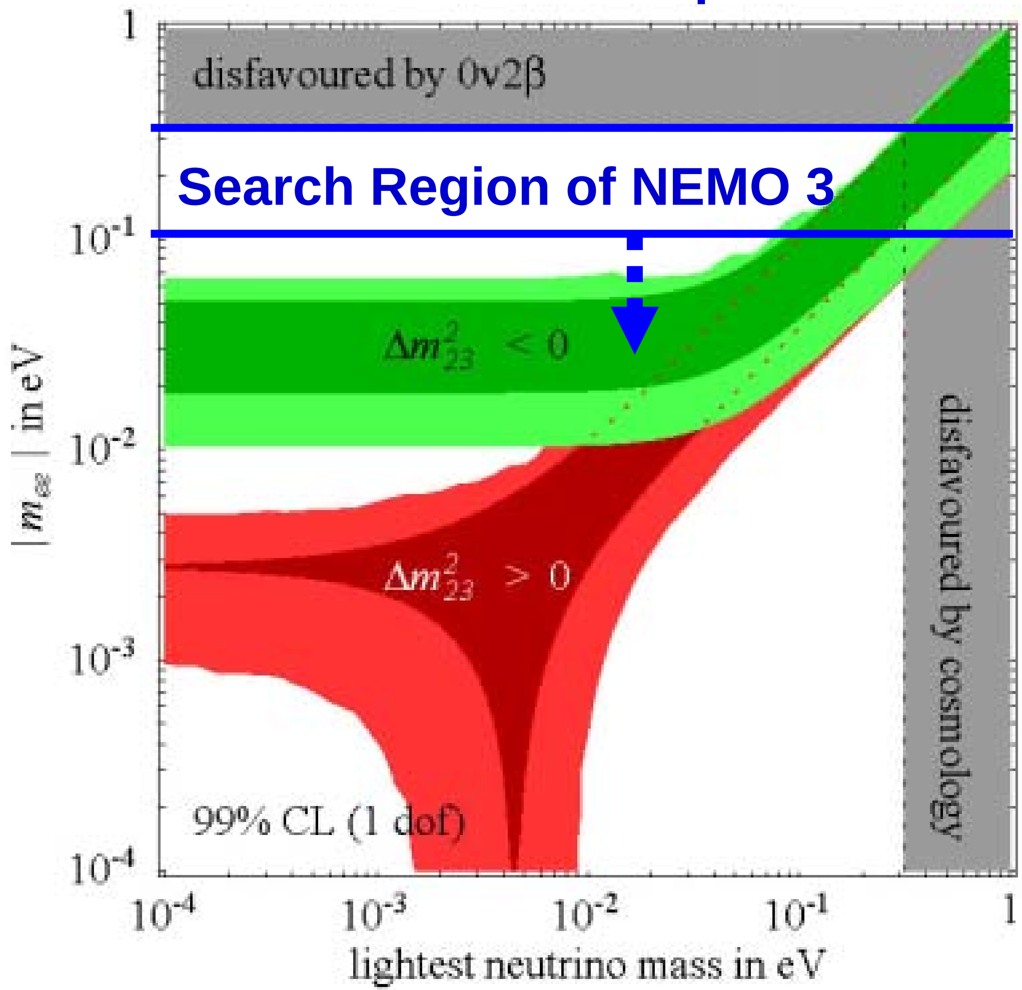
932 g of ^{82}Se **$T_{1/2}(\beta\beta0\nu) > 8\ .10^{23}$ y (90% C.L.)**
$\langle m_\nu \rangle < 0.6 – 1.7$ eV

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

From NEMO 3 to SuperNEMO

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

From NEMO 3 to Super-NEMO



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

(hep-ph/0503246 A.Strumia and F.Vissani)

From NEMO to SuperNEMO

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

Light Majorana neutrino exchange: $\langle m_\nu \rangle$ ~50 meV

Detection efficiency — Mass of isotope ββ (g)

