SuperNEMO

M. Nomachi, Osaka University
SuperNEMO collaboration

Double beta decay detector

- DBD = two electron
- Calorimetric detector
  - Observe total energy of two beta-rays. (E1+E2)
  - Detector = Source
    - High detection efficiency
- Tracking detector
  - Observe individual energy of two beta-rays.
    - Efficient back ground rejection
    - Reaction mechanism
  - Detector ≠ source
  - Measure several sources on the same setup
    - Reduce systematic error

Present & near future detectors

Calorimeter

- **Semiconductor**
  - ε, ΔE
  - ^{76}Ge
  - → GERDA, MAJORANA
- **Bolometers**
  - ε, ΔE
  - ^{130}Te, ^{82}Se, ^{100}Mo
  - → CUORE, LUCIFER, ZnMo4
- **Liquide Xe**
  - ε, M, (N_{bckd})
  - ^{136}Xe
  - → EXO
- **Scintillator**
  - ε, M
  - ^{136}Xe, , ^{48}Ca, ^{150}Nd, ^{100}Mo
  - → KamLAND-Zen, CANDLES, SNO+, Borexino, CdWO4, AMoRE

Tracker

- **Tracko-calo**
  - N_{Bckg} , isotopes
  - ^{82}Se (^{150}Nd,^{48}Ca)
  - → SuperNEMO
- **Pixellise CdZnTe**
  - ε, N_{Bckd}
  - ^{116}Cd
  - → COBRA
- **TPC**
  - ε, N_{Bckd}
  - ^{136}Xe, ^{150}Nd
  - → MTD, EXO-gas, NEXT

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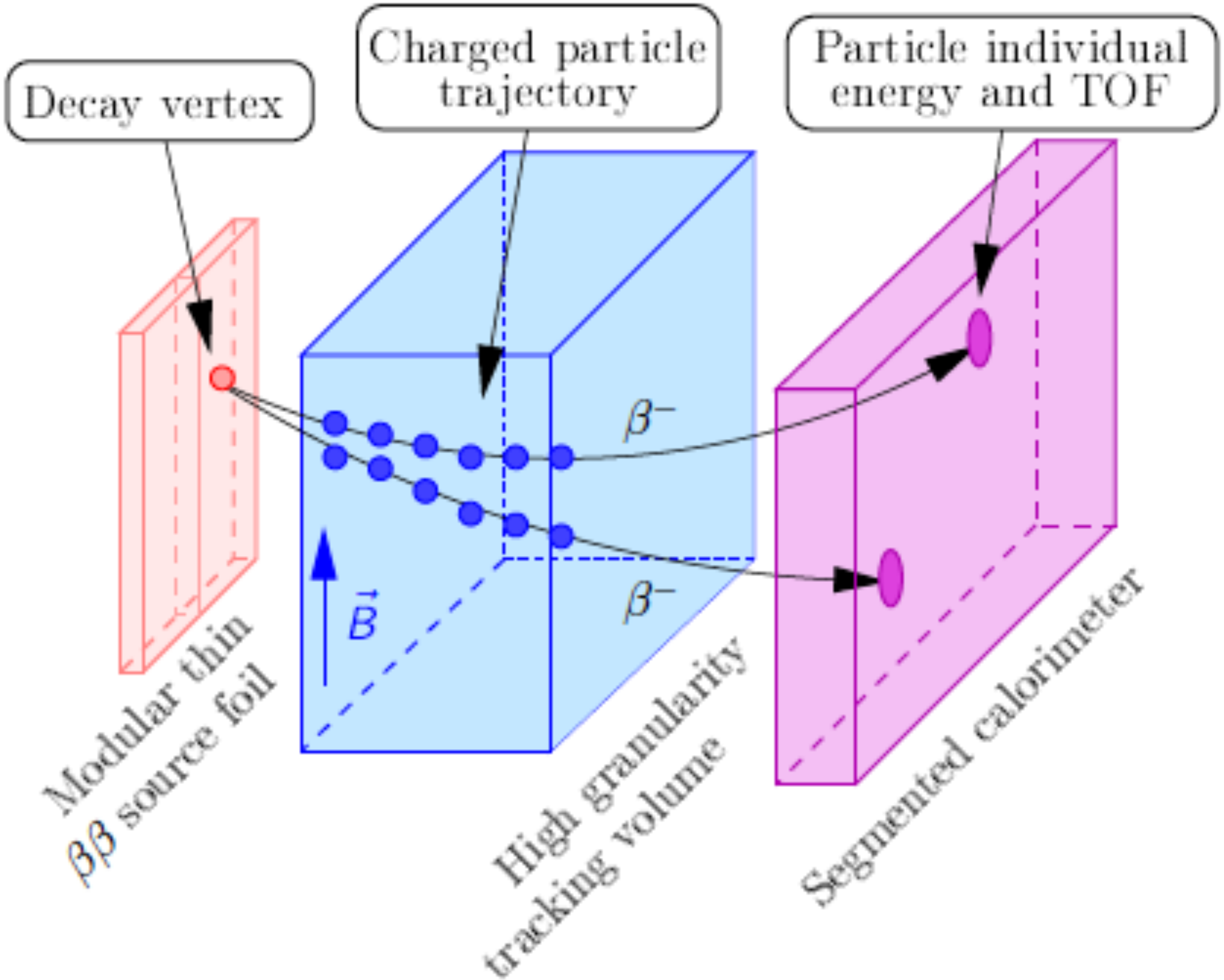
Advantages of the tracko-calo technique

- Powerful background rejection
  - Identification of **two** electrons
  - Identification of e^+, γ, α particles
  - event topology
  - Vertex reconstruction:
    - possible identification of hot spots on the source foil
  - Identification and cross-check of backgrounds with several topologies

- Isotopes flexibility
  - Identification and cross-check of backgrounds with several isotopes

- Measurement of all kinematics parameters
  - possibility to determine the underlying physics mechanism in case of signal

background rejection



Progress of Theoretical Physics, Vol. 70, No. 5, November 1983

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The Energy Spectrum and the Angular Correlation in the $\beta\beta$ Decay

Masaru DOI, Tsuneyuki KOTANI,* Hiroyuki NISHIURA* and Eiichi TAKASUGI*

$$[T_{0\nu}(0^+\to 0^+)]^{-1}=|M_{GT}^{(0\nu)}|^2\left\{C_1\left(\frac{\langle m_\nu\rangle}{m_e}\right)^2+C_2\langle\lambda\rangle\frac{\langle m_\nu\rangle}{m_e}\cos\psi_1+C_3\langle\eta\rangle\frac{\langle m_\nu\rangle}{m_e}\cos\psi_2+C_4\langle\lambda\rangle^2+C_5\langle\eta\rangle^2+C_6\langle\lambda\rangle\langle\eta\rangle\cos(\psi_1-\psi_2)\right\}, \quad (3\cdot5\cdot10)$$

two right-handed weak current parameters (λ and η)

$$\frac{d\Gamma}{d\varepsilon_1 d\cos\theta} \propto [1+\alpha(\varepsilon_1,\varepsilon_2)\cos\theta]$$

