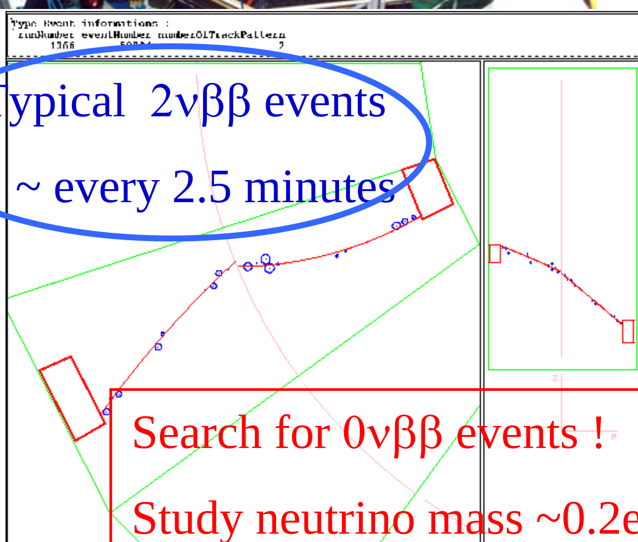
NEMO 3 and SuperNEMO

Hideaki OHSUMI (Saga Univ.)
(NEMO/SuperNEMO Collaboration)

(Present) NEMO 3 is now runing at LSM

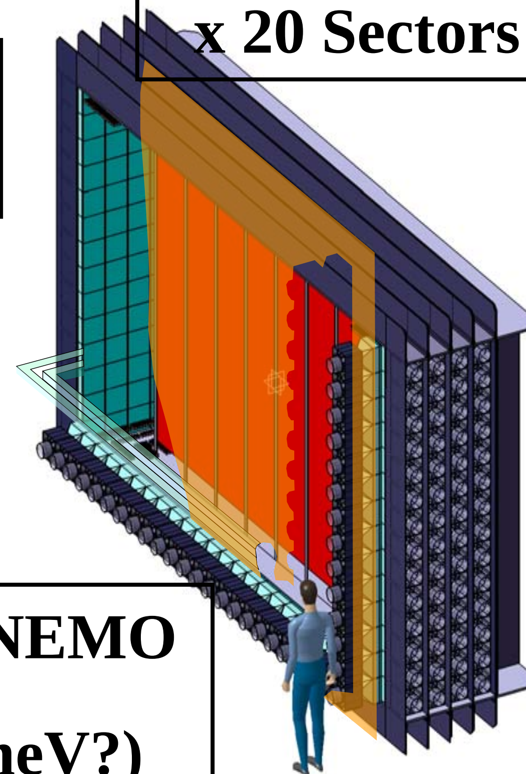


Typical 2νββ events

~ every 2.5 minutes

Search for 0νββ events !

Study neutrino mass ~0.2eV



x 20 Sectors

(Future) SuperNEMO

to find ν_m (50meV?)

PLAN

- **Short quick tour of NEMO-3 detector**
- **Overview of 2νββ results**
  (^{100}Mo , ^{82}Se , ^{116}Cd, ^{150}Nd ,^{96}Zr ^{48}Ca)
  Single electron spectrum (^{100}Mo)
  Decay to the excited 0^+ (^{100}Mo)
- **Phase I → Phase II (Low radon) and 0νββ results**

- **SuperNEMO**

Philosophy of the NEMO-3 experiment

- **Neutrinoless Double Beta Decays ($0\nu\beta\beta$)**

  Majorana ν and effective mass $<m_\nu>$? or new physics (SUSY) ?

- **Measure several isotopes ($0\nu\beta\beta$, $2\nu\beta\beta$)**

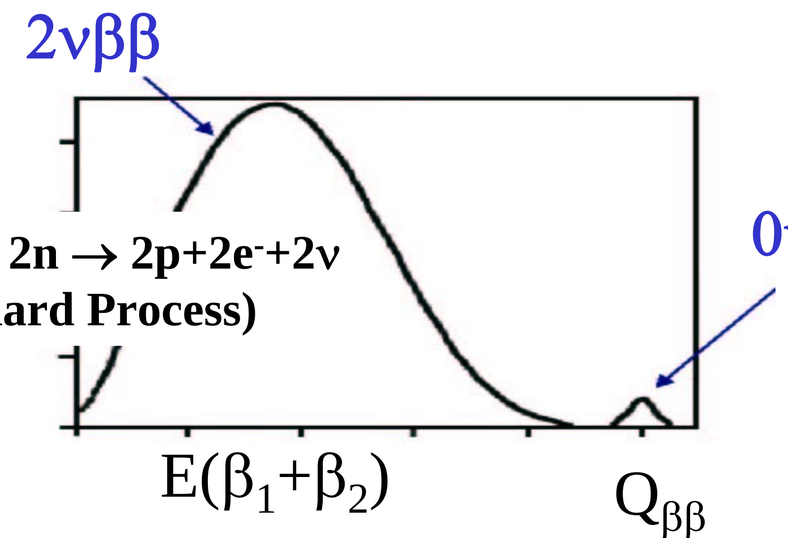
  ^{100}Mo(~7kg) , ^{82}Se(~1kg) , ^{130}Te , ^{116}Cd, ^{96}Zr , ^{48}Ca , ^{150}Nd (no ^{76}Ge, ^{136}Xe)

- **Tag and measure all the BG events**

  e^-, e^+, γ, α, neutron

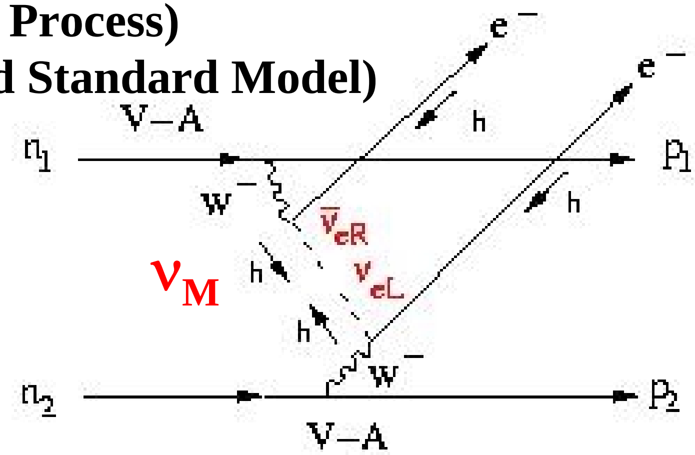
  Tracking chamber+Calorimeter+$\vec{B}$-field+Shields

→ "zero background" experiment



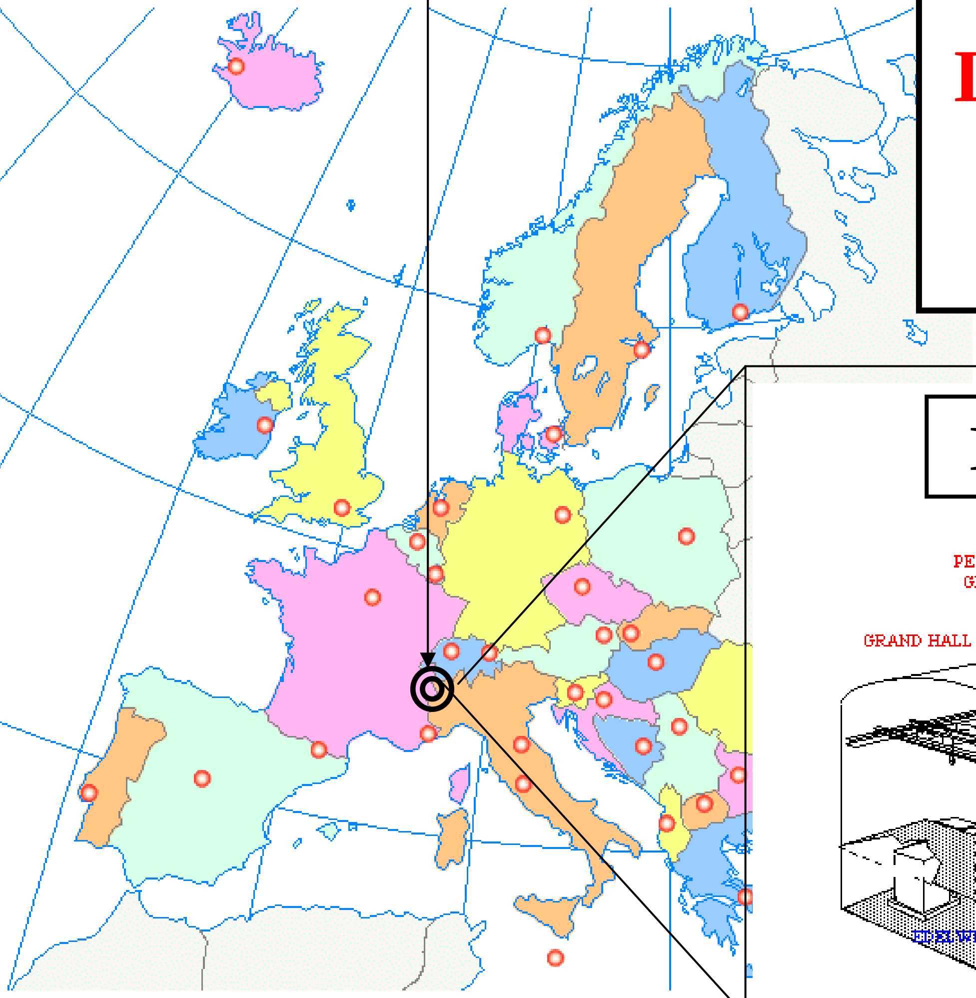
$2\nu\beta\beta$: $2n \rightarrow 2p+2e^-+2\nu$
(Standard Process)

$0\nu\beta\beta$: $2n \rightarrow 2p+2e^-$
($\Delta L = 2$ Process)
(Beyond Standard Model)



The Location of the NEMO3

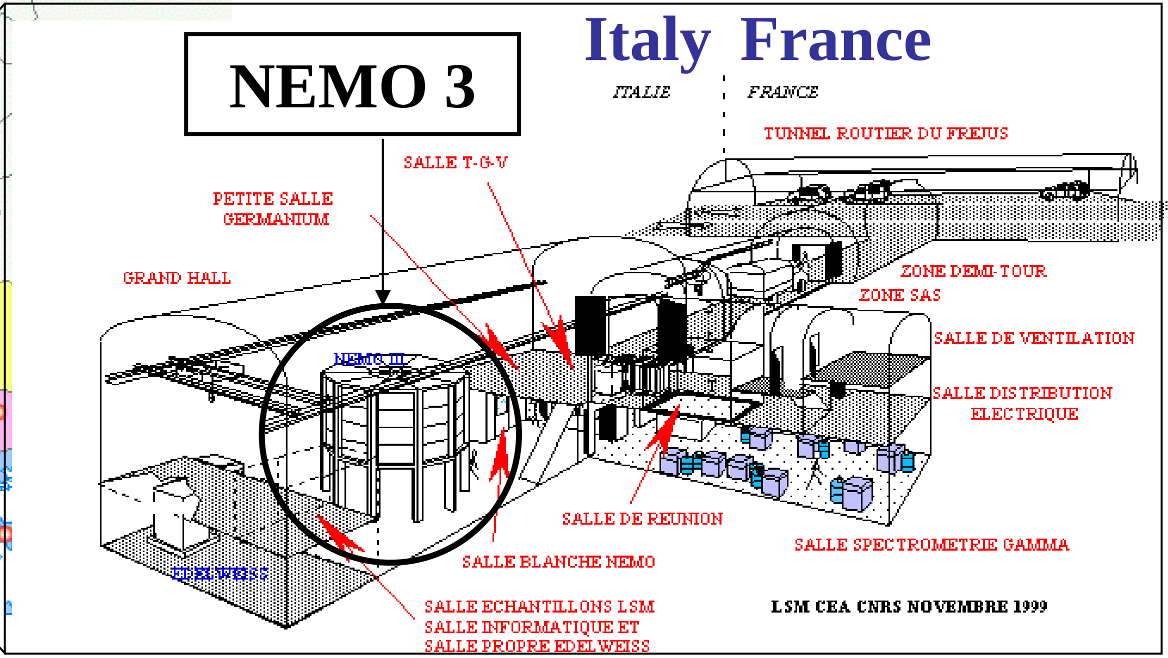
NEMO 3 is here !