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

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

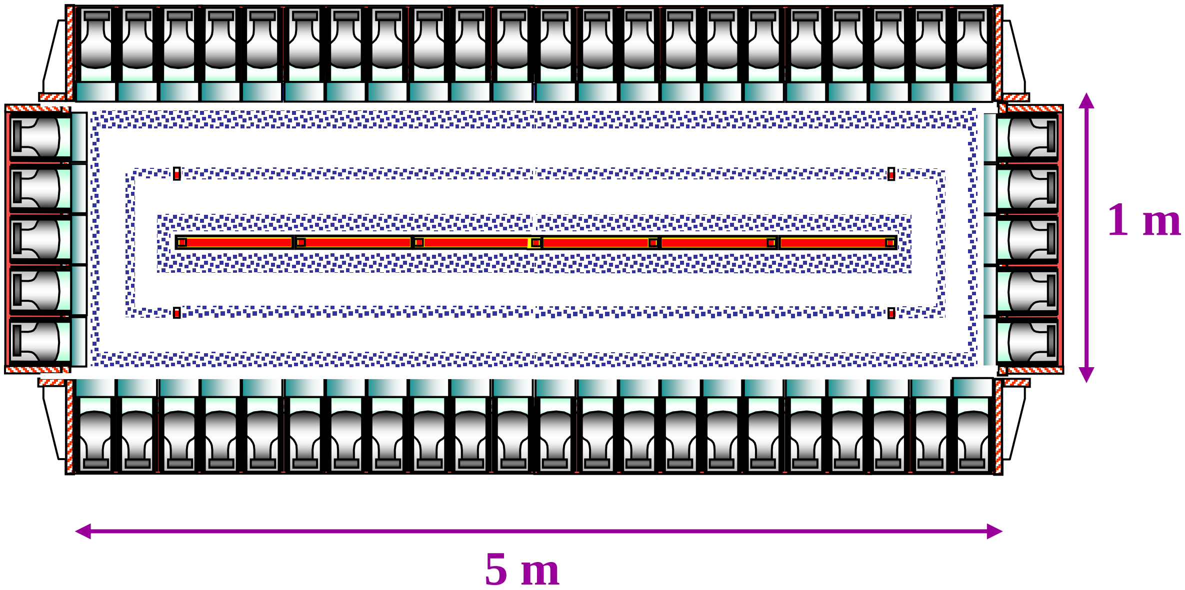
Source (40 mg/cm^2) 12m^2, tracking volume (~3000 channels) and calorimeter (~1000 PMT)

Modular (~ 5 kg of enriched isotope/module)