Angular correlation

mass square term

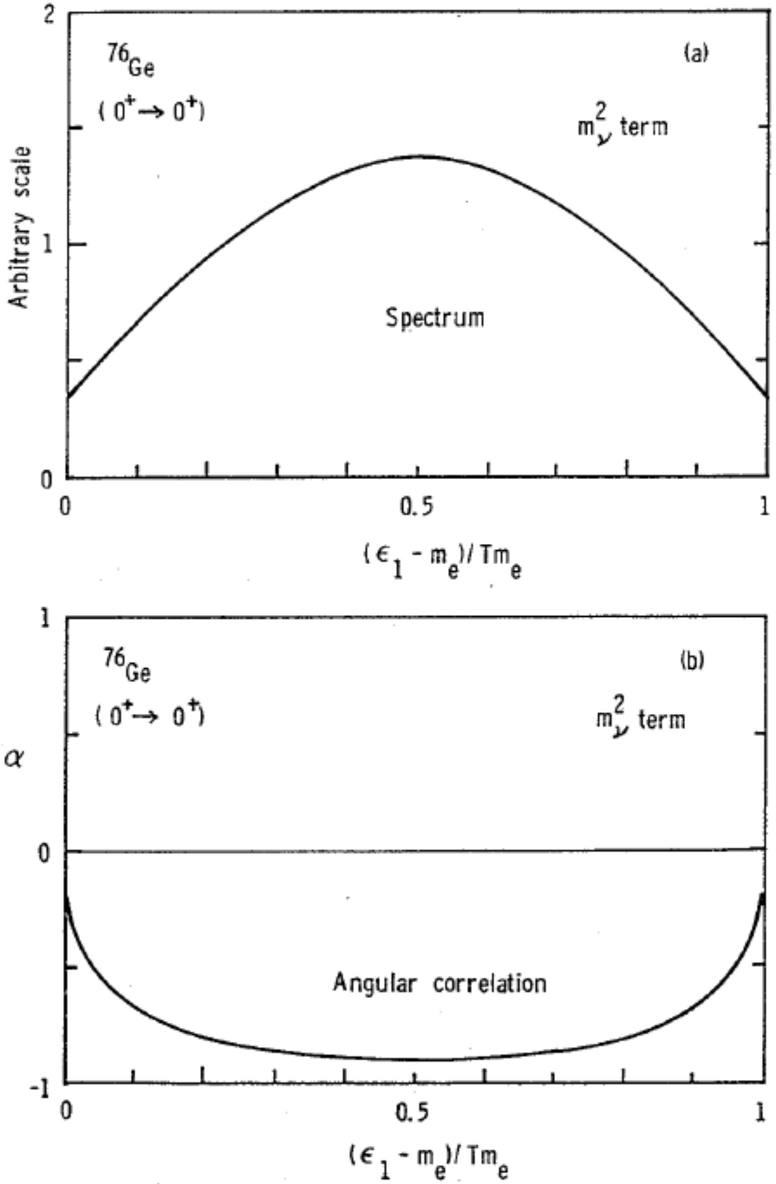

Fig. 6.5.

Right-hand weak current term

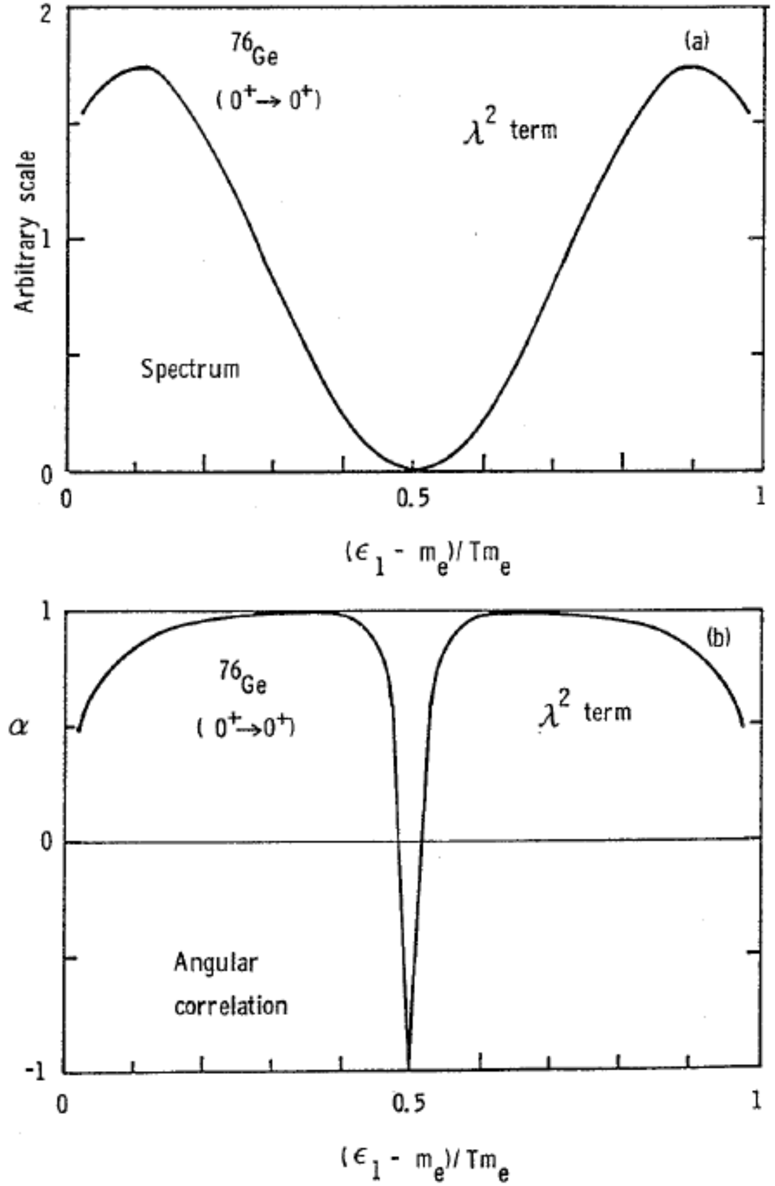

Fig. 6.6.

ELEGANT V (Osaka Univ.)

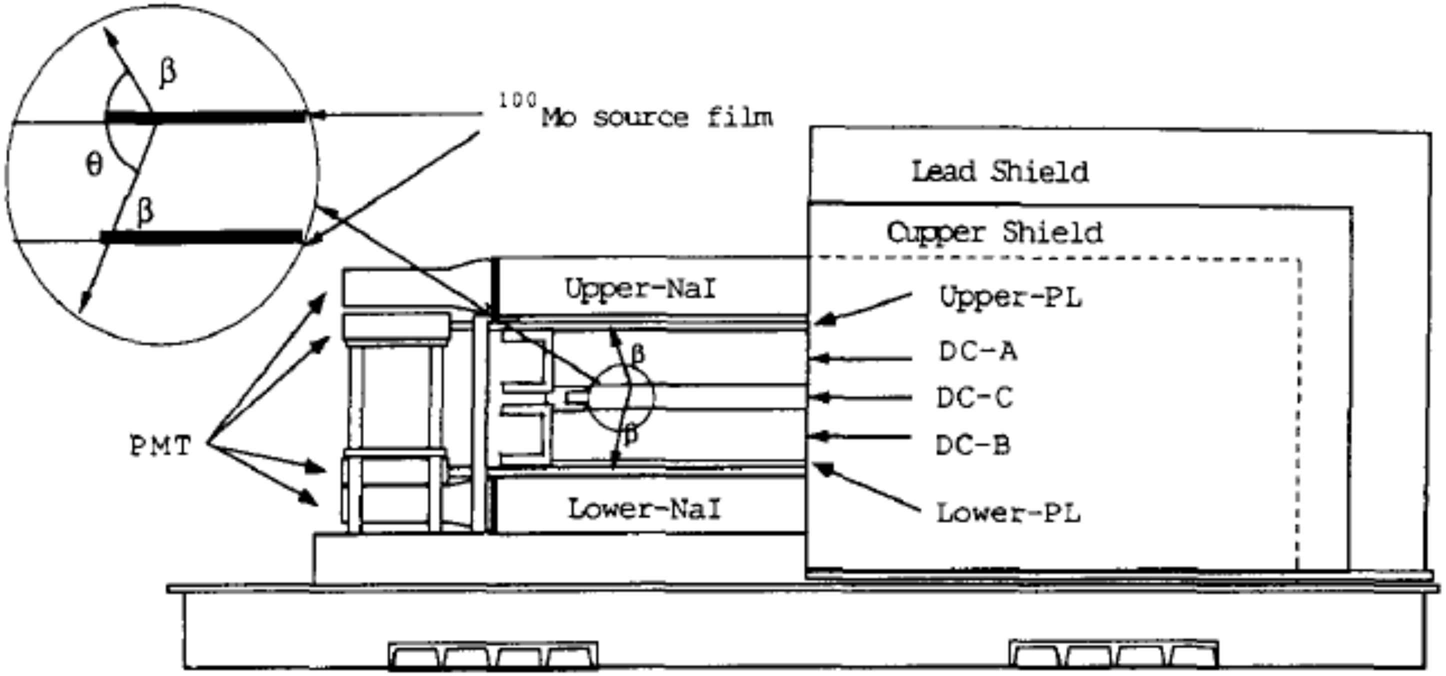

Fig. 3. Schematic view of ELEGANT V [7]. DC-A, DC-B and DC-C are the lower, upper and central drift chambers.