Frejus Underground Laboratory

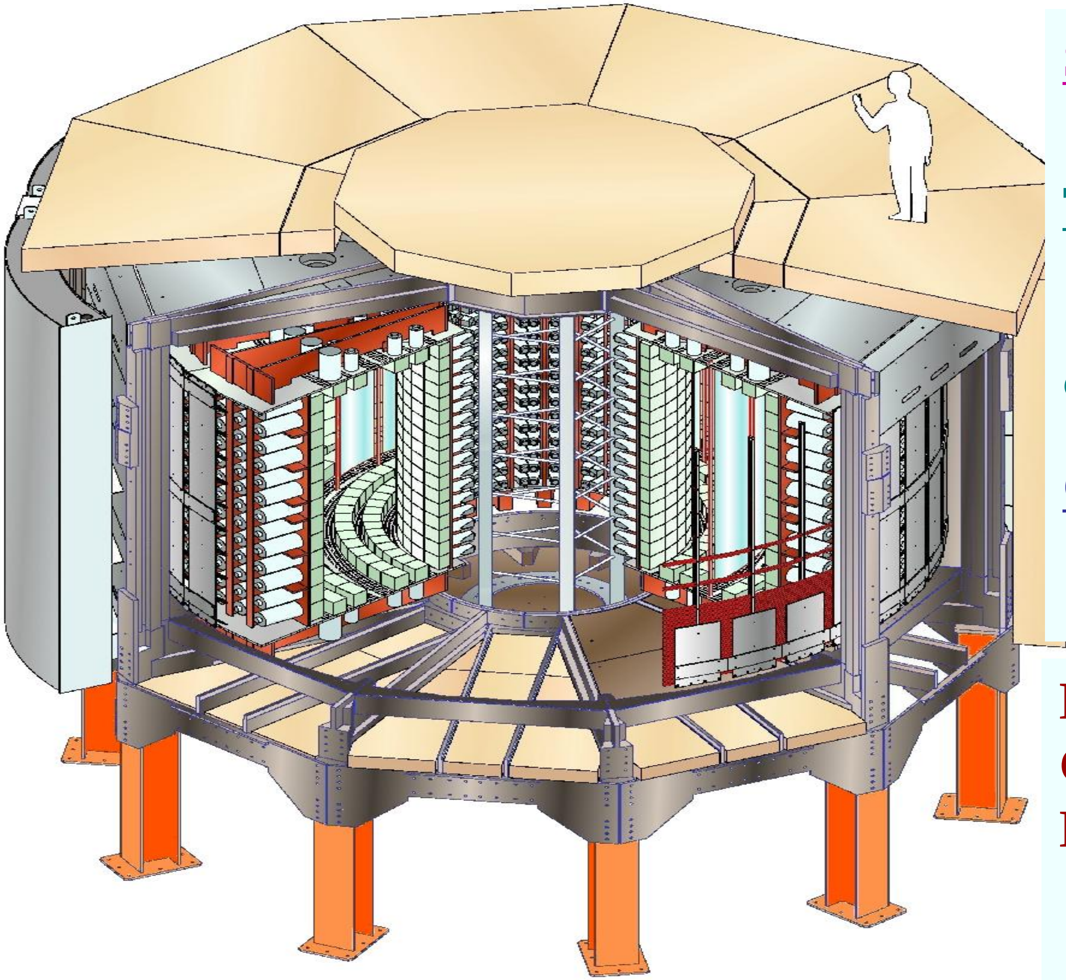
Laboratoire Souterraine de Modane(LSM)

(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

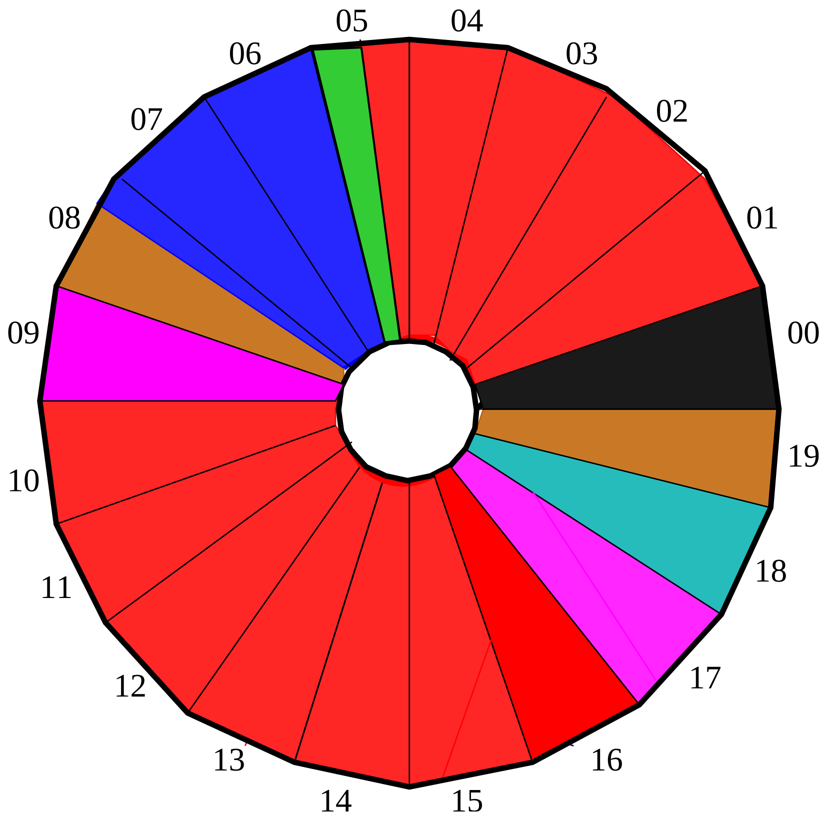
Calorimeter:
1940 plastic scintillators
coupled to low radioactivity PMTs

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**


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

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

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)

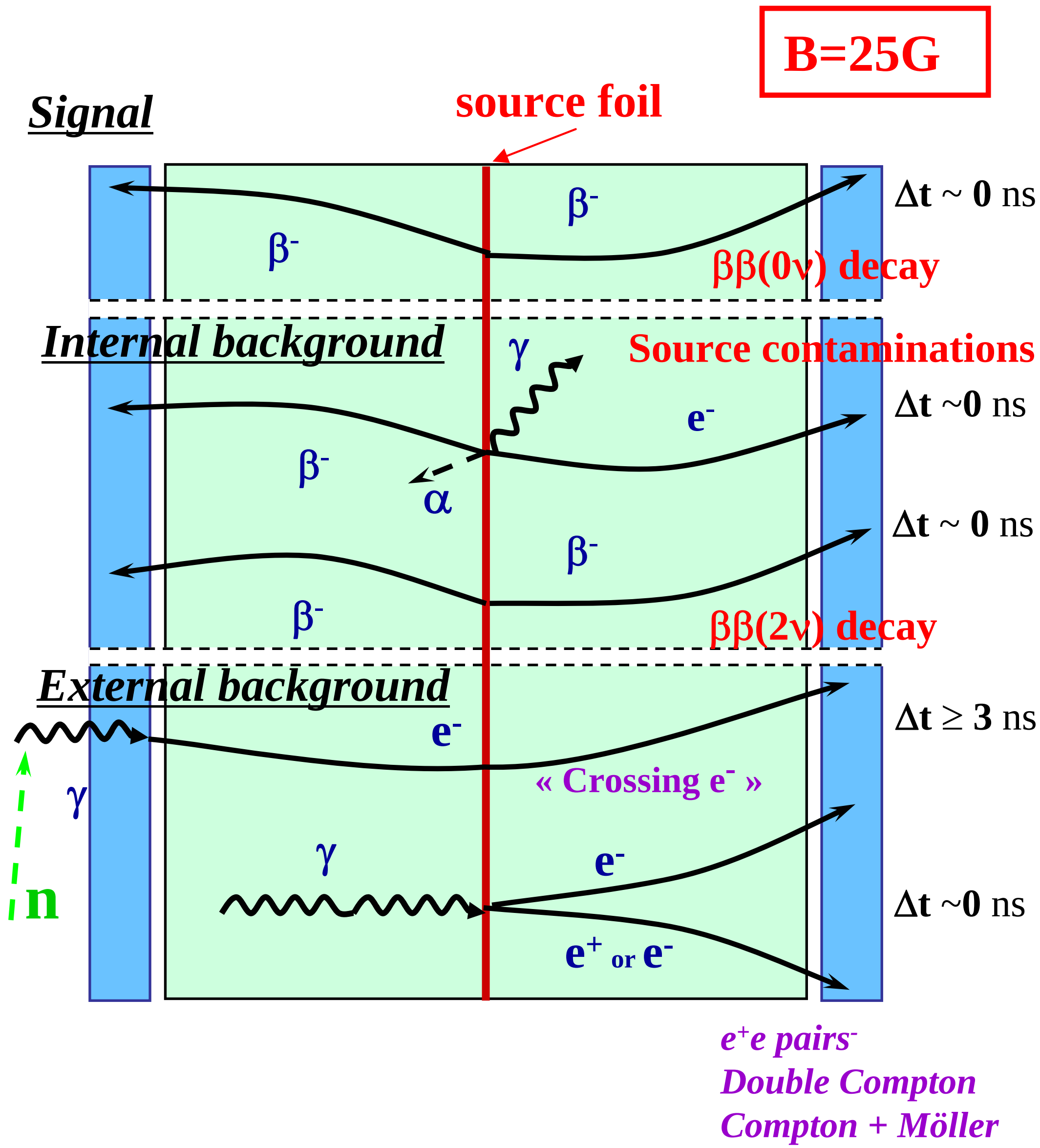
  (^{214}Bi->^{214}Po->^{210}Pb)

- **^{208}Tl** eγ, eγγ, eγγγ, with γ (2.6MeV)

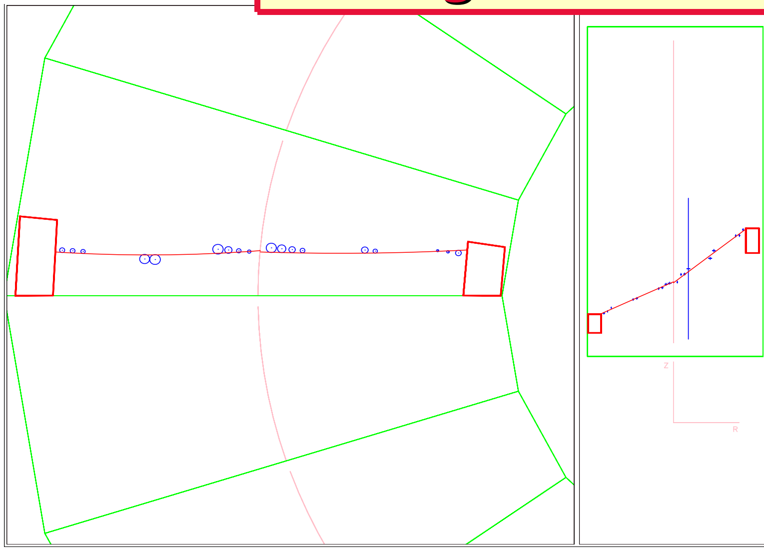
  or Taggd by e(γ) α (~300ns)

  (^{212}Bi->^{212}Po->^{208}Pb)

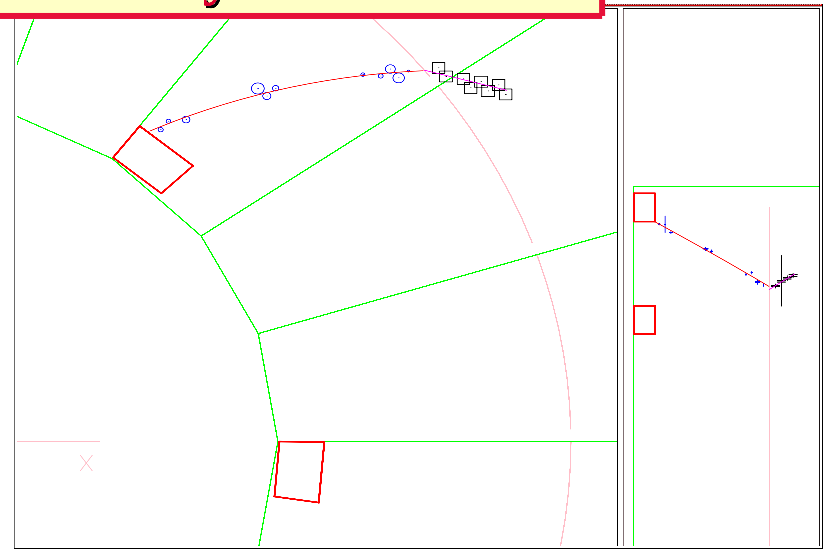
- **Neutron** Crossing e (4~8MeV)