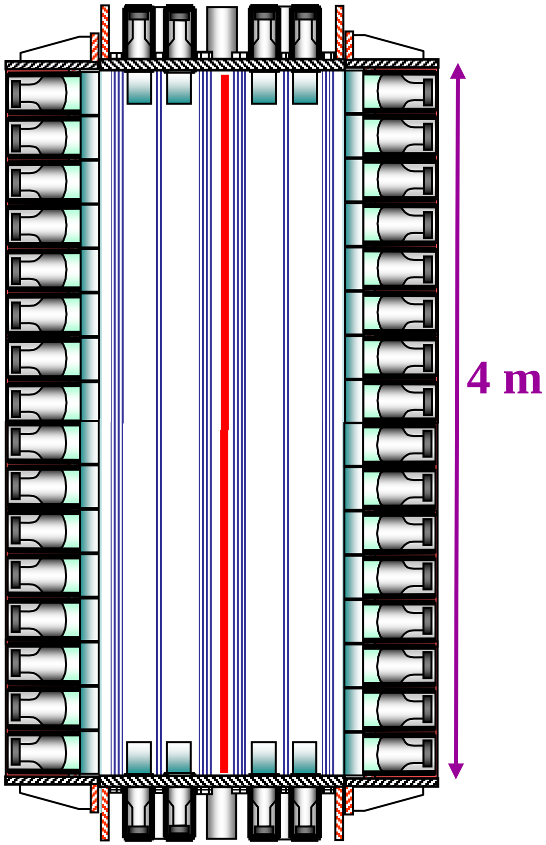
100 kg: 20 modules

~ 60 000 channels for drift chamber

~ 20 000 PMT

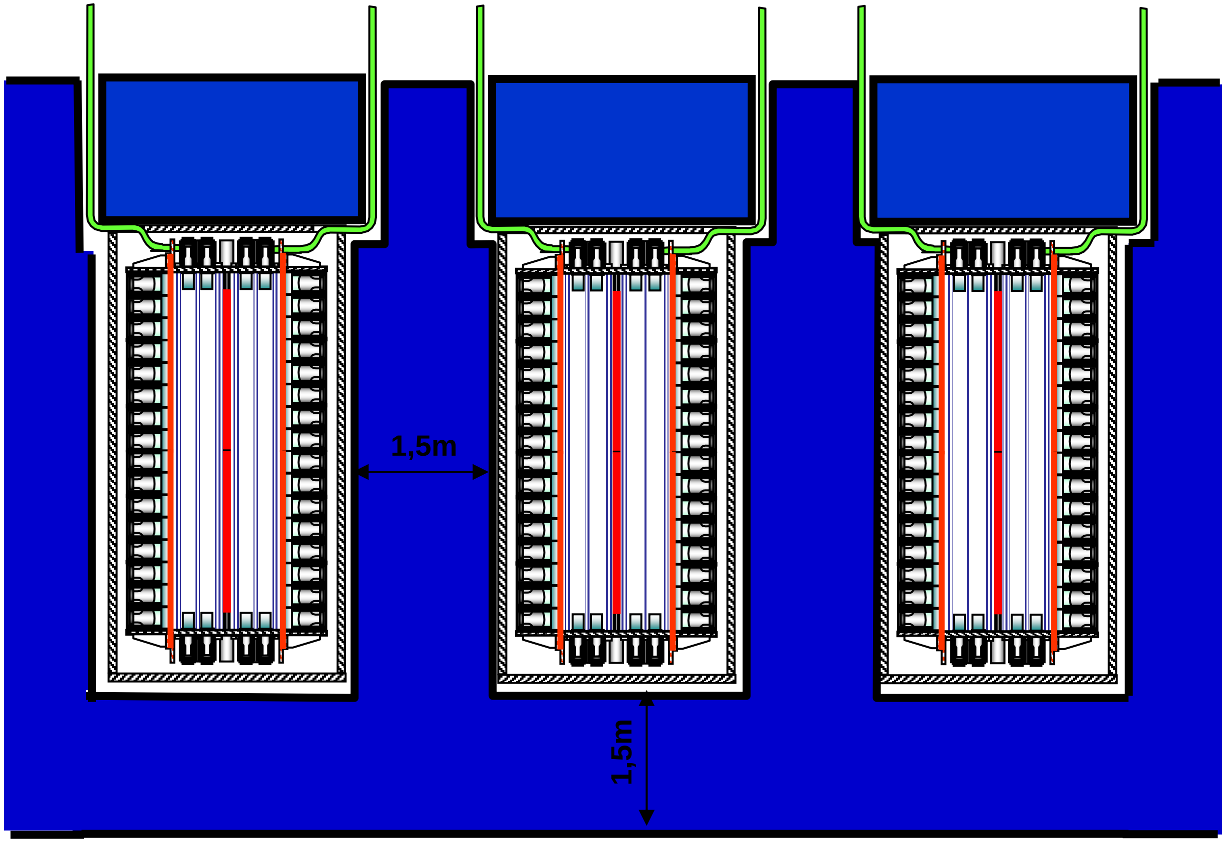


Top view



Side view

Water shield



Need of cavity of ~ 60m x 15m x15m

Possible in Gran Sasso or in Modane if a new cavity

Concluding Remarks

- NEMO3 is running for ≈ 5 years
- What we learnt with NEMO
  - 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)

⇒ technique can be extrapolated
R&D program for Super NEMO

Thank you