SuperNEMO

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Plan

- **Physique du neutrino et double désintégration bêta**

- **NEMO 3**

- **SuperNEMO**

Double désintégration bêta sans neutrino

- Non-conservation du nombre leptonique

- Nature du neutrino : Dirac ($\nu \neq \bar{\nu}$) or Majorana ($\nu = \bar{\nu}$)

- Masse absolue du neutrino et hiérarchie des masses

- Interaction par courant droit

- Violation de CP dans le secteur leptonique

- Recherche supersymétrie et nouvelles particules

Propriétés du neutrino

Oscillations $\Rightarrow$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Atmosphériques (SK)
Accélérateurs (K2K,Minos)

Réacteurs (CHOOZ)
Accélérators (JPARC)

Solaires (SNO, SK)
Réacteurs (KamLAND)

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha/2} & 0 \\ 0 & 0 & e^{i\alpha/2+i\beta} \end{pmatrix}$$

$\tan^2\theta_{23}$=1.0 0.3

$\sin^2 2\theta_{13} < 0.16$

$\tan^2\theta_{12}$=0.39 0.05

α,β : CP pahse Majorana

δ_{CP}= CP phase de Dirac

$$\Delta m^2_{atm} = \Delta m^2_{31} = (2.3 \pm 0.2)\ 10^{-3}\ eV^2$$

$$\Delta m^2_{sol} = \Delta m^2_{12} = (7.9 \pm 0.3)\ 10^{-5}\ eV^2$$

Neutrino mass

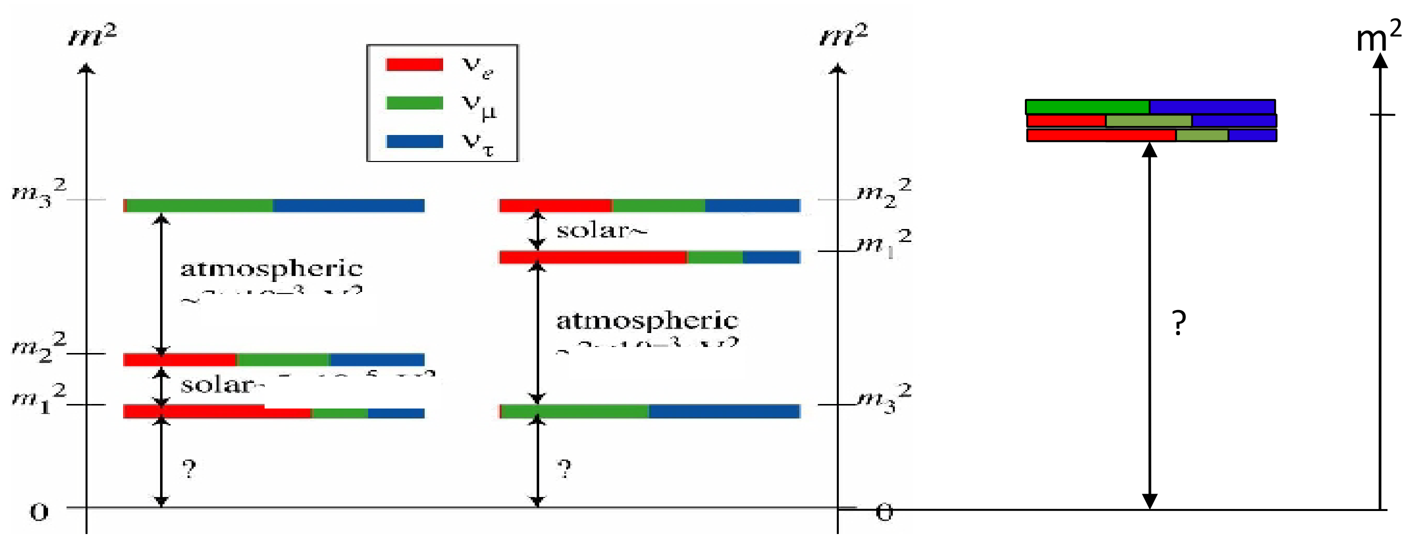
Masse absolue ?

Bêta simple $m_\nu = \left[\Sigma\, |U_{ei}|^2 m_i^{\,2}\right]^{1/2} < 2.3\ \text{eV}$

Double bêta $|\langle m_\nu\rangle| = |\Sigma U_{ei}^2 m_i| < 0.2 - 0.8\ \text{eV}$

Cosmologie $\Sigma m_i = m_1 + m_2 + m_3 <\sim 1\ \text{eV}$

Hiérarchie ?