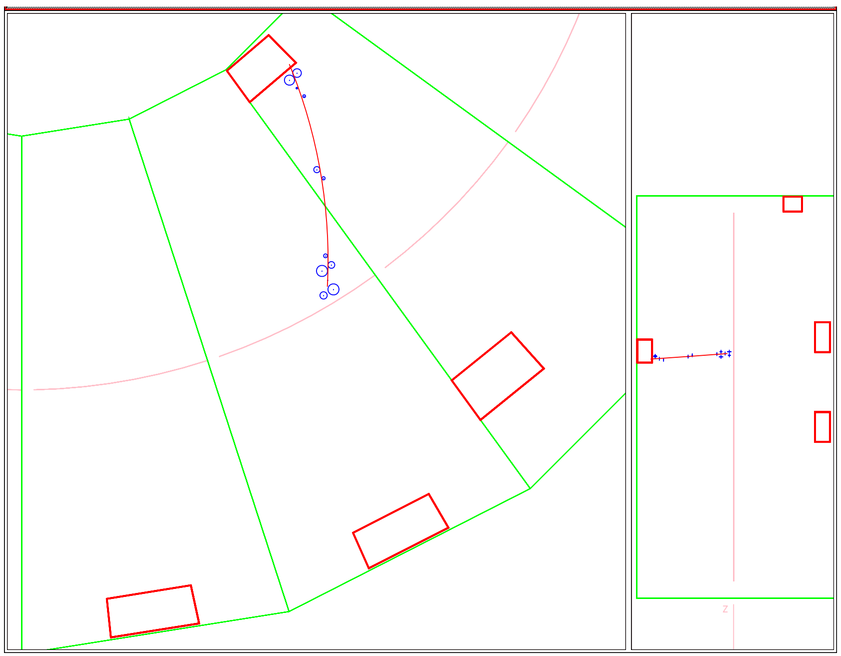
Background events observed by NEMO-3…



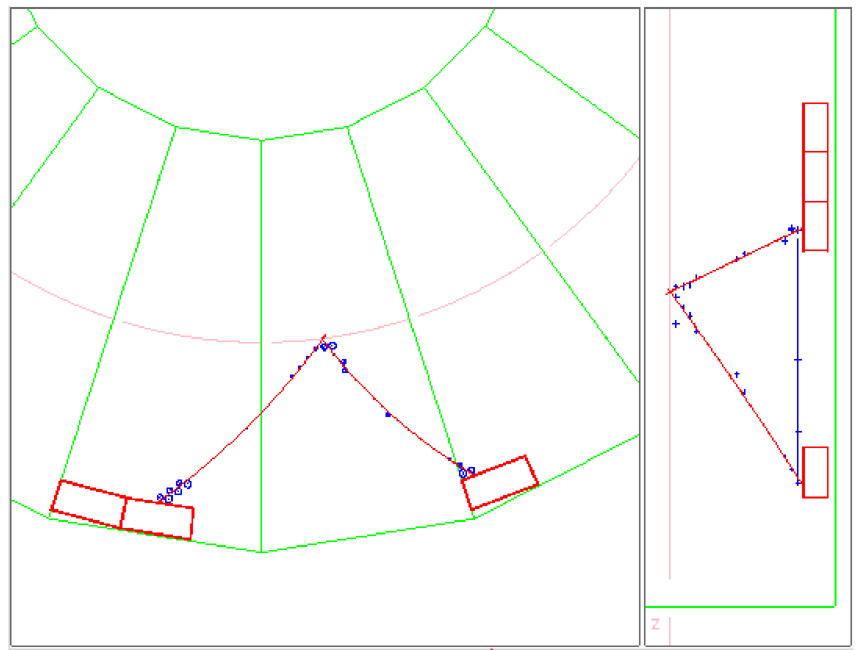
Electron crossing > 4 MeV **Neutron capture**



Electron + α delay track (164 μs) ^{214}Bi $\rightarrow$ ^{214}Po $\rightarrow$ ^{210}Pb



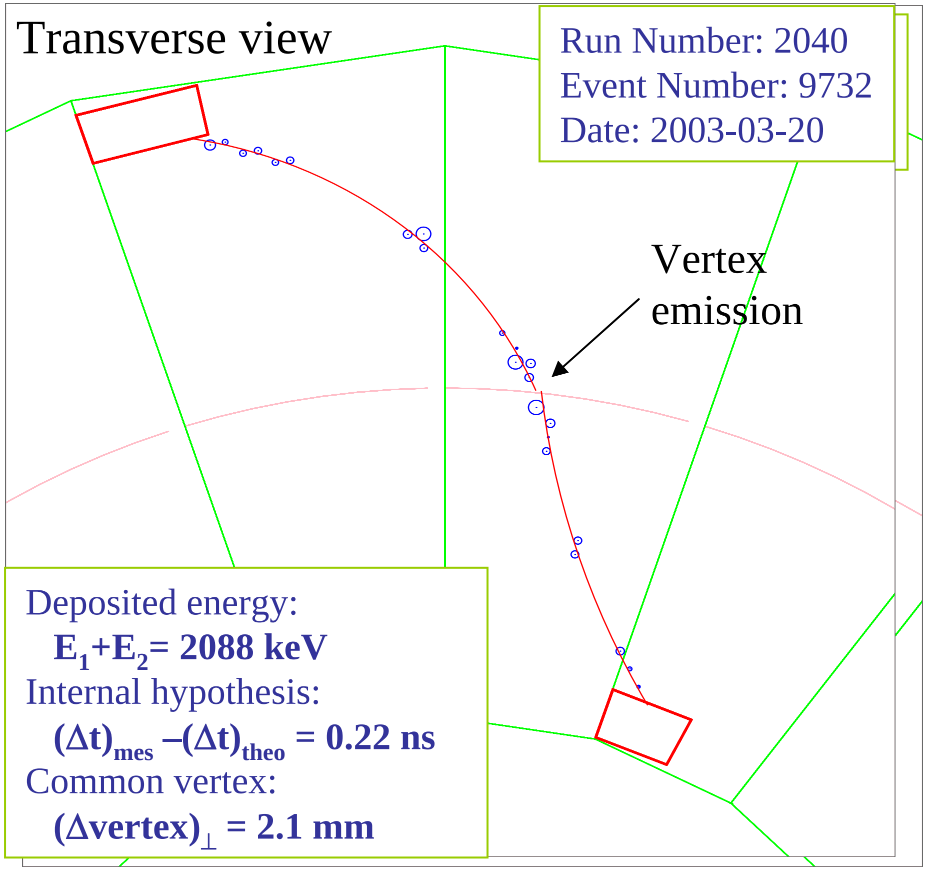
Electron + N γ's ^{208}Tl ($E\gamma$ = 2.6 MeV)

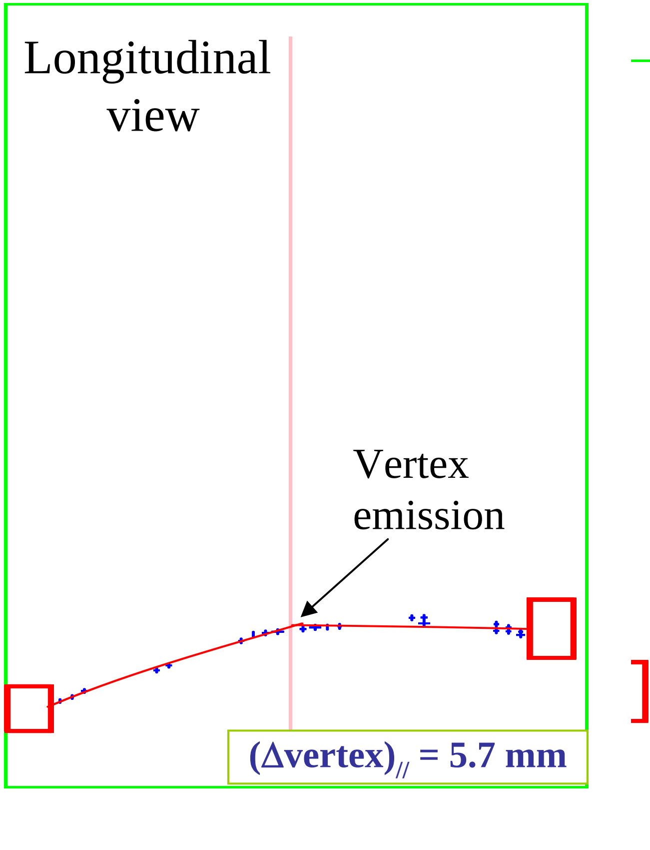


Electron – positron pair $\vec{B}$ rejection

ββ events selection in NEMO-3

Typical ββ2ν event observed from ^{100}Mo





Trigger: at least 1 PMT > 150 keV

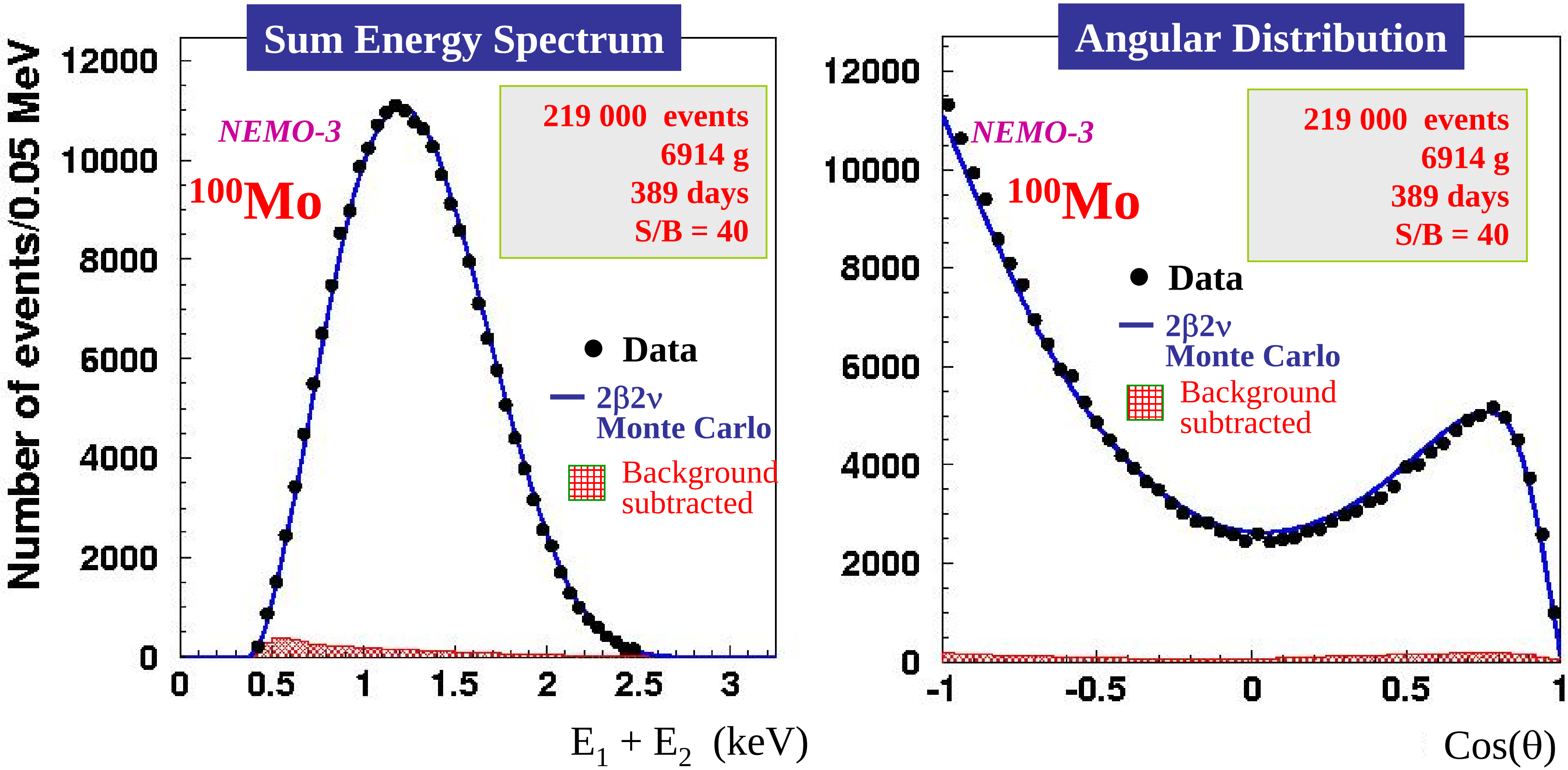
≥ 3 Geiger hits (2 neighbour layers + 1)

Trigger rate = 7 Hz

ββ events: 1 event every 2.5 minutes

^{100}Mo 2β2ν preliminary results

(Data Feb. 2003 – Dec. 2004) → (Phase I)



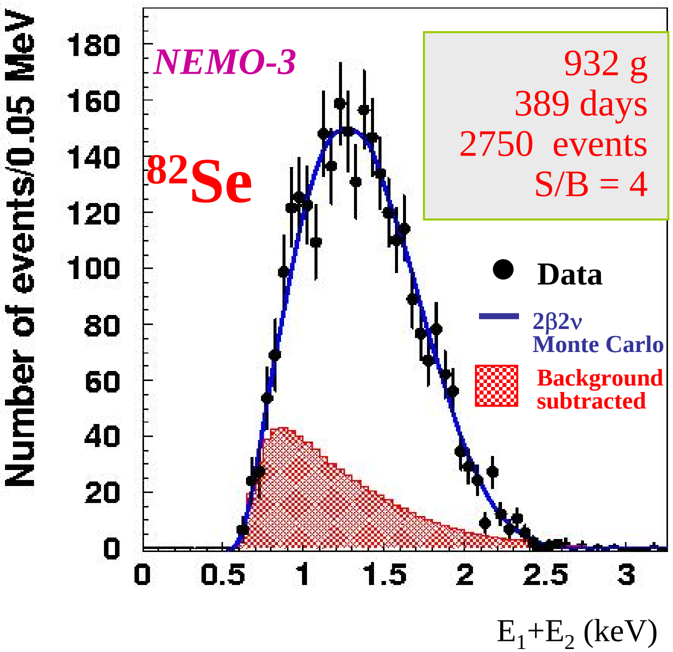
7.37 kg.y

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

Phys Rev Lett 95, 182302 (2005)

No Significant discrepancy → 2νββ is really standard process!