NEMO-3

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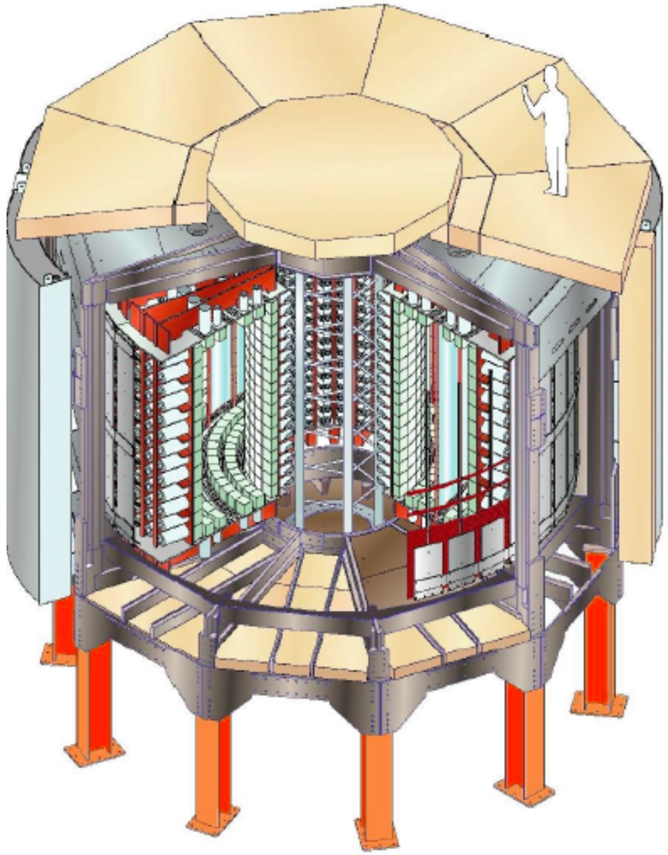
Data taking (2 phases) from February 2003 to January 2011

- ^{100}Mo 6,9 kg
- ^{82}Se 0,93 kg
- ^{130}Te 0,45 kg
- ^{116}Cd 0,40 kg
- ^{150}Nd 36,5 g
- ^{96}Zr 9,43 g
- ^{48}Ca 6,99 g

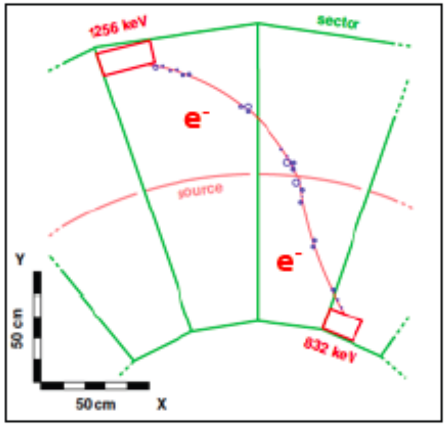


Main characterisitics

- Source: 10 kg of $\beta\beta$ isotopes, S=20 m^2, $e \simeq$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, radon free
- Calorimeter: 1940 plastic scintillators coupled to low radioactivity PMTs
- Magnetic field: 25 gauss
- Gamma shield: pure Iron (18 cm)
- Neutron shield: borated water (30 cm, ext. wall), wood (40 cm, top+bottom)
- Rn trapping facility + tent
- Low radioactivity materials
- Fréjus Underground Laboratory (4800 m.w.e.)

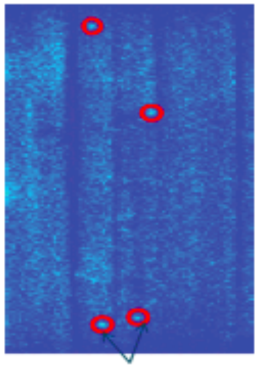
Event selection

Identification of electrons



Vertex reconstruction:

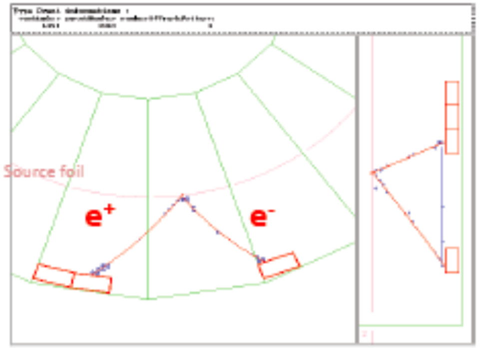
possible identification of
« hot spots » on the source foil



Hotspots

Identification of e^+, γ, α particles

e^+e^- pair



e-nγ (Ex: ^{214}Bi and ^{208}Tl)

e-α-nγ (Ex: ^{214}Bi)

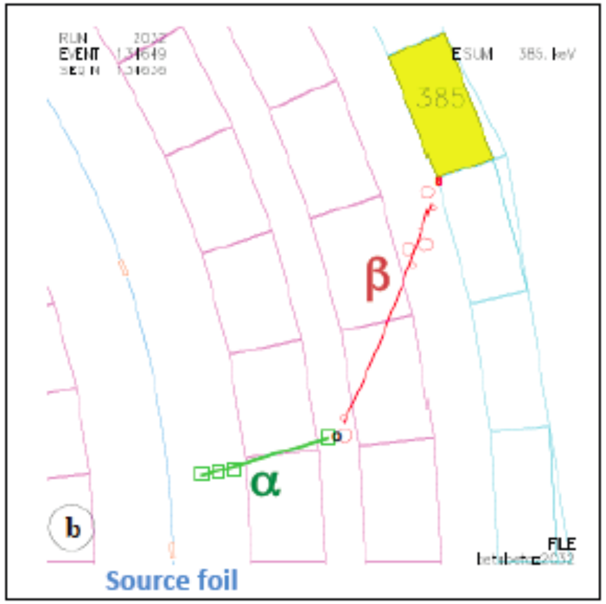
- Powerful background rejection by topology
- Identification and cross-check of backgrounds with several topologies