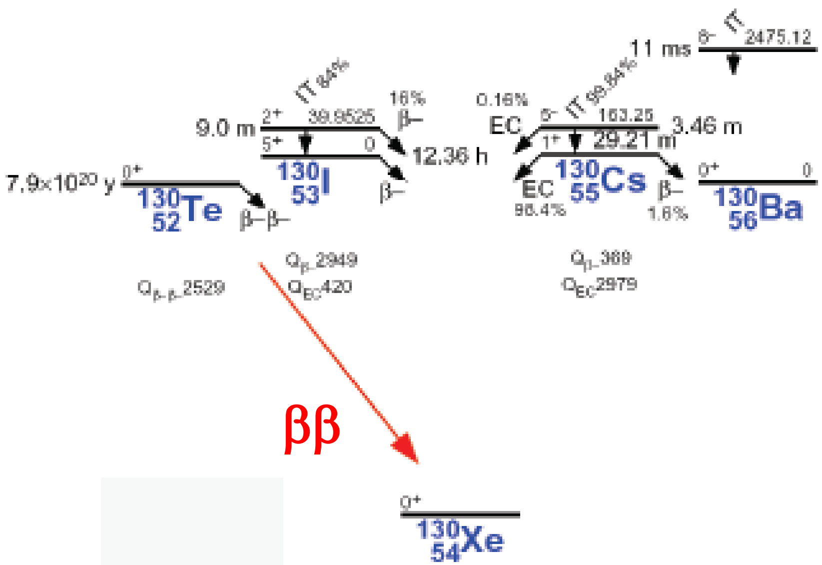


Normale $m_3 >> m_2 \sim m_1$

Inversée $m_2 \sim m_1 >> m_3$

Dégénérée $m_1 \approx m_2 \approx m_3 \gg |m_i - m_j|$

Décroissance double bêta

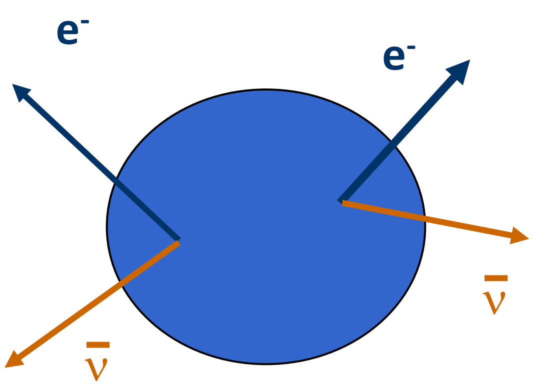


Bêta simple interdite (énergie)

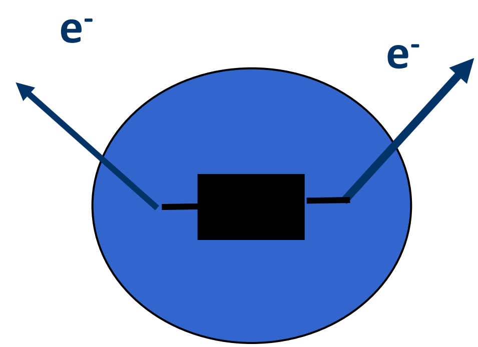
ou fortement supprimée

Décroissance possible vers l'état fondamentale ou les états excités

$\beta\beta(2\nu)$



$\beta\beta(0\nu)$



$\Delta L = 2$

Processus au 2nd ordre de l'interaction faible

Déjà observé pour plusieurs noyaux

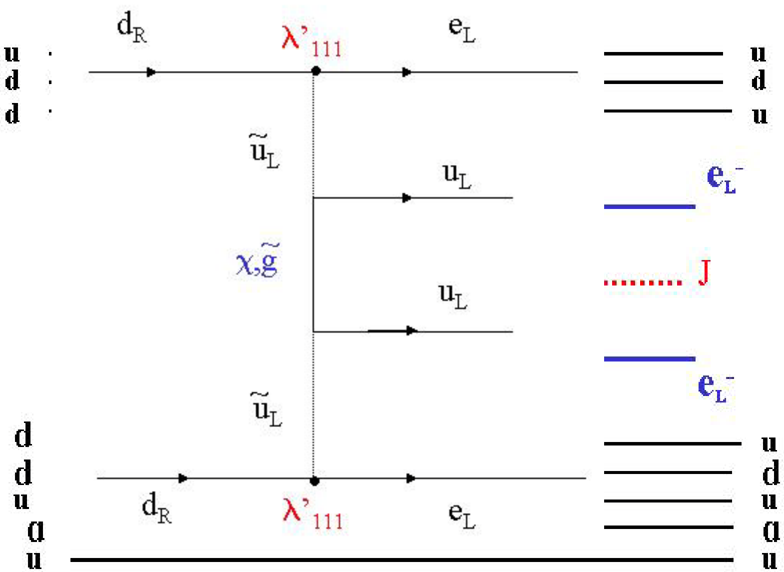
$\beta\beta(0\nu) \rightarrow$ Majorana neutrino ($\nu=\bar{\nu}$)