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



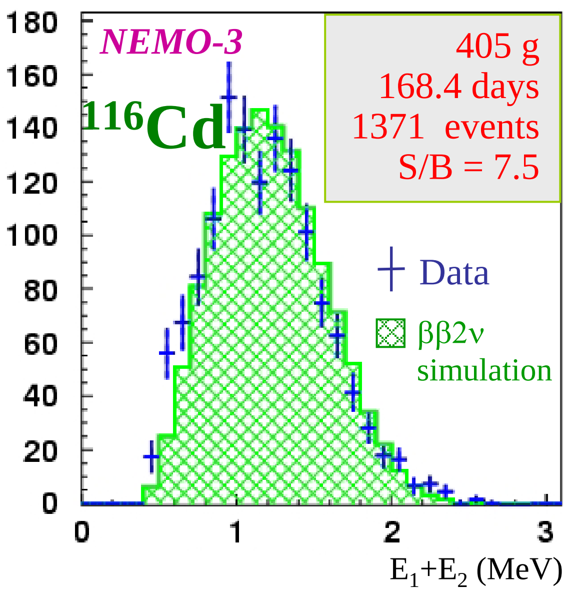
^{82}Se $T_{1/2}$ = 9.6 ± 0.3 (stat) ± 1.0 (syst) × 10^{19} y

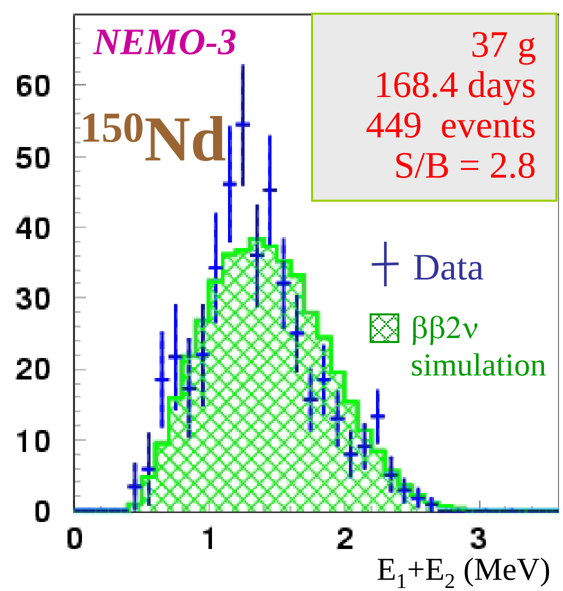
^{116}Cd $T_{1/2}$ = 2.8 ± 0.1 (stat) ± 0.3 (syst) × 10^{19} y

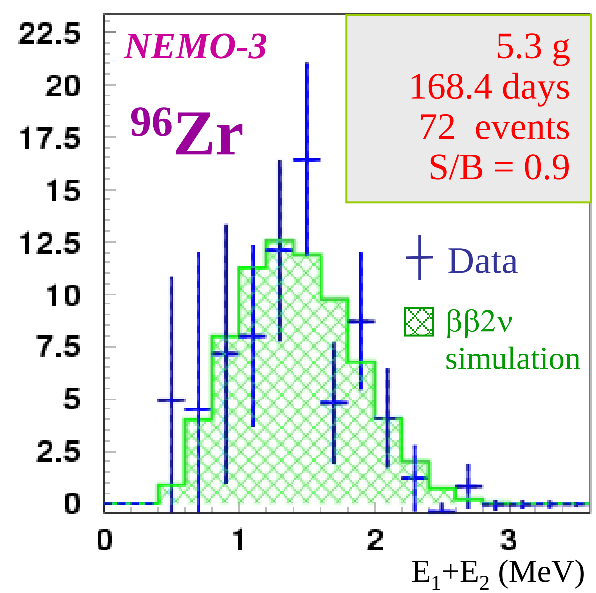
^{150}Nd $T_{1/2}$ = 9.7 ± 0.7 (stat) ± 1.0 (syst) × 10^{18} y

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

Background subtracted





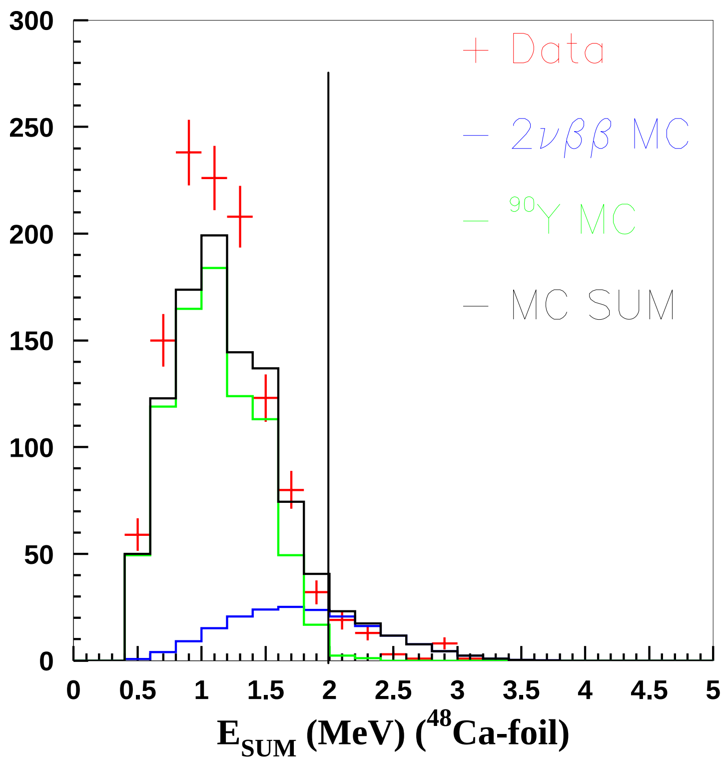


^{48}Ca analysis 1st preliminary result

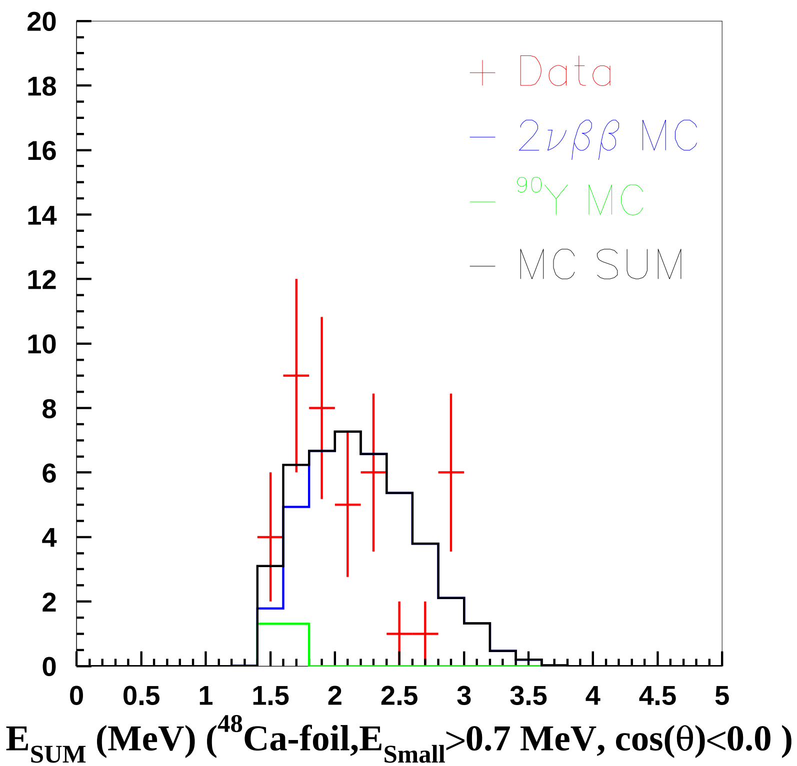
1.07y

7g of ^{48}Ca enough radio pure after chemistry ^{214}Bi, ^{208}Tl but 30m Bq of ^{90}Sr!
to remove Möller scattering pure beta emitter (^{90}Y)
(1) E_{SUM}>2.MeV or (2) Eth > 0.7 MeV cosθ < 0 back to back

$$T_{1/2} = [3.9 \pm 0.7(stat) \pm 0.6(syst)] \cdot 10^{19}\ y$$



Esmall > 0.2 MeV

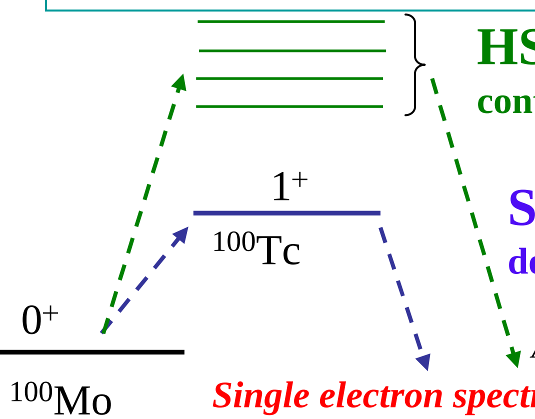


Esmall > 0.7 MeV cos(θ)<0.0

Single electron spectum $2\nu\beta\beta$ (^{100}Mo)

$T_{1/2} = 7.11 \pm 0.02\ (\text{stat}) \pm 0.54\ (\text{syst}) \times 10^{18}$ y
Phys. Rev. Lett. 95 (2005) 182302

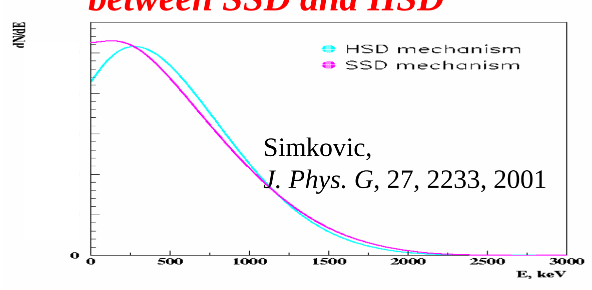
SSD model confirmed



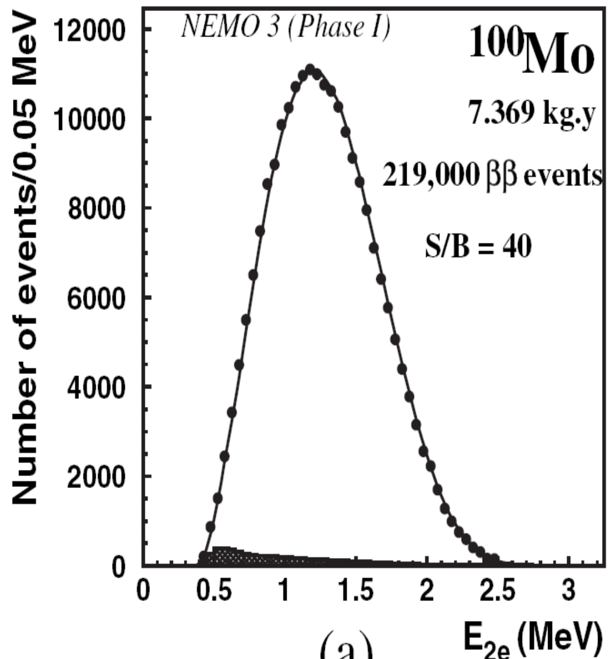
HSD, higher levels contribute to the decay

SSD, 1+ level dominates in the decay
(Abad et al., 1984, *Ann. Fis.* A 80, 9)

Single electron spectrum different between SSD and HSD

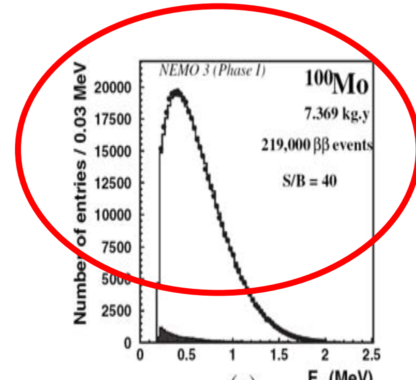


E_{single} (keV)

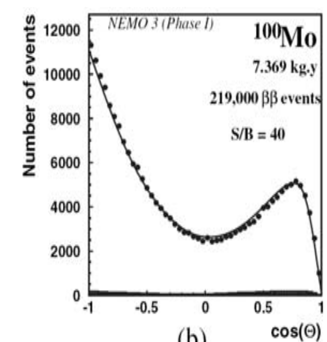


(a)

SSD simulation



(c)



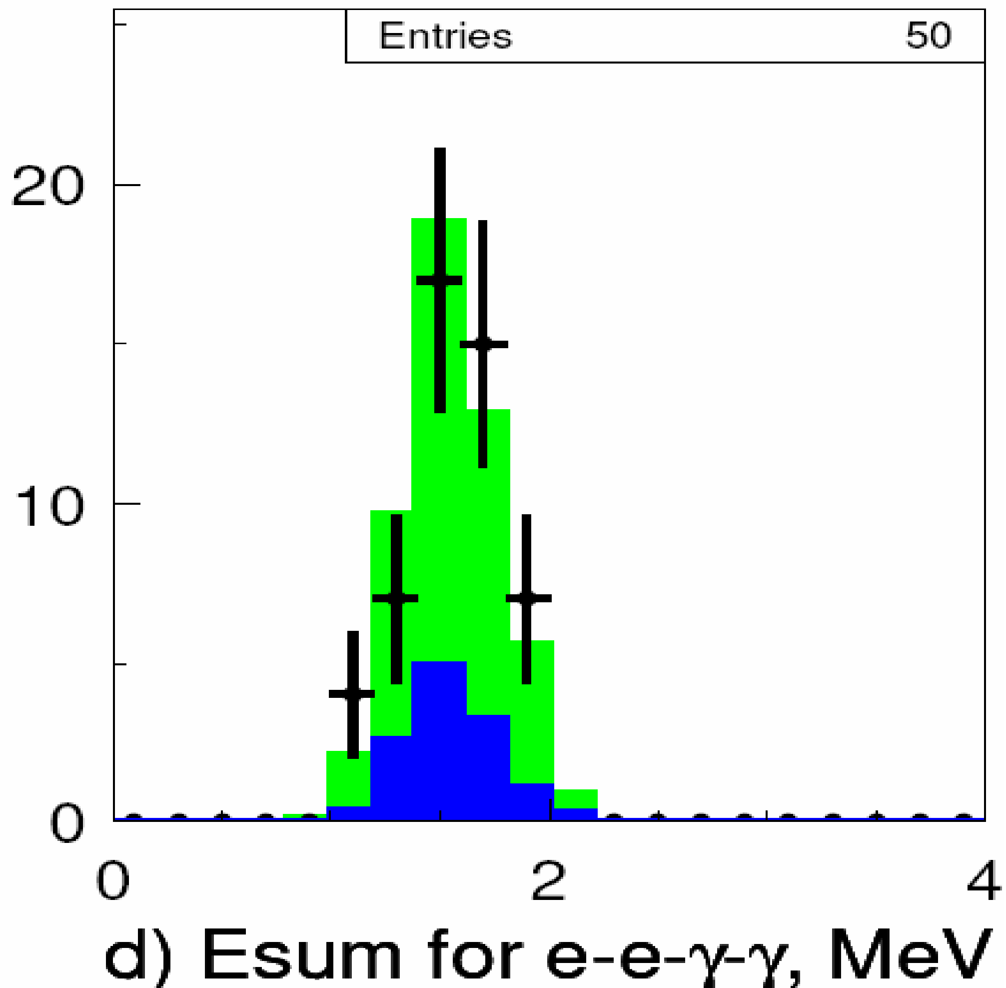
(b)

Decay to the excited 0^+ (^{100}Mo $2\nu\beta\beta$)

Decay to the excited 0^+ state (1130keV) of ^{100}Ru

$T_{1/2} = 5.7^{+1.3}_{-0.9}$ (stat) $\pm$ 0.8 (syst) $\times 10^{20}$ y

Nuclear Physics A781 (2006) 209-226.



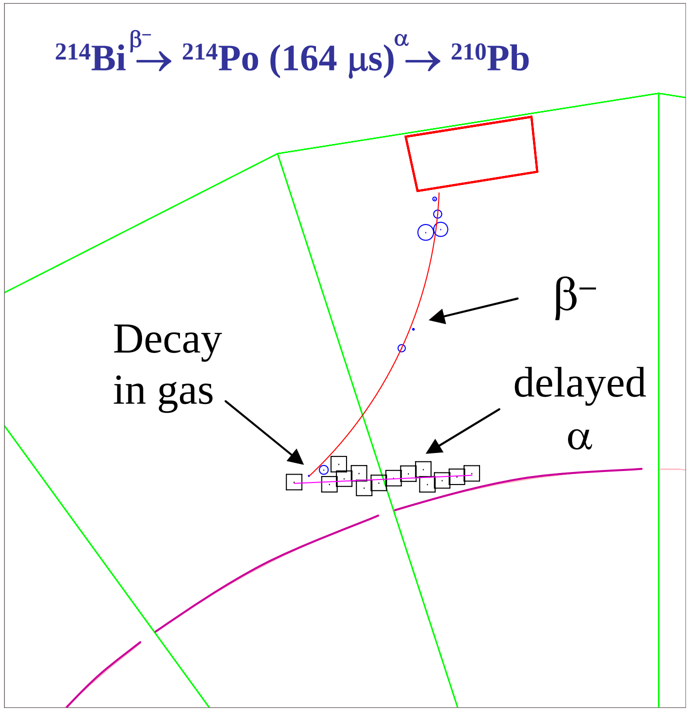
ββ0ν Analysis: Background Measurement

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
  $^{214}Bi \rightarrow {}^{214}Po\ (164\ \mu s) \rightarrow {}^{210}Pb$
  ~ 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 at Phase 1

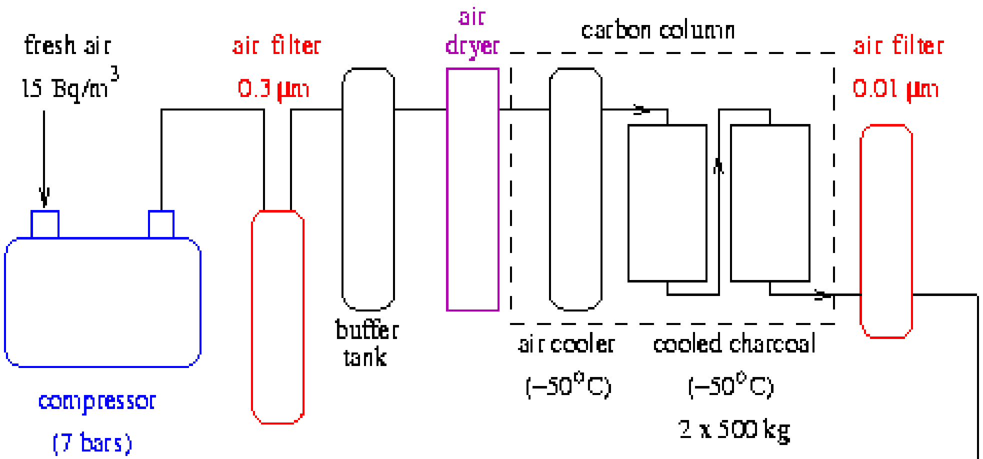
for ββ0ν search in NEMO-3 !!!

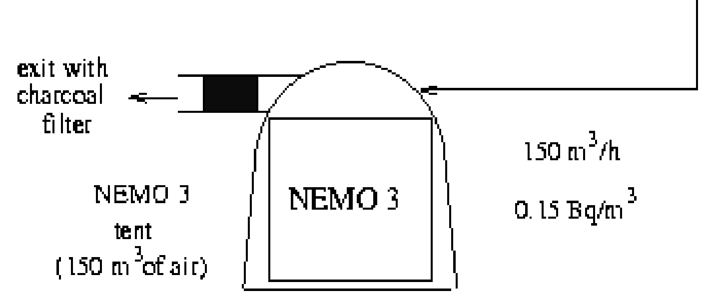
Free-Radon Air factory

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





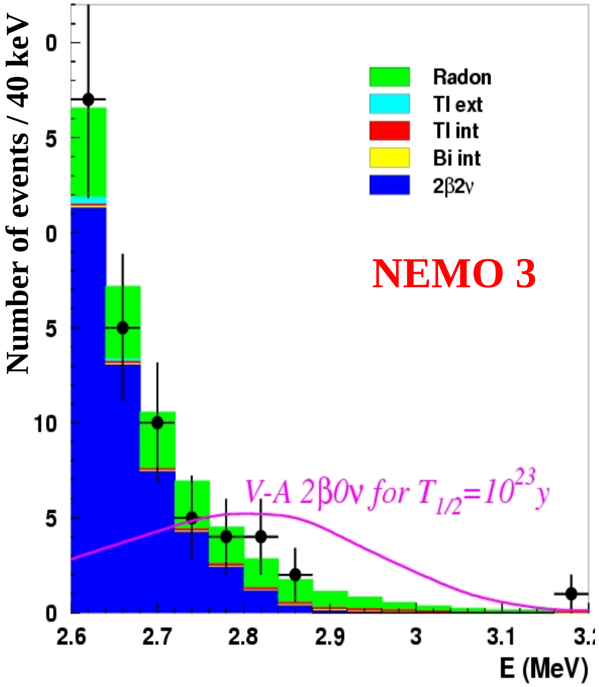
NEMO Tent for Free-Radon air Installation

May 2004 : Tent surrounding the detector

Phase I → Phase II

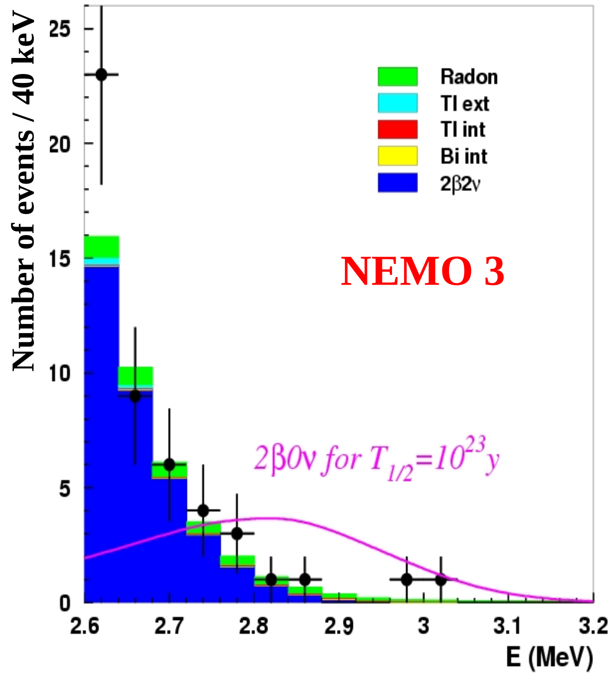
Preliminary results with ^{100}Mo (7 kg) $0\nu\beta\beta$

Phase I, High radon
394 days



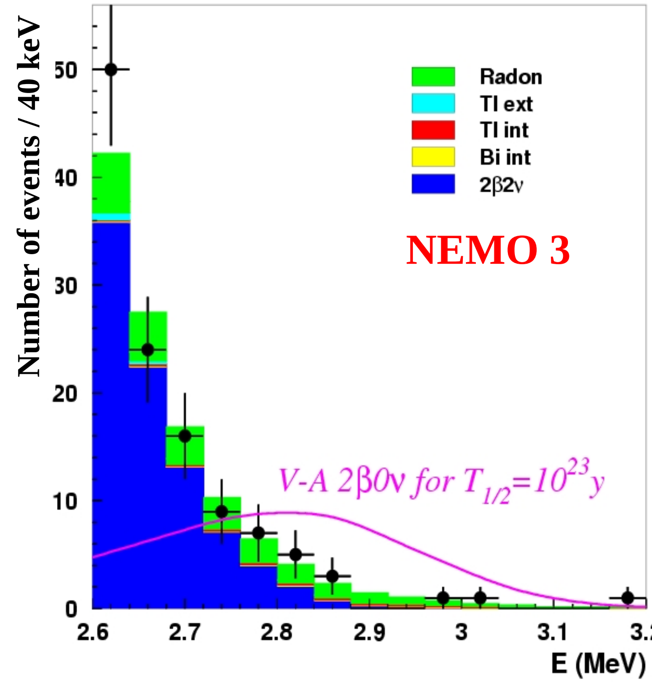
[2.8-3.2] MeV: $\varepsilon(\beta\beta0\nu)$ = 8 %
Expected bkg = 8.1 events
$N_{observed}$ = 7 events

Phase II, Low radon
299 days



[2.8-3.2] MeV: $\varepsilon(\beta\beta0\nu)$ = 8 %
Expected bkg = 3.0 events
$N_{observed}$ = 4 events

Phase I + II
693 days



Phases I + II (preliminary) **$T_{1/2}(\beta\beta0\nu) > 5.8 \times 10^{23}$ (90 % CL) $<m_\nu> < 0.6 – 2.4$ eV**

expected in 2009 **$T_{1/2}(\beta\beta0\nu) > 2 \times 10^{24}$ (90 % CL) $<m_\nu> < 0.3 – 1.3$ eV**

NEMO-3 Expected sensitivity without radon

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: $T_{1/2} = 7.11\ 10^{18}$ 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 $T_{1/2}(\beta\beta0\nu) > 2\ 10^{24}$ y (90% C.L.)
$\langle m_\nu \rangle < 0.3 - 1.3$ 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)

Present status: 2ν decay(NEMO3)

Nuclei	Enriched Source in NEMO 3	$T_{1/2}$, y (NEMO 3) (partially preliminary)		
^{48}Ca (4.271 MeV) (0.187%)	7.0 g	3.9(+/-0.7+/-0.6)$\cdot 10^{19}$		
^{76}Ge (2.040 MeV) (7.8%)				
^{82}Se (2.995 MeV) (9.2%)	932 g	9.6(+/-0.3+/-1.0)$\cdot 10^{19}$		
^{96}Zr (3.350 MeV) (2.8%)	9.4 g	2.0(+/-0.3+/-0.2)$\cdot 10^{19}$		
^{100}Mo (3.034 MeV) (9.6%)	6914 g	7.11(+/-0.02+/-0.54)$\cdot 10^{18}$		
^{116}Cd (2.802 MeV) (7.5%)	405 g	2.8(+/-0.1+/-0.3)$\cdot 10^{19}$		
^{130}Te (2.528 MeV) (33.8%)	454 g	Please wait ….		
^{136}Xe (2.479 MeV) (8.9%)				
^{150}Nd (3.367 MeV) (5.6%)	37 g	9.7(+/-0.7+/-1.0)$\cdot 10^{18}$		

^{100}Mo to the excited 0^+ (1.130 keV) $T_{1/2}$ = 5.7(+1.3-0.9 +/- 0.8) $\cdot 10^{20}$ y

From NEMO3 to SuperNEMO

$$T_{1/2}(\beta\beta0\nu) > \ln2 \times \frac{N_{avo}}{\mathbf{A}} \times \frac{\mathbf{M} \times \varepsilon \times T_{obs}}{\mathbf{N_{exclu}}}$$