Radon background

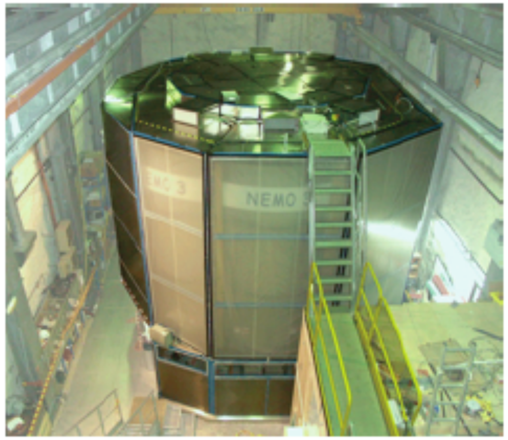
Air in the LSM: 15 Bq/m^3

PHASE I: 40 ± 7 mBq/m^3

e$^-$ - α in the tracking volume



Radon-free air factory: 150 m³/h with 15 mBq/m³ of radon



Installation of a tent flushed with radon free air

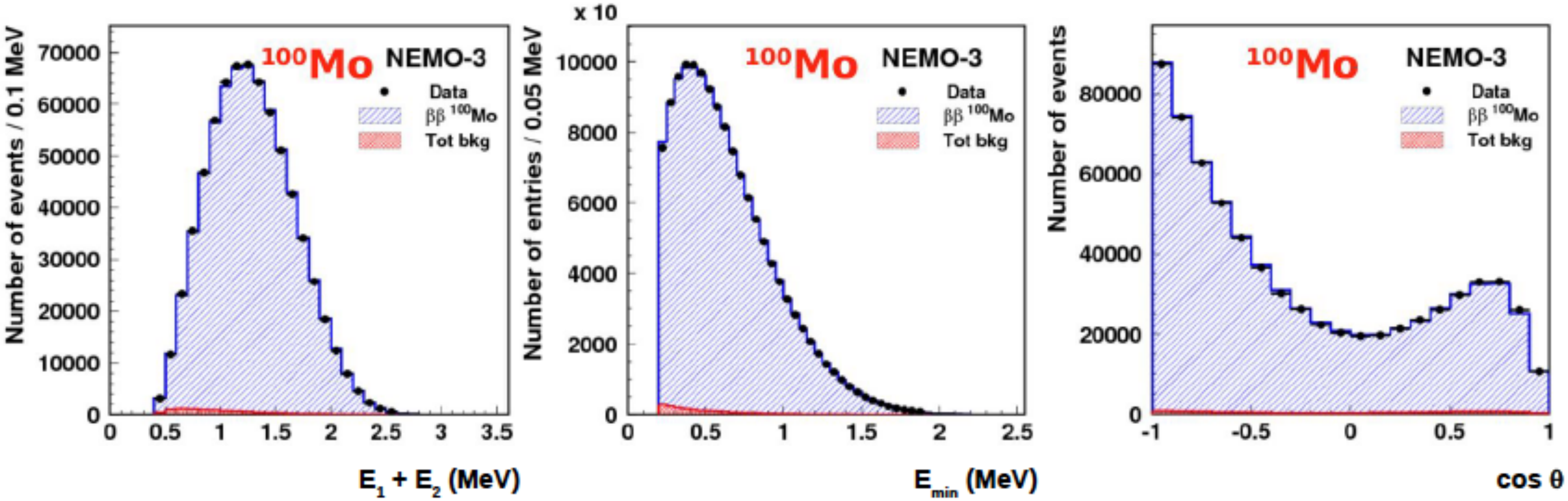
PHASE II: 7 ± 3 mBq/m^3

Phase II: expected level of radon
remaining level due to joint leak and/or emanation from material

$2\nu\beta\beta$ main results

Isotope	Mass	$T^{2\nu}_{1/2}$(years)	Ref.
^{100}Mo	6.9 kg	7.16 ± 0.01 (stat) ± 0.54 (sys) 10^{18}	*PRL 95 (2005) 182302*
^{82}Se	0.93 kg	9.6 ± 1.0 10^{19}	*PRL 95 (2005) 182302*
^{150}Nd	36.5 g	9.1 ± 0.7 10^{18}	*Phys. Rev. C 80 (2009) 032501*
^{96}Zr	9.43 g	2.35 ± 0.21 10^{19}	*Nucl. Phys. A 847 (2010) 168*
^{130}Te	0.45 kg	7.0 ± 1.4 10^{20}	*PRL 107 (2011) 062504*

Analysis in other isotopes (^{48}Ca, ^{116}Cd ...) in progress



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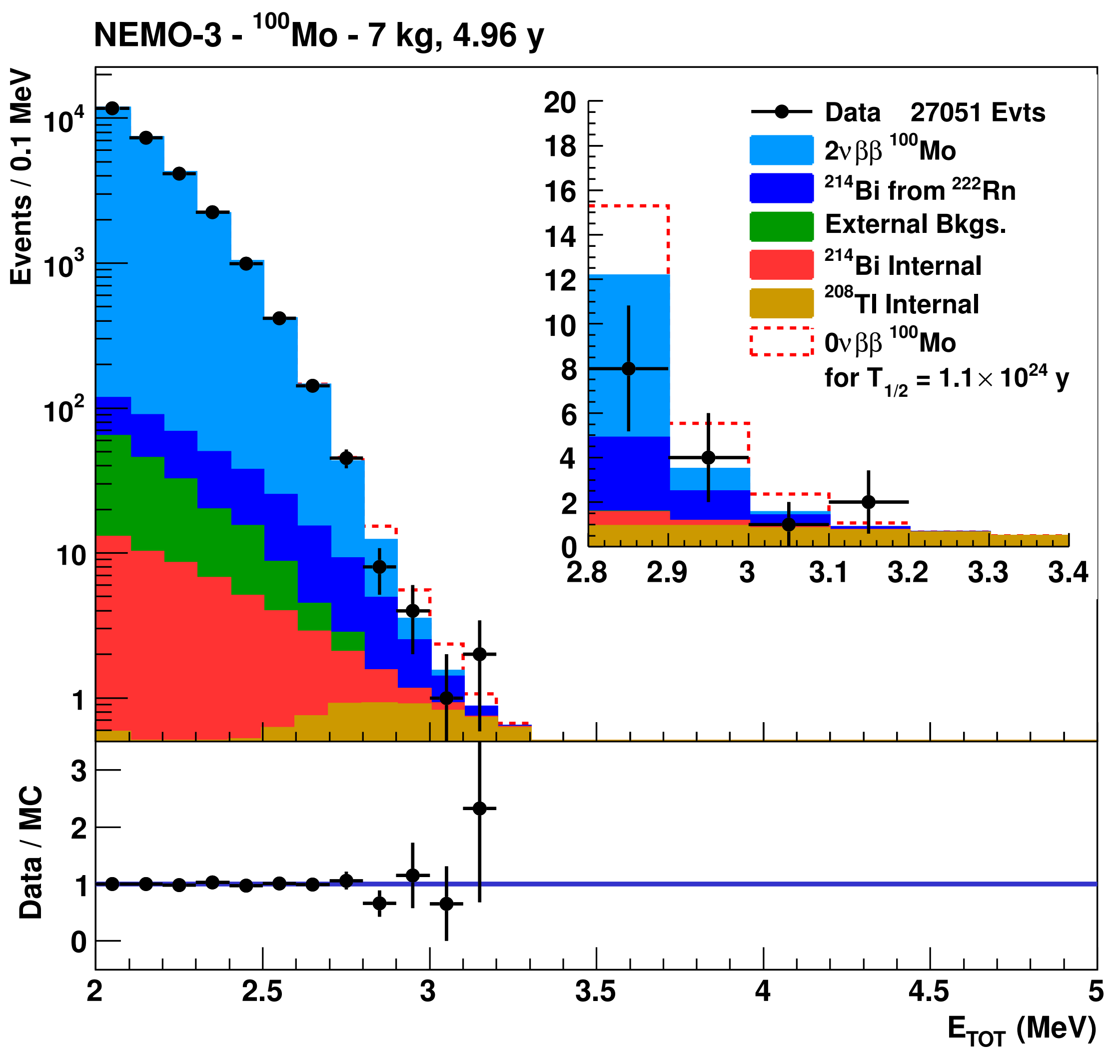


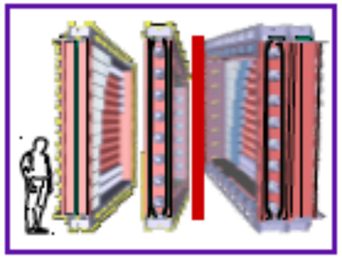
Need
- Better energy resolution
- Less radioactivity

No event excess for ^{100}Mo after 34.3 kg y exposure

$T^{0\nu}_{1/2} > 1.1\ 10^{24}$ y (90 % C.L.) $\rightarrow \langle m_{\beta\beta} \rangle < 0.3 – 0.9$ eV

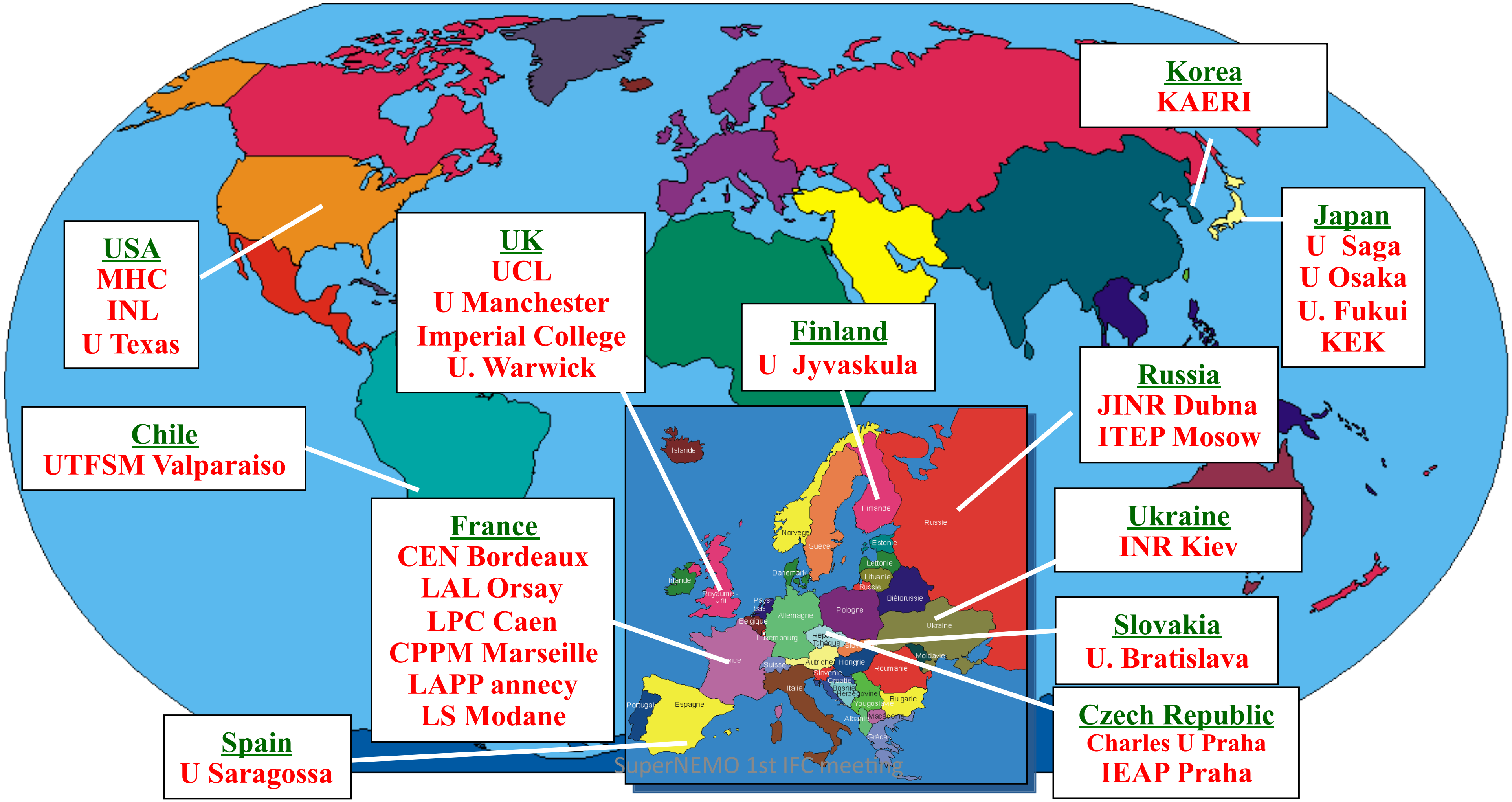
No events above 3.2 MeV

From NEMO 3 to SuperNEMO

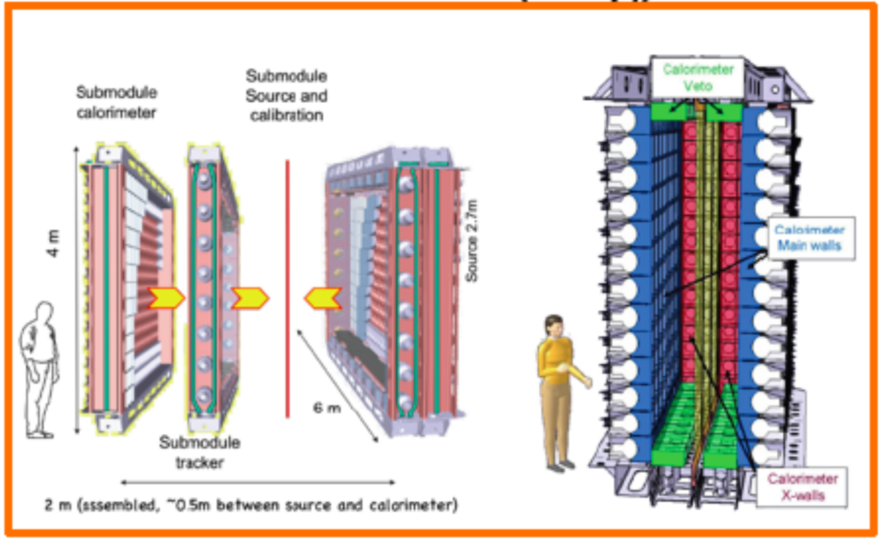


NEMO 3		SuperNEMO
^{100}Mo, ^{82}Se and others	*Isotope*	^{82}Se (^{150}Nd or ^{48}Ca?)
7 kg	*Mass*	~100 kg
60 mg/cm^2	*Foil Density*	40 mg/cm^2
15 % FWHM @ 1 MeV	*Energy Resolution*	7 % FWHM @ 1 MeV
8 % FWHM @ 3 MeV		4 % FWHM @ 3 MeV
~ 100 μBq/kg	*^{208}Tl source radiopurity*	< 2 μBq/kg
< 300 μBq/kg	*^{214}Bi source radiopurity*	< 10 μBq/kg
~ 5 mBq/m^3	*Rn level in Tracker*	~ 0.15 mBq/m^3
6180	*Tracking cells*	20 x 2034
1940	*Calorimeter Blocks*	20 x 712
1.3 10^{-3}	*Total Background (c/keV/kg/y)*	5 10^{-5}
$T^{0\nu}_{1/2} > 1.1\ 10^{24}$ y	*Sensitivity*	$T^{0\nu}_{1/2} > 1\ 10^{26}$ y
$<m_{\beta\beta}> < 0.3 – 0.9$ eV		$<m_{\beta\beta}> < 0.04 – 0.1$ eV

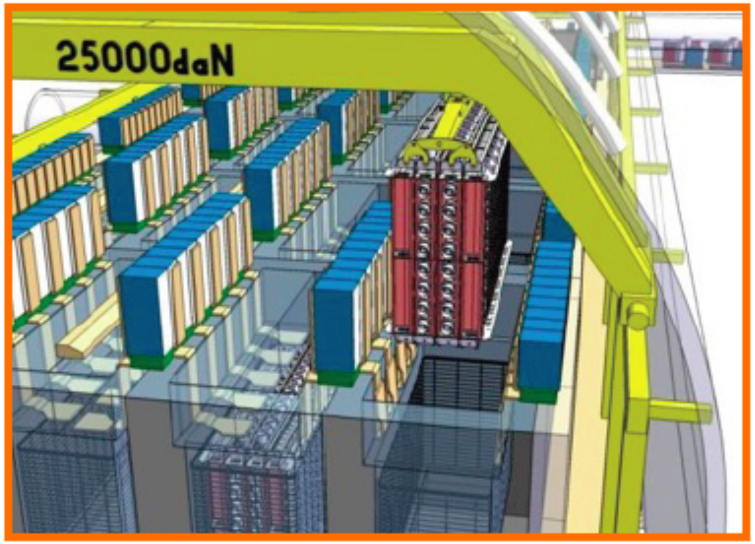
SuperNEMO collaboration



A module (5 kg)

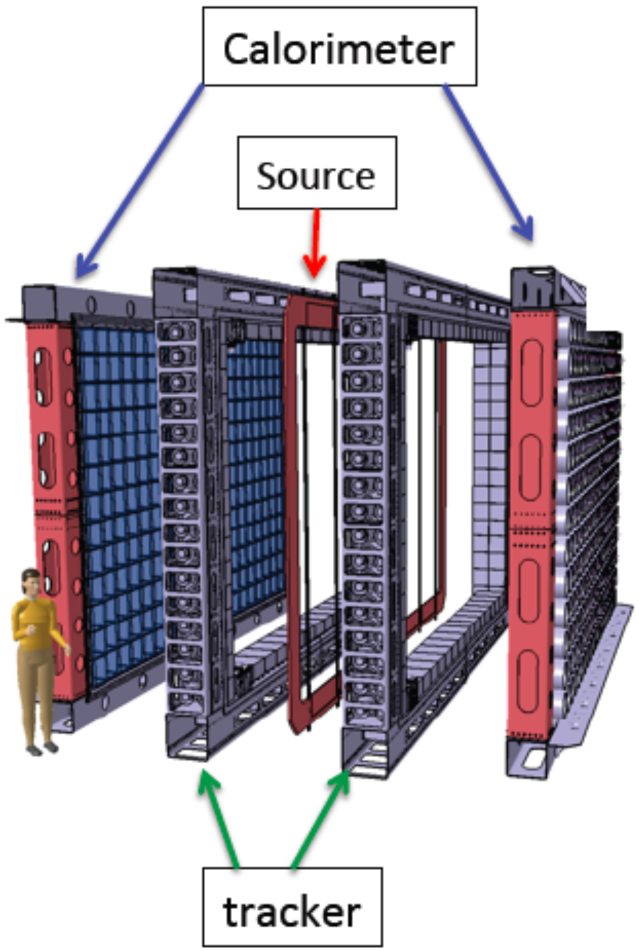


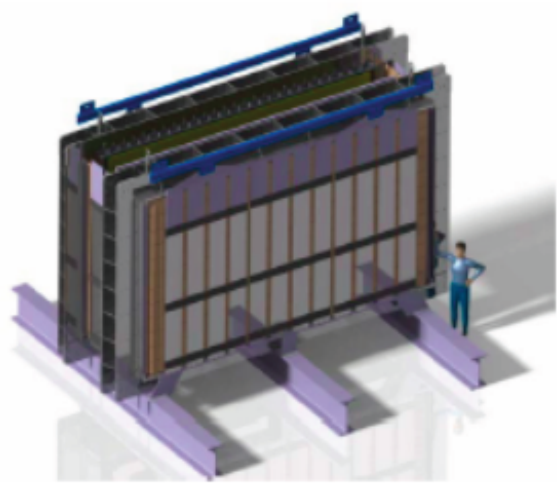
20 modules (100 kg)

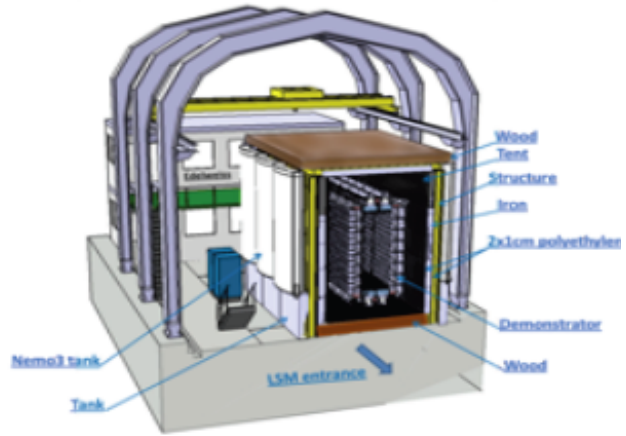


	Demonstrator module	20 Modules
Source : ^{82}Se	7 kg	100 kg
Drift chambers for tracking	2 0000	40 000
Electron calorimeter	500	10 000
γ veto (up and down)	100	2 000
$T_{1/2}$ sensitivity	6.6 10^{24} y (No background)	1. 10^{26} y
$<m_\nu>$ sensitivity	200 – 400 meV	40 – 100 meV

Demonstrator

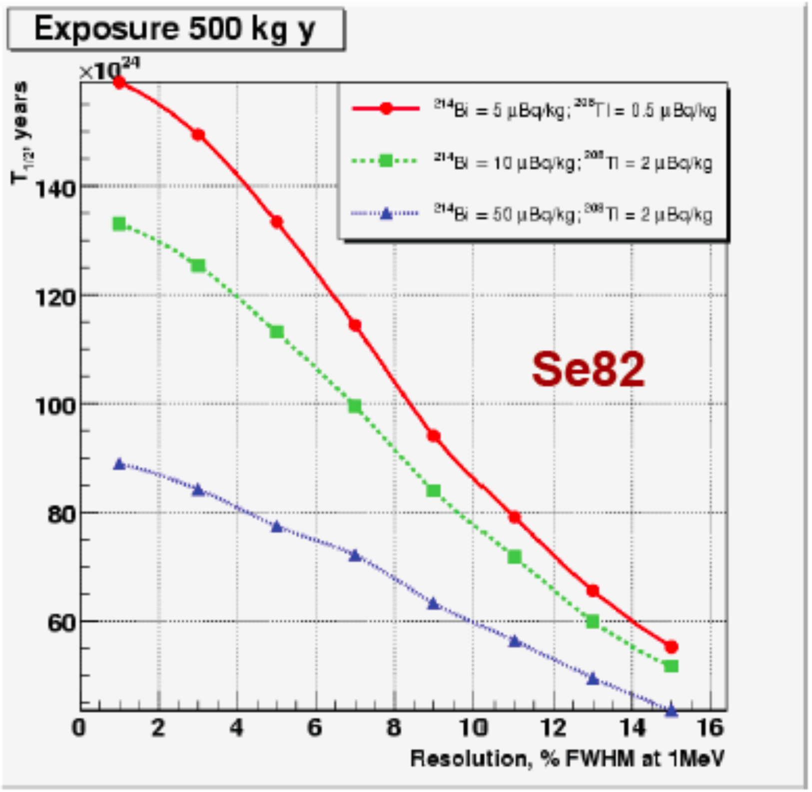






- Ultra low background detector
- Modular detector with 3 main components :
  - ❑ Central source foil frame : 7 kg of isotope
  - ❑ Tracking : 2 000 drift chambers
  - ❑ Calorimeter : 712 scintillators+ PMTs
- Shielded by iron (300 tons) and water
- Construction in progress

sensitivity



	Half-life sensitivity, (y)	$<m_\nu>$ sensitivity meV
Full SuperNEMO (100kg)		
^{82}Se 90 % (CL)	> 1.10^{26} y	< 40 - 110
^{82}Se 5σ	2. 10^{25} Y	100 - 250
Demonstrator (7 kg)		
^{82}Se 90 % (CL)	> 6 10^{24} y	< 160 - 440

Calorimeter:

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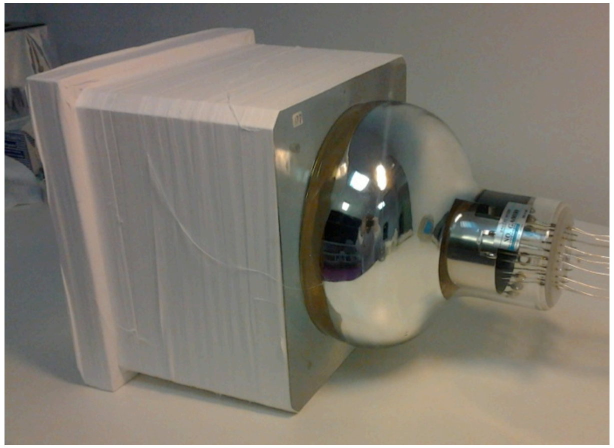
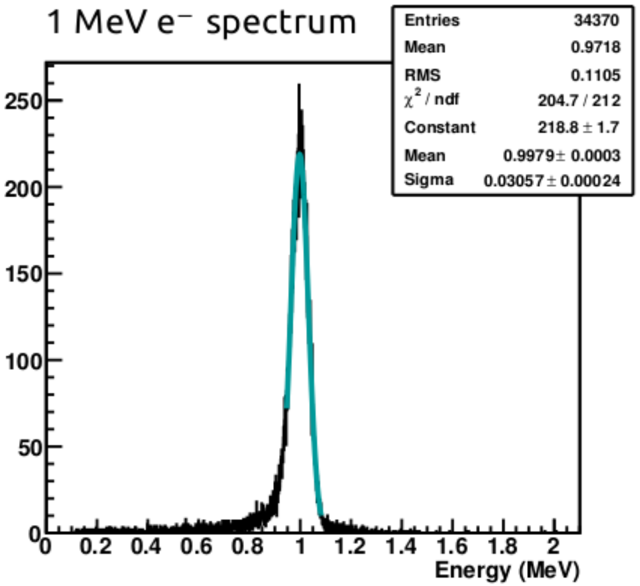
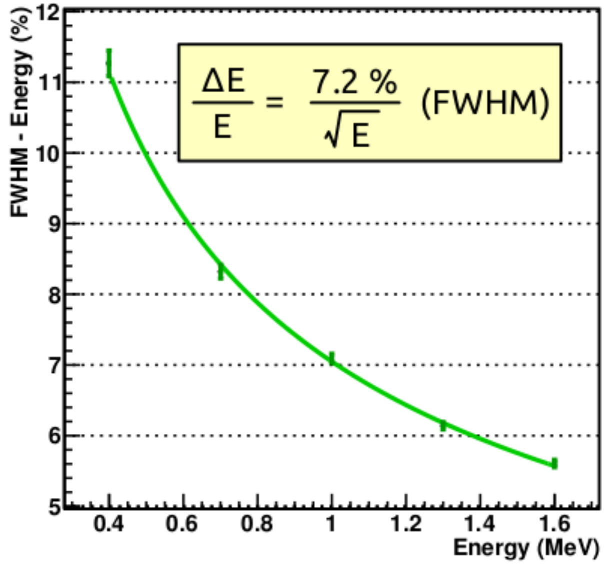
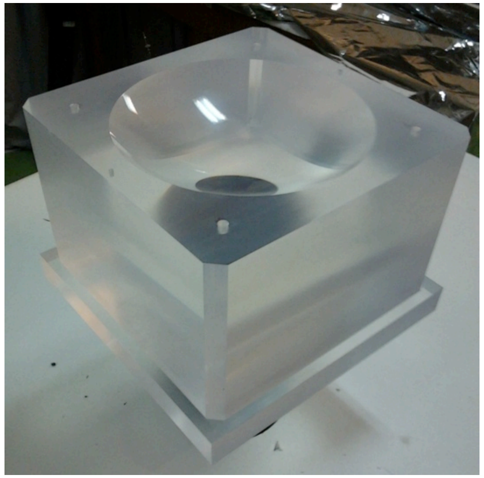
- Hamamatsu R9512
  - 8" and high quantum efficiency
  - Improved HV divider (less noise)
- Direct coupling PMT – Polystyrene Scintillator Block
  - Optimized geometry for the scintillator
- Tested with DAQ equivalent to the SuperNEMO one
  - ~2 GS/s for pulse sampling
- Energy resolution tests
  - 7.8 % FWHM @ 1 MeV









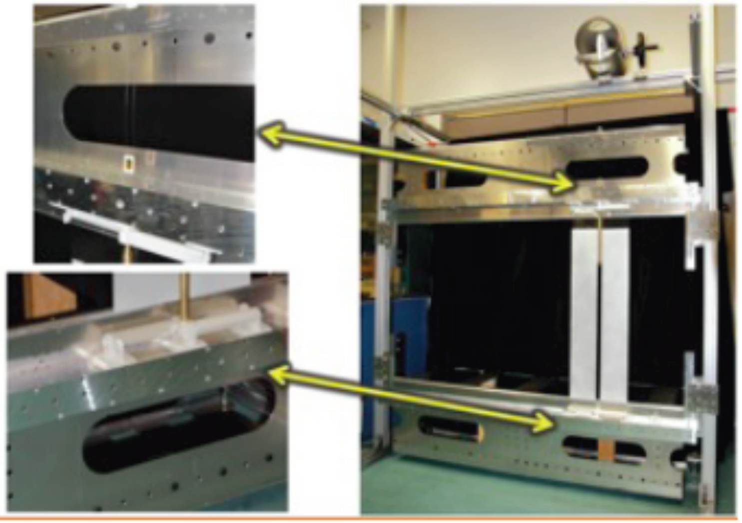
Source foil

Choice of ^{82}Se with a long $\beta\beta(2\nu)$ half-life compare to ^{100}Mo
Background decreased by a factor 13

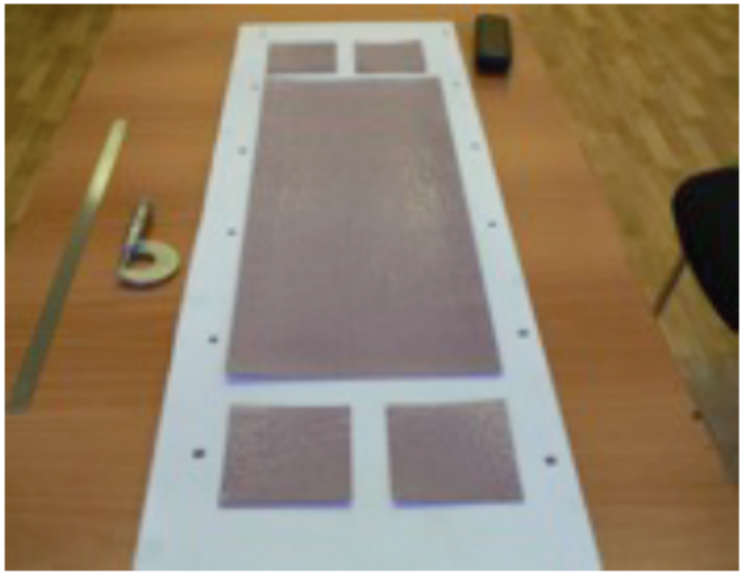
Optimization of the source foil thickness to reduce energy losses of electrons vs total mass of isotopes

Control of the uniformity of the source foil thickness

Source frame prototype



U. of Texas



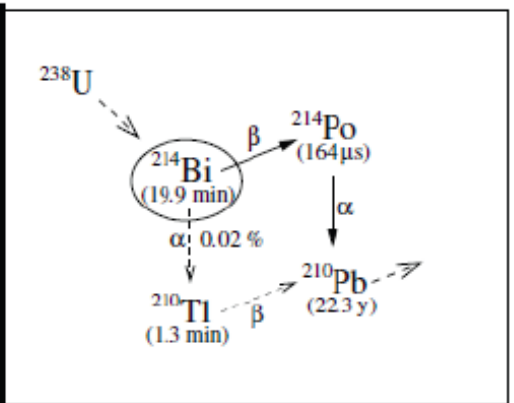
Source production R&D @ LAPP (FR), U. of Texas, ITEP (RU)

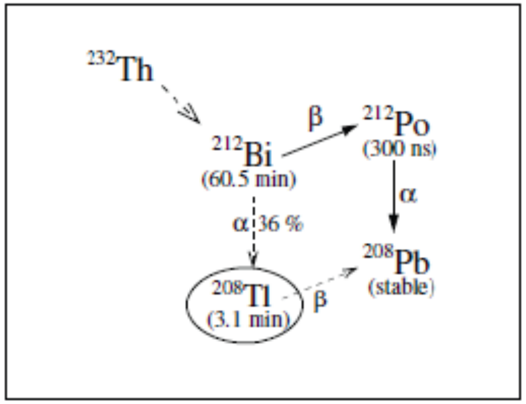
Requirements::