Neutrinoless Double Beta decay

$$(A,Z) \longrightarrow (A,Z+2) + 2\,e^-$$

Découverte implique ΔL=2 and neutrino de Majorana

Processus:	paramètres
Exchange neutrino léger	$\langle m_\nu \rangle$
Courant (V+A)	$\langle m_\nu \rangle, \langle \lambda \rangle, \langle \eta \rangle$
Emission de Majoron(s)	$\langle g_M \rangle$
SUSY	$\lambda'_{111}, \lambda'_{113} \lambda'_{131}, \ldots$



Phase space factor

Nuclear matrix element

$$\left(T^{0\nu}_{1/2}\right)^{-1} = C_1 \left(\frac{\langle m_\nu \rangle}{m_e}\right)^2 + C_2 \langle \lambda \rangle \ldots + C_3 \ldots + C_4 \ldots$$

$$\left(T^{0\nu}_{1/2}\right)^{-1} = F(Q_{\beta\beta}, Z)\, |M|^2 \langle m_\nu \rangle^2$$

$$\left(T_{1/2}\right)^{-1} = F\, |M|^2 \langle g_M \rangle^2$$

R-parity violation: T depends on $(\lambda'_{111})^2$, gluino and squarks mass

C_i: Coefficients containing phase space factor and nuclear matrix elements

$\langle m_\nu \rangle$: effective neutrino masse

Effective mass:

coupling between right lepton and left quarks, right quarks

Coupling between Majoron and neutrinos

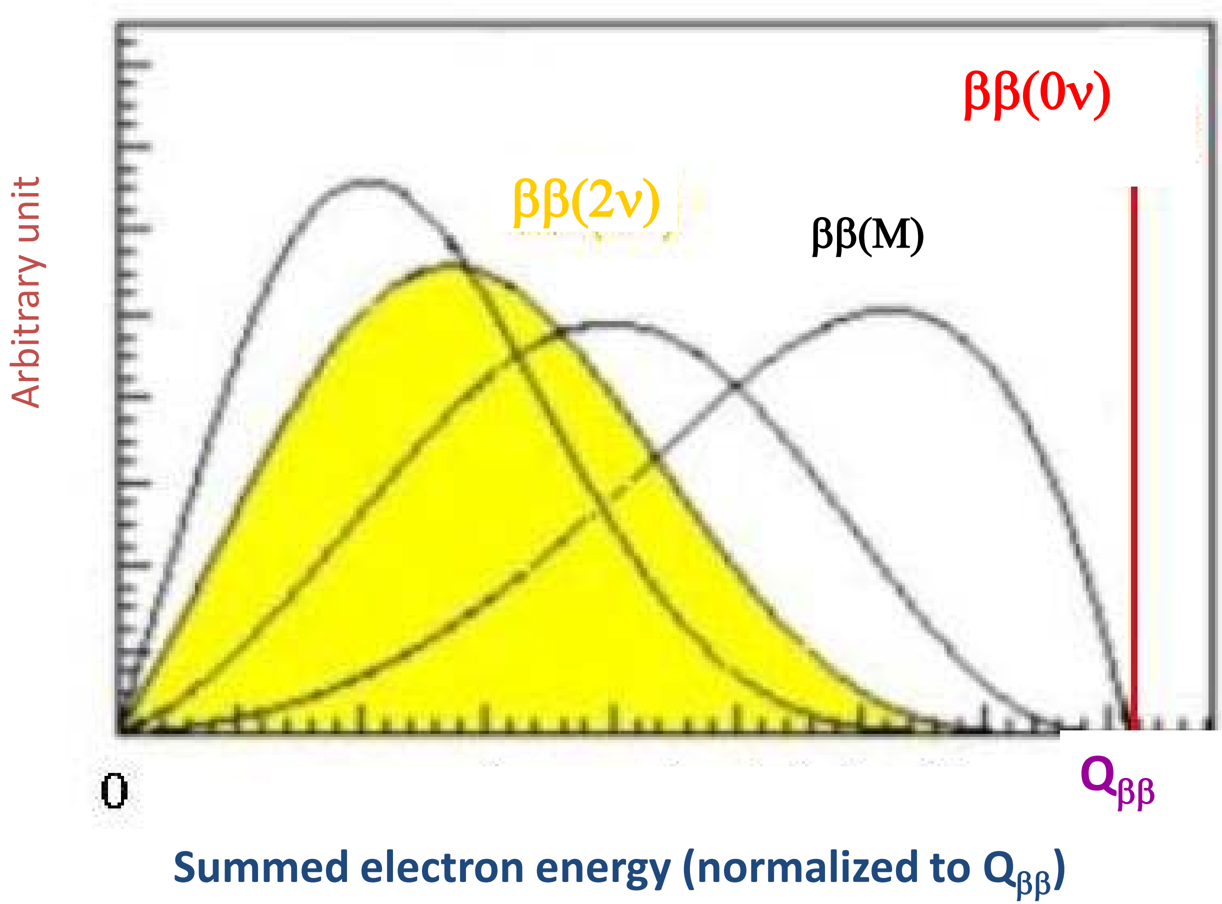
phase between neutrino and

$$\langle m_\nu \rangle = m_1 |U_{e1}|^2 + m_2 |U_{e2}|^2 . e^{i\alpha 1} + m_3 |U_{e3}|^2 . e^{i\alpha 2}$$

|Uei|: mixing matrix element

α1 et α2: Majorana phase

ββ(0ν) :les observables

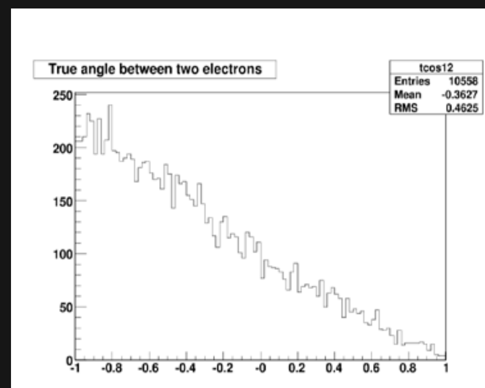


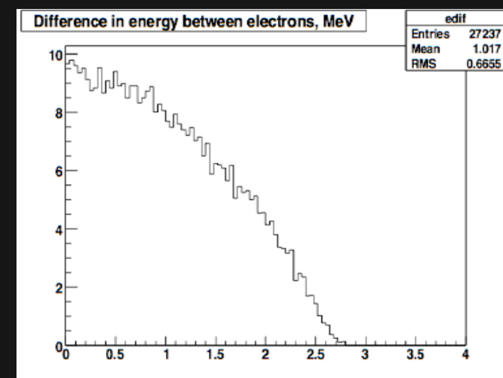
ββ(0ν): les observables

From G. Gratta

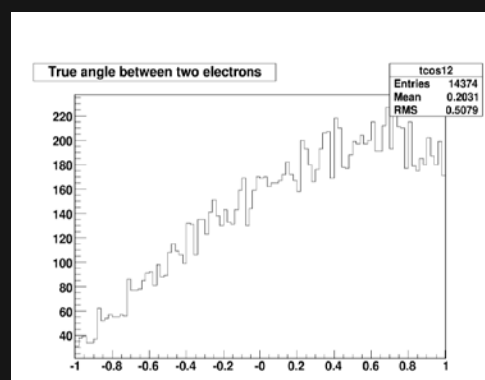
Cos θ | **Energy difference**

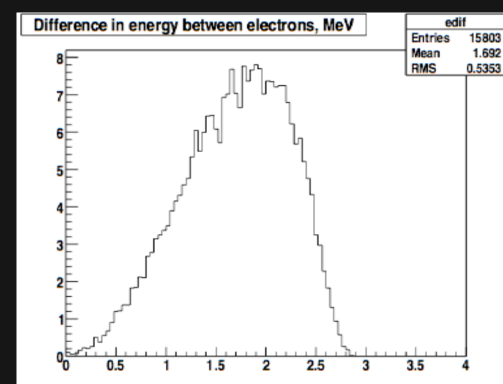
Light neutrino exchange