NEMO-3		SuperNEMO
^{100}**Mo** **$T_{1/2}(\beta\beta2\nu)$ = 7. 10^{18} y**	Choice of isotope	^{150}**Nd or** ^{82}**Se** **$T_{1/2}(\beta\beta2\nu)$ = 10^{20} y**
7 kg	Isotope mass **M**	**100 - 200** kg
$\varepsilon(\beta\beta0\nu)$ = **8 %**	Efficiency **ε**	$\varepsilon(\beta\beta0\nu)$ ~ **30 %**
^{214}Bi < **300** μBq/kg ^{208}Tl < **20** μBq/kg (^{208}Tl, ^{214}Bi) ~ **1** evt/ 7 kg /y ββ2ν ~ **2** evts / 7 kg / y FWHM(calo)=**8%** @3MeV	$\mathbf{N_{exclu}}$ = f(BKG) *Internal contaminations* ***^{208}Tl and ^{214}Bi** in the ββ foil* *ββ(2ν)* ***IF***	^{214}Bi < **10** μBq/kg ^{208}Tl < **2** μBq/kg (^{208}Tl, ^{214}Bi) ~ **1** evt/ 100 kg /y ββ2ν ~ **1** evt / 100 kg/ y FWHM(calo)=**4%** @3MeV
$T_{1/2}(\beta\beta0\nu)$ > 2. 10^{24} y **$\langle m_\nu \rangle$ < 0.3 – 1.3 eV**	**SENSITIVITY**	**$T_{1/2}(\beta\beta0\nu)$ > 10^{26} y** **$\langle m_\nu \rangle$ < 50 meV**

Main R&D tasks:

1) ββ source production

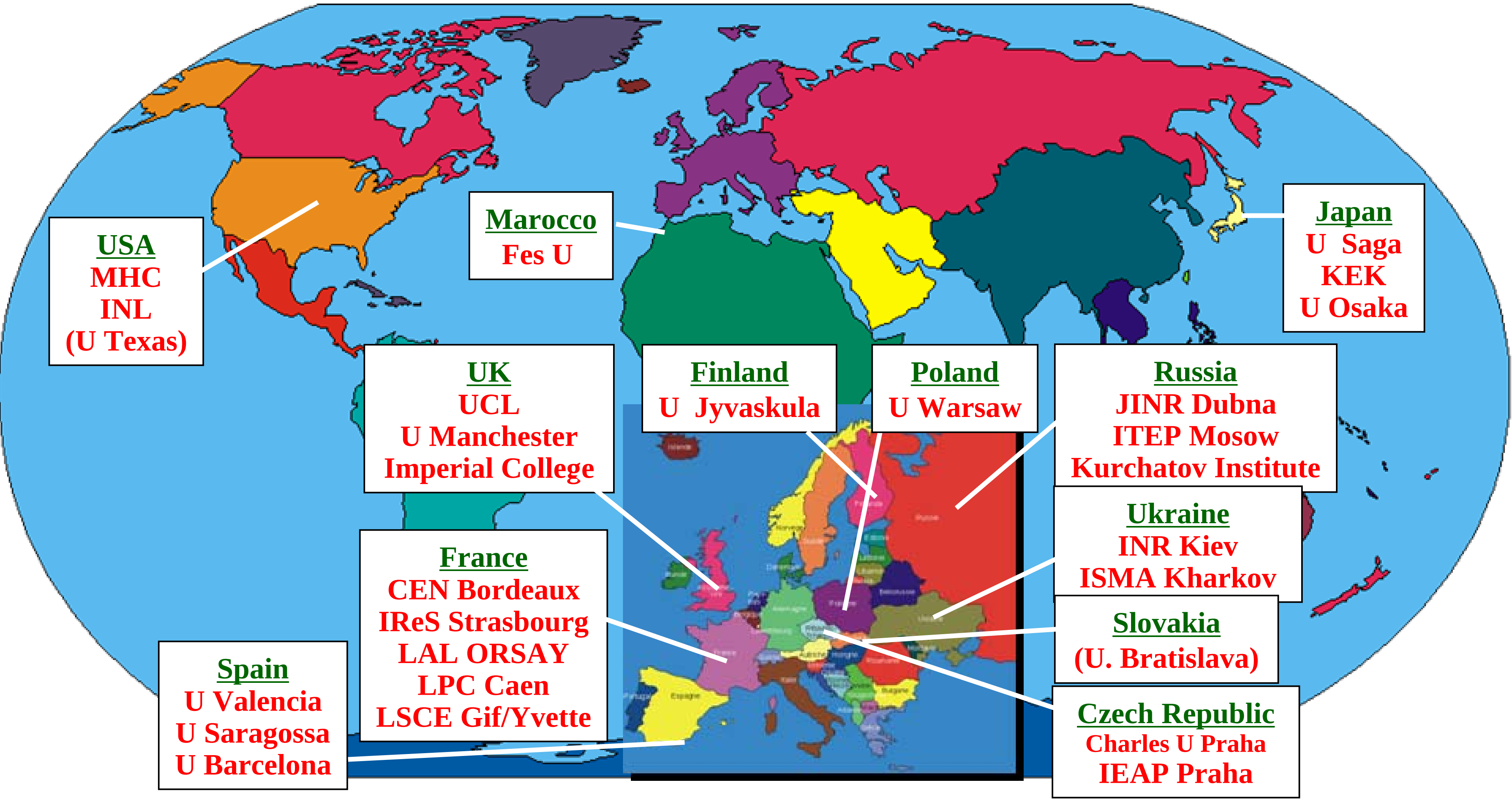
2) Energy resolution

3) Radioprurity

4) Tracking

SuperNEMO Collaboration

~ 60 physicists, 12 countries, 27 laboratories



Conceptual SuperNEMO design

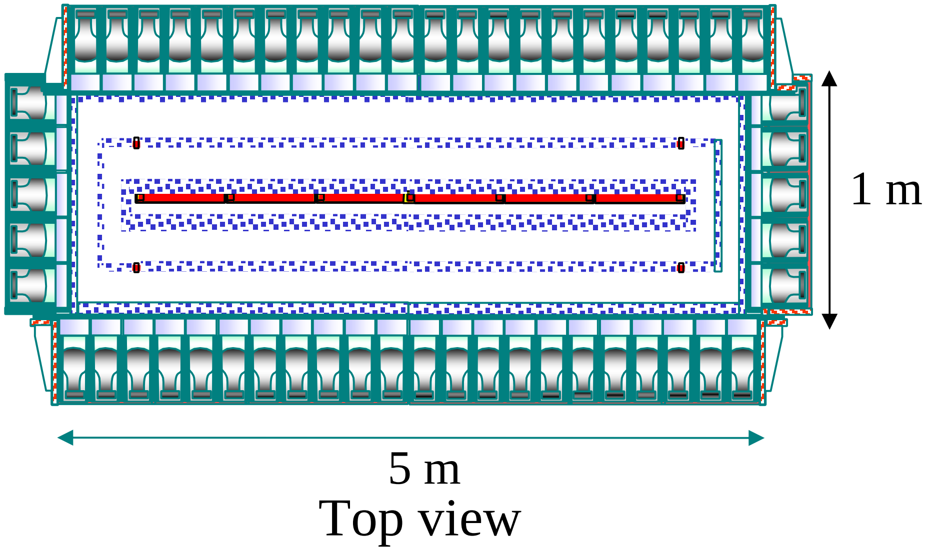
Planar and modular design: ~ 100 kg of enriched isotopes (20 modules × 5 kg)

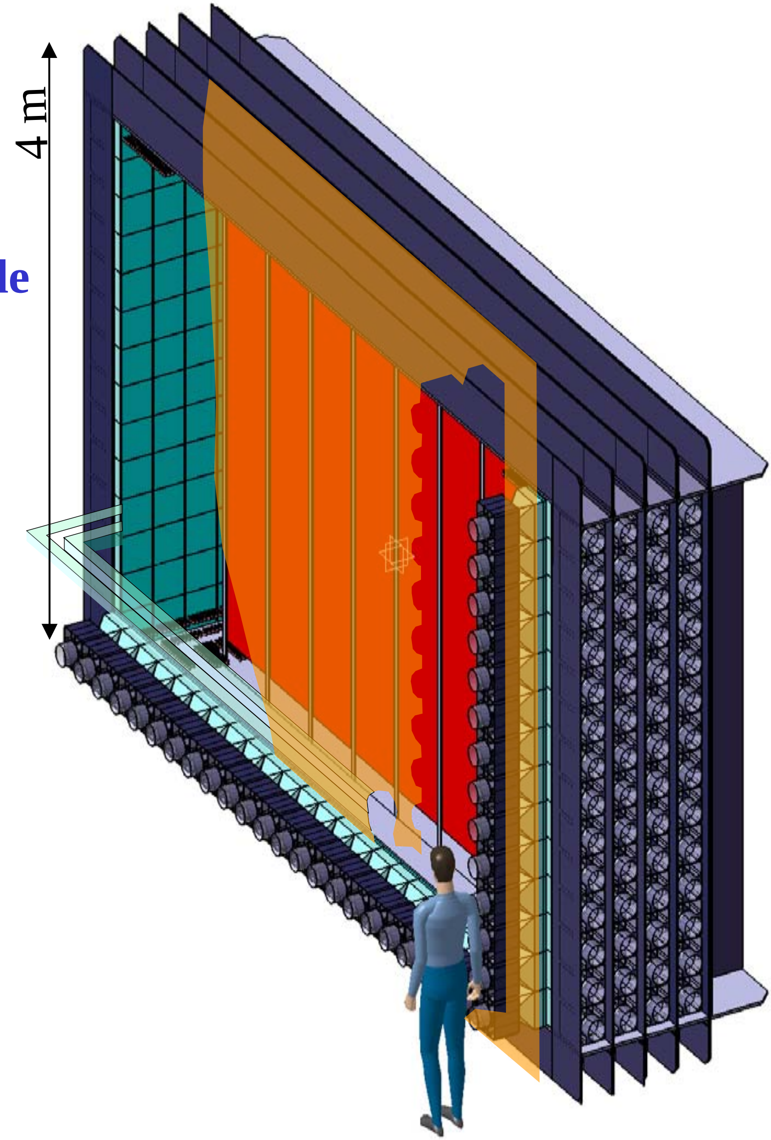
1 module:

Source (40 mg/cm²) 4 x 3 m²

Tracking : drift chamber ~3000 cells in Geiger mode

Calorimeter: scintillators + PM
~1 000 PM if scint. blocks
~ 100 PM if scint. bars





SuperNEMO Status

-Large Scale R&D funded by France, UK and Spain,
(Similar proposal in Japan with MOON team …. See Nomachi's talk)

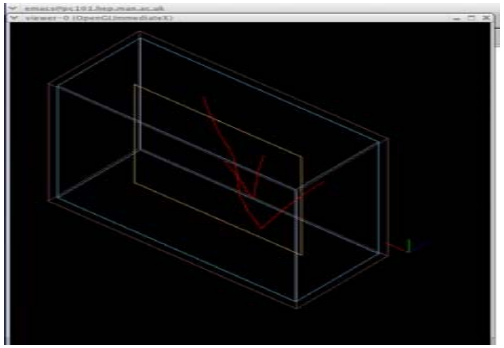
- Possibility to produce 100 kg of ^{150}Nd with laser enrichment method under study

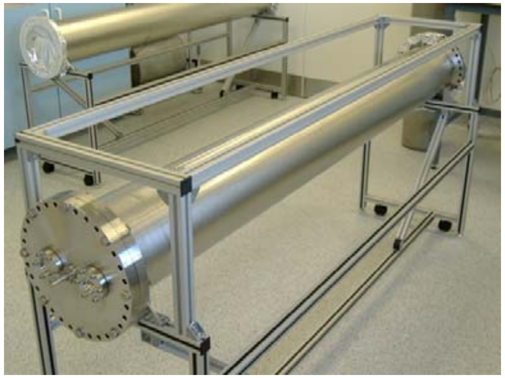
- Test of tracker prototype and design of automatic winring robot

- Prototype of BiPo detector to measure contaminations in thin source foils with 1uBq/kg sensitivity running in Canfranc underground laboratory (Spain)

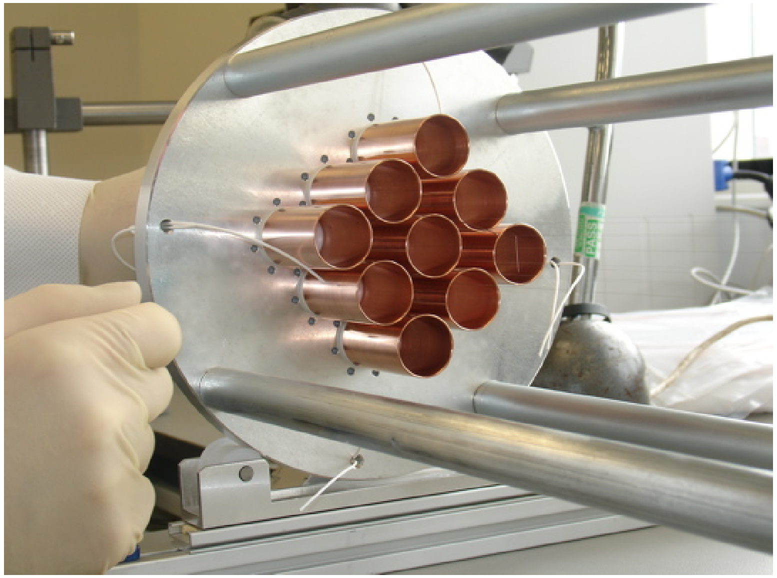
- 7% FWHM at 1 MeV reached for individual plastic and liquid scintillator samples. R&D towards bigger block sizes and large production scale underway