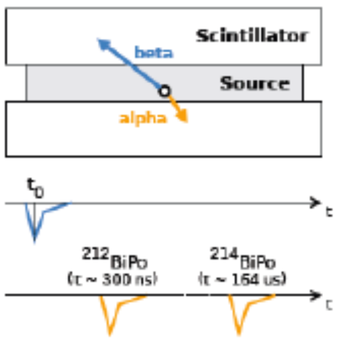
- <2 μBq/kg for ^{208}Tl

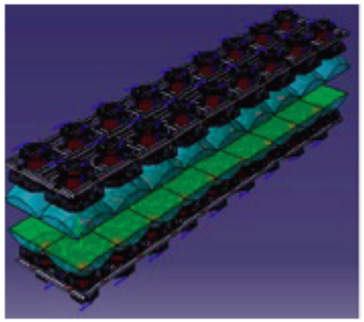
- <10 μBq/kg for ^{214}Bi

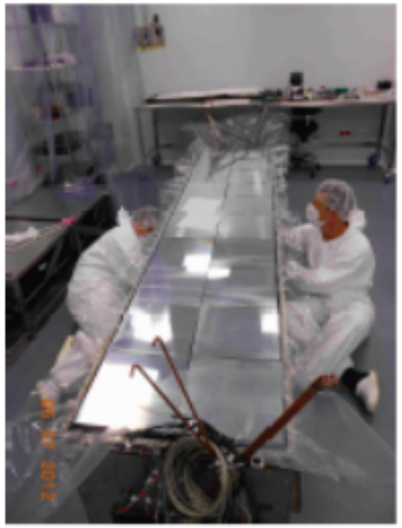
- Using of the Bi – Po delayed coincidence in U and Th chains

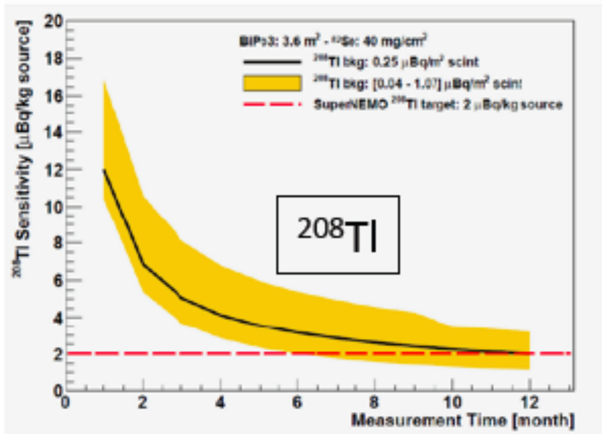












BiPo3 running at in LS Canfranc (ES)

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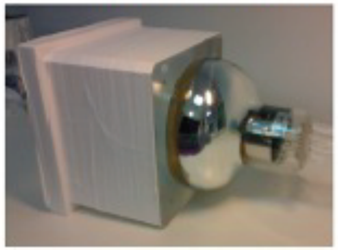
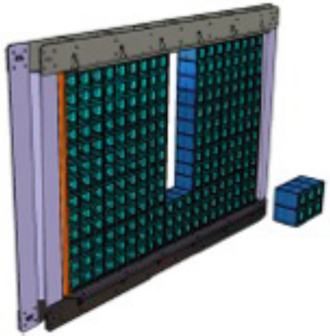
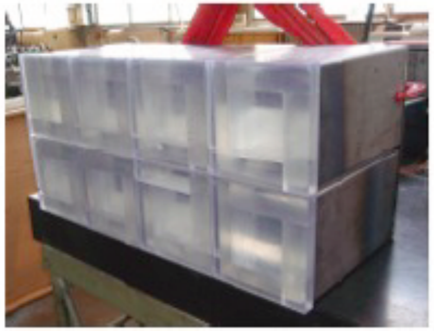
Calorimeter

- Scintillators under production and 8'' Hamamatsu PMT's in 03/2014
- FE digitizer boards OK, cnotrol and trigger boards under development
- Blocks, wall design and technical tests OK → construction in progress

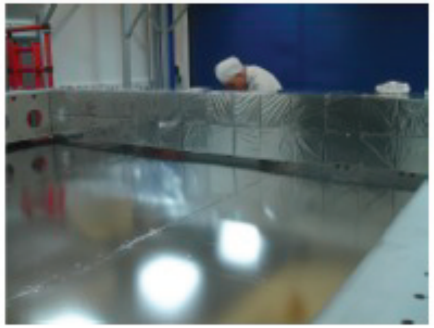
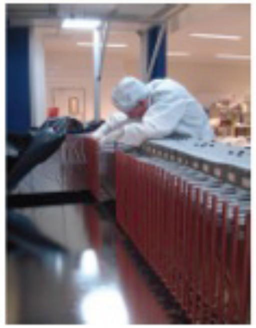
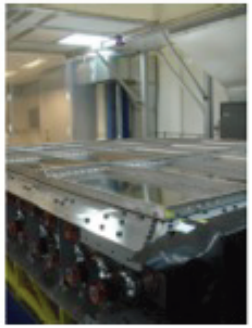
256 x 256 x 194 mm^3



Tracker

- Automated drift cells production ongoing with the wiring robot
- First 1 / 4 tracker C0 tested for radon emanation and cells propulation
- C0 commissioning at see-level and underground in 2014

Source

- 5.5 kg of ^{82}Se, 4.5 kg purified
- Source materials (glue, films,...) under HPGE and BiPO selection processes
- Calibration sources deployment system and LED survey system under test

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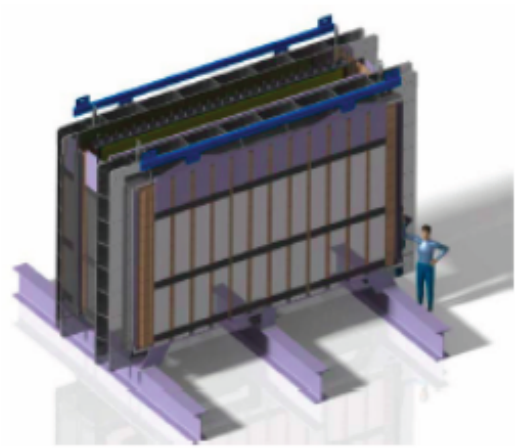


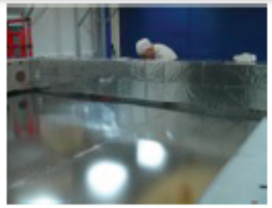
Demonstrator of SuperNEMO under construction

Installation and commissioning 2014 – 2015
@Modane underground laboratory

Data taking 2015 – 2017

No background expected

Validation of background requirement in 2016
→ decision for full scale SuperNEMO



with fully assembled demonstrator will be in 2nd mid 2016

Summary & Conclusions

NEMO – 3

Unique experiment capable to reconstruct energy and tracks of the 2 electrons

Signature of the $\beta\beta$ events with high background rejection capabilities

^{100}Mo data have no event excess after 34.7 kg y exposure

$T^{0\nu}_{1/2} > 1.1\ 10^{24}$ y → $<m_{\beta\beta}> < 0.3 – 0.9$ eV

Other results in $2\nu\beta\beta$ processes for several isotopes and other LNV measurements with ^{100}Mo

Phys. Rev. D 89 (2014) 111101

It showed the potential of developing a new generation experiment using this detection technique

SuperNEMO Demonstrator

~ 7 kg of ^{82}Se

No background in the $0\nu\beta\beta$ region after 2.5 years of data taking

$T^{0\nu}_{1/2} > 6.5\ 10^{24}$ y → $<m_{\beta\beta}> < 0.2 – 0.4$ eV

Demonstrate the background free possibility for SuperNEMO construction

Full SuperNEMO

100 kg of ^{82}Se

$T^{0\nu}_{1/2} > 1\ 10^{26}$ y → $<m_{\beta\beta}> < 0.04 – 0.1$ eV