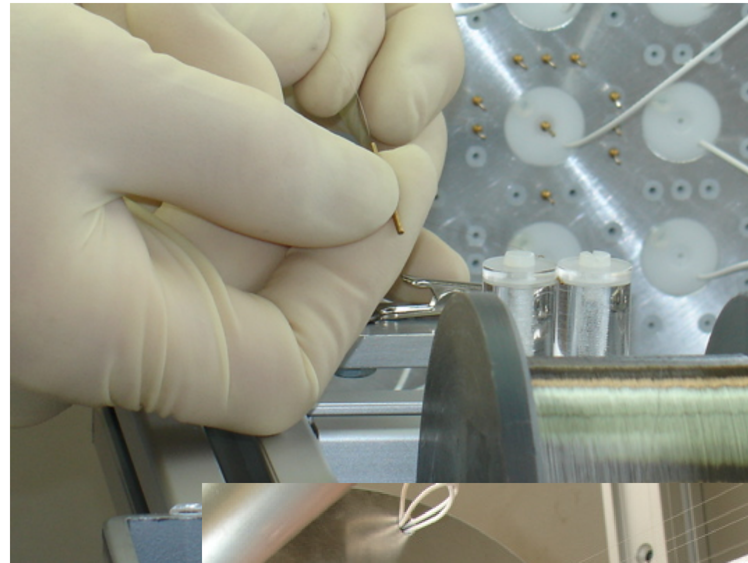
- Simulations in progress

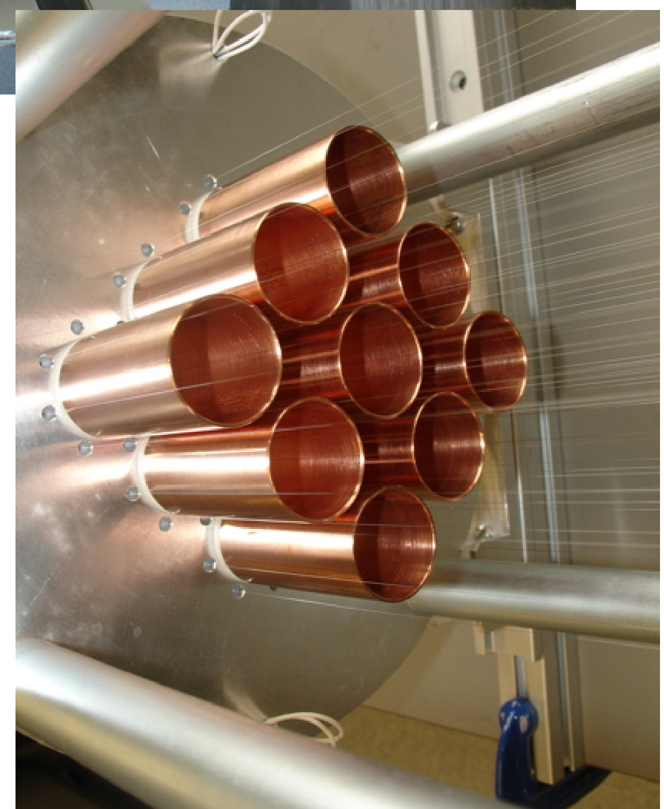




Tracking prototype in UK







R&D Scintillators

- **Plastic scintillators** (collaboration with Karkhov and Dubna = PICS)
  - Improvement on polystyrene production
  - Development of Polyvinylxylene
  - Geometry and wrapping (chemical treatment Karkhov)

Tests in CENBG of different production and size of scintillators with an e- spectrometer

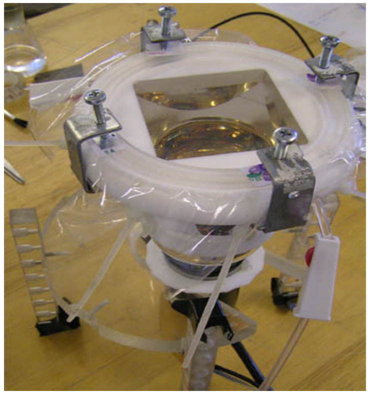
Scintillator blocks 6 x 6 x 2 cm^3
PMT XP5312B (Photonis)

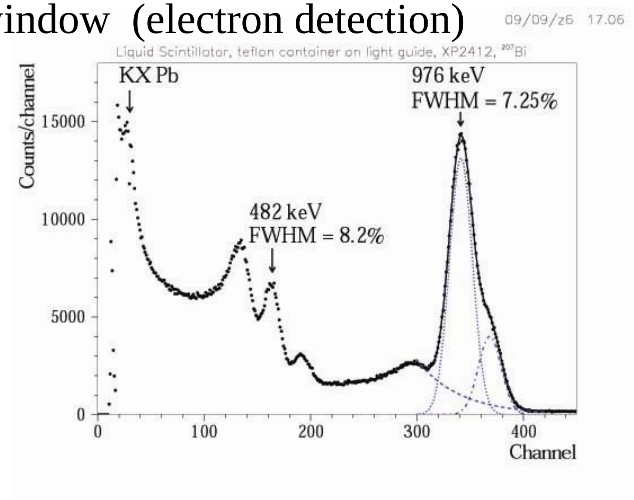
FWHM @ 1 MeV ~ 7%

- **Liquid scintillators**
  - Advantages: high light yield + very good uniformity and transparency
  - Challenge: mechanical contraints particularly for the entrance window (electron detection)

Liq. Scintillator 75 x 75 x 20 mm^3
+ Light guide + PMT 3"

FWHM @ 1 MeV = 7.3 %





- **Photomultipliers**
  - Hamamatsu and Photonis
  - Large size and Large Quantum Efficiency: QE ~ 45 % for 3" PMTs

R&D - Sources

ECP (Electro-Chemical Plant, Svetlana) Zelenogorsk (Siberia)

Enrichment

Goal: To be able to produce 100 kg of ^{82}Se

- **Facilities exist in Russia**
  - 30 kg of ^{76}Ge for GERDA
  - 100 kg of ^{82}Se possible in 3 years
  - Distillation of ^{82}Se (for purification) possible
    Distillation of ^{116}Cd tested with NEMO3
  - 3.5 kg of ^{82}Se funded by ILIAS(*) (2005-2007)

Chemical purification at INL (US)

Purification

Goal: ^{208}Tl < 2 µBq/kg

^{214}Bi < 10 µBq/kg

- **Collaboration with INL (chemical method)**
  - 600 g of ^{nat}Se done
  - 1 kg ^{82}Se done

All funded by ILIAS(*)

Installation of NEMO3 foils (LSM)

Source foils production

Goal: 250 m^2 of ^{82}Se foils of 40 mg/cm^2

NEMO3: ITEP (Moscow) powder + glue (60mg/cm^2)

=>Extrapolation 100 kg possible if very clean conditions

Or new technique in test in LAL

- **Collaboration with Kurchatov and Nijni-Novgorod Institutes (distillation)**
  - 2 kg of ^{nat}Se done

(Integrated Large Infrastructures for Astroparticle Science) : european network
Laboratoires souterrains - Ondes gravitationnelles - Matière noire - Double bêta

R&D - Measurement of materials radiopuity

Ge detectors

today : NEMO HPGe **400 cm^3**
60 µBq/kg ^{208}Tl and **200 µBq/kg ^{214}Bi** (1 month, 1 kg)

Goal: Improve the sensitivity …

⇒ **Development of 800 cm^3 HPGe (Canberra-Eurysis)**
+ Shields improvement
+ New ultra-pur cryostat

⇒ **New planar Ge detector (σ=0.5 keV@40keV)**

Radon detectors

Today : **1 mBq/m^3** Volume: 70l

Goal: 0,1 mBq/m^3

⇒ **Development V=700 l (Japan)**
+ Improvement of diodes radiopurety

Other way of detection….(liquid scintillators) ?

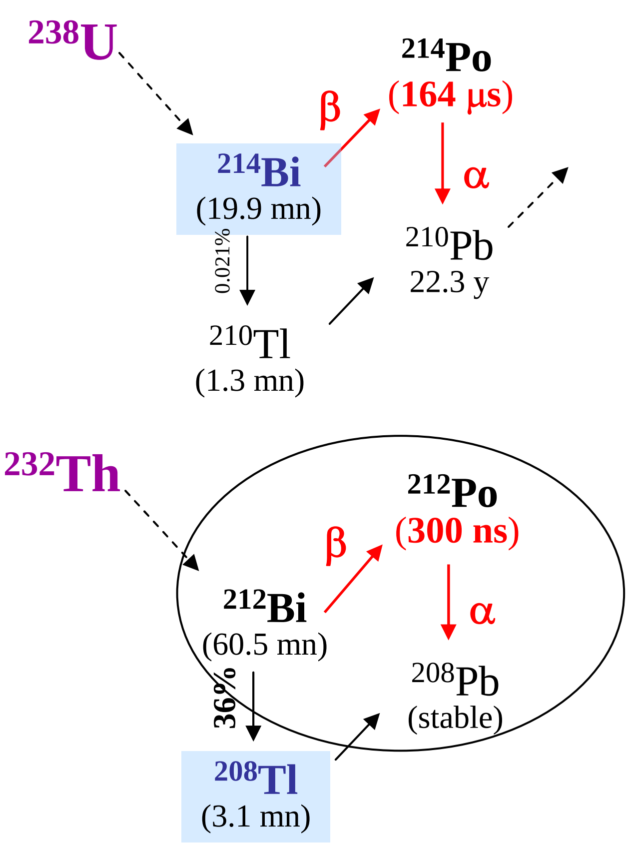
BiPo DETECTOR

To measure the purity in ^{208}Tl and ^{214}Bi of the ββ source foils before the installation in SuperNEMO

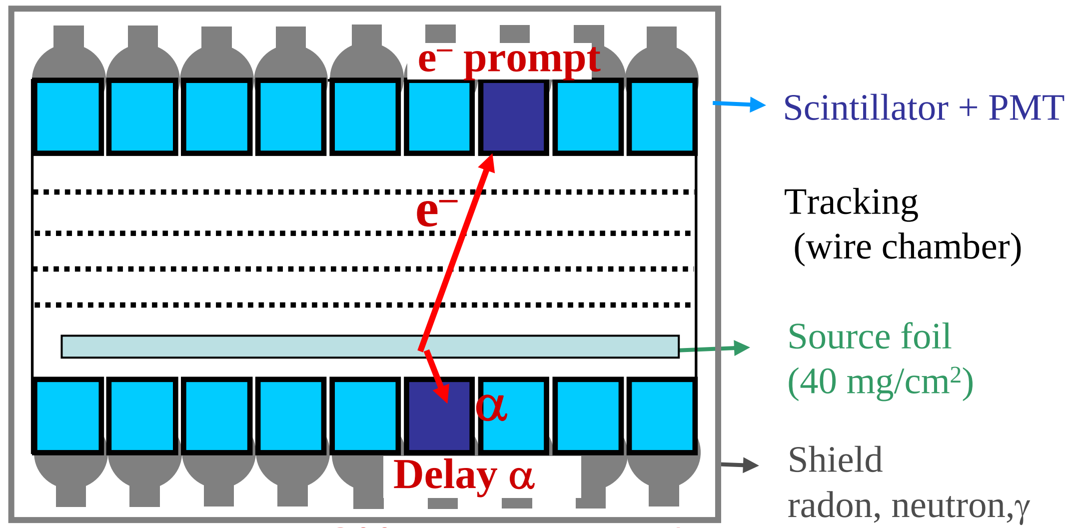
Goal: To measure 5 kg of foils (12 m², 40 mg/cm²) in 1 month with a sensitivity of:

^{208}Tl < 2 μBq/kg and ^{214}Bi < 10 μBq/kg

Bi-Po Process



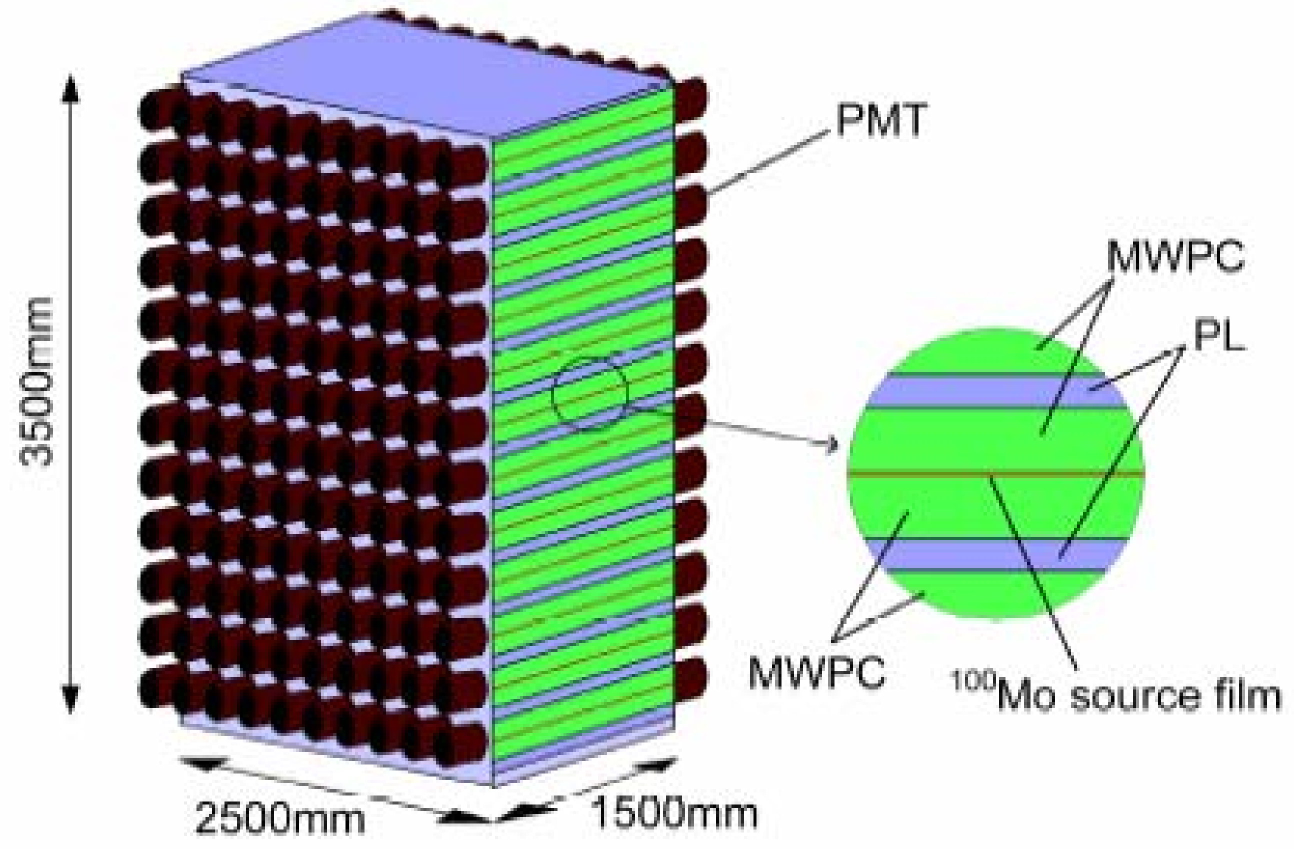
Q_β (^{212}Bi) = 2.2 MeV



$T_{1/2}$ ~ 300 ns $E_{deposited}$ ~ 1 MeV

2 modules 2×3 m² → 12 m²
Background < 1 event / month

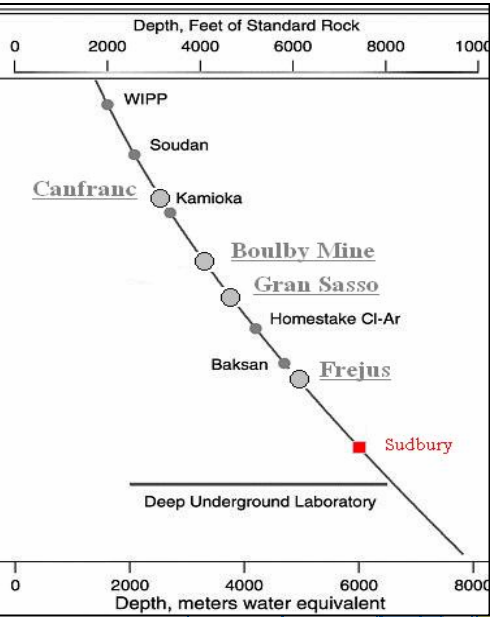
other possible SuperNEMO design

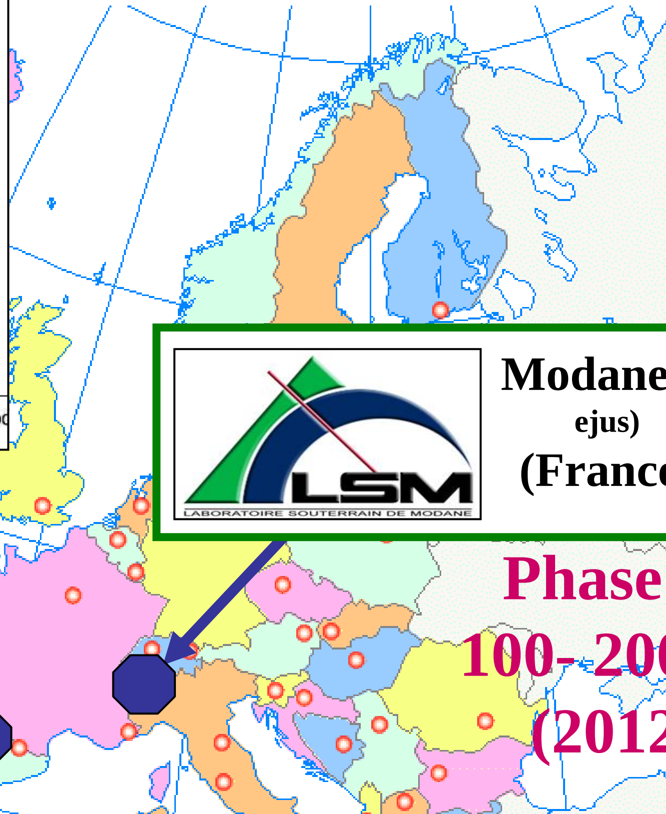


MOON module with 20kg of source

See Nomachi's (MOON) talk

Possible Locations of the SuperNEMO





Modane(Frejus) (France)

Phase II

100- 200 kg

(2012)

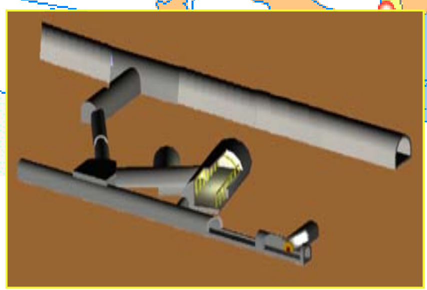
Prototype of BiPo

Phase I

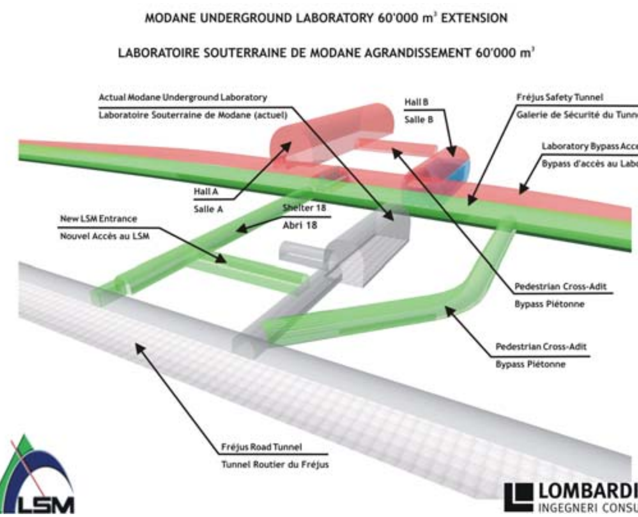
20 kg

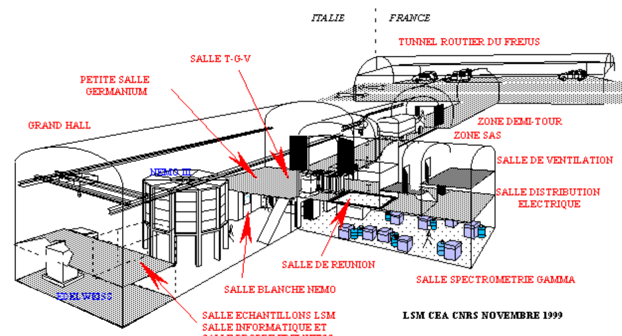
(2010)

Canfranc (Spain)



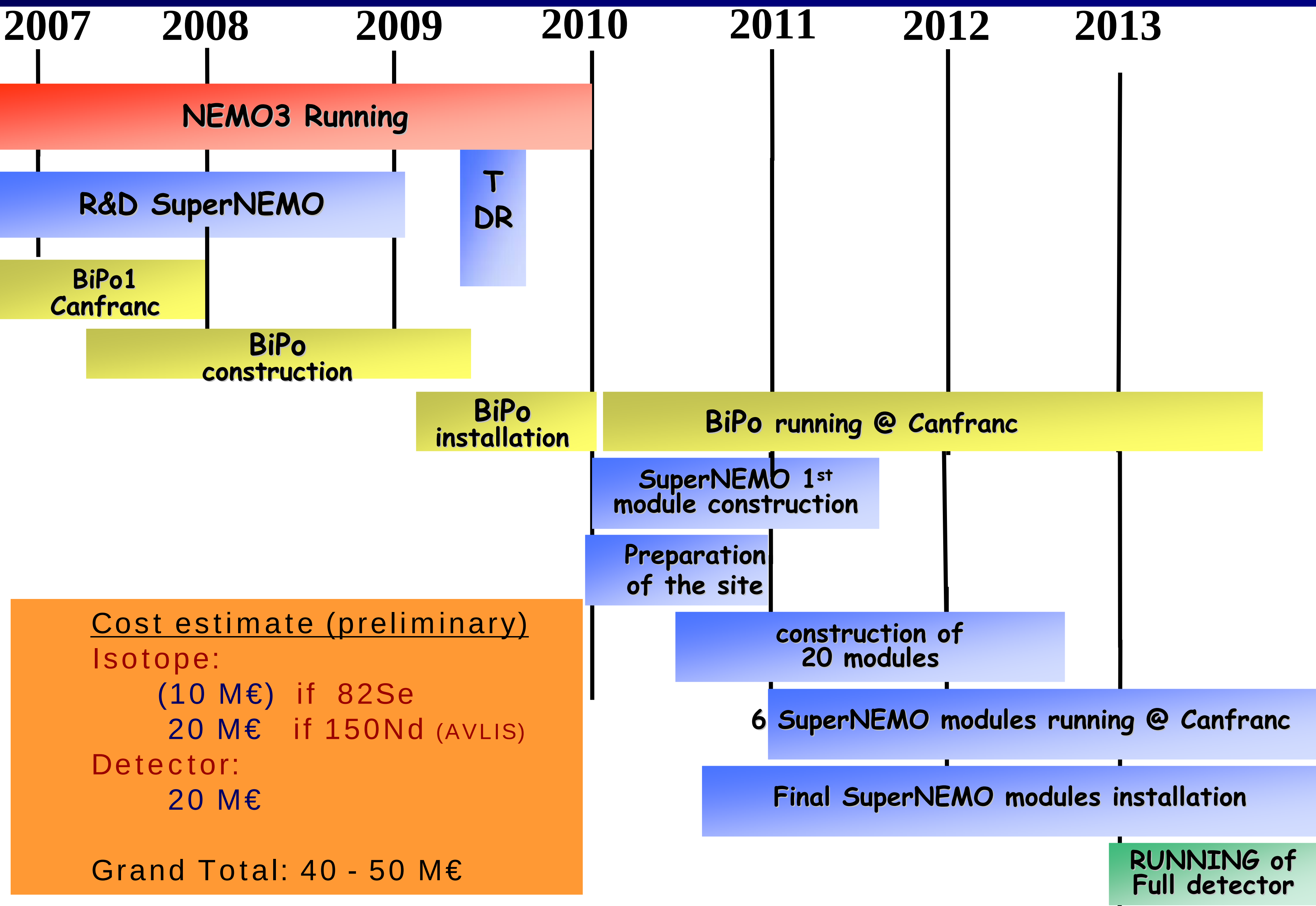
Gran Sasso ?, Boulby ?





Present NEMO 3

SuperNEMO schedule summary



Cost estimate (preliminary)

Isotope:

(10 M€) if 82Se

20 M€ if 150Nd (AVLIS)

Detector:

20 M€

Grand Total: 40 - 50 M€

We need ^{150}Nd for the ββ0ν experiment

$$\frac{1}{T^{0\nu}_{1/2}} = G_{0\nu}\, M^2_{0\nu}\, \langle m_\nu \rangle^2$$

SuperNEMO
SNO++
DCBA
etc.

Isotope	$Q_{\beta\beta}$ (MeV)	$G_{0\nu}$ (y^{-1})	$T_{1/2}(0\nu)$ with m_ν=50meV Shell Model	QRPA
^{48}Ca	**4.271**	**2.44**	***9.2 10^{26}***	***2.9 10^{27}***
^{76}Ge	2.040	0.24	***7 10^{27}***	***2.4 10^{27}***
^{82}Se	**2.995**	**1.08**	***9.6 10^{26}***	***7.4 10^{26}***
^{96}Zr	3.350	2.24		***1.5 10^{28}***
^{100}Mo	3.034	1.75		***1.4 10^{27}***
^{116}Cd	2.802	1.89		***10^{27}***
^{130}Te	2.528	1.70	***3.6 10^{26}***	***10^{27}***
^{136}Xe	2.479	1.81	***5.2 10^{26}***	***2-5 10^{27}***
^{150}Nd	**3.367**	**8.00**		***1.2 10^{26}***

Shell Model: Caurier et al.
QRPA: Feasller Rodin Simkovic Vogel 2005

$Q_{\beta\beta}$ ^{150}Nd
Beyond the γ of 2.614 MeV(^{208}Tl)
Beyond ^{214}Bi Q_β (3.2 MeV)

-Possibility to produce 100 kg of ^{150}Nd with laser enrichment method under study

Continue …. Comments on Enrichment of ^{150}Nd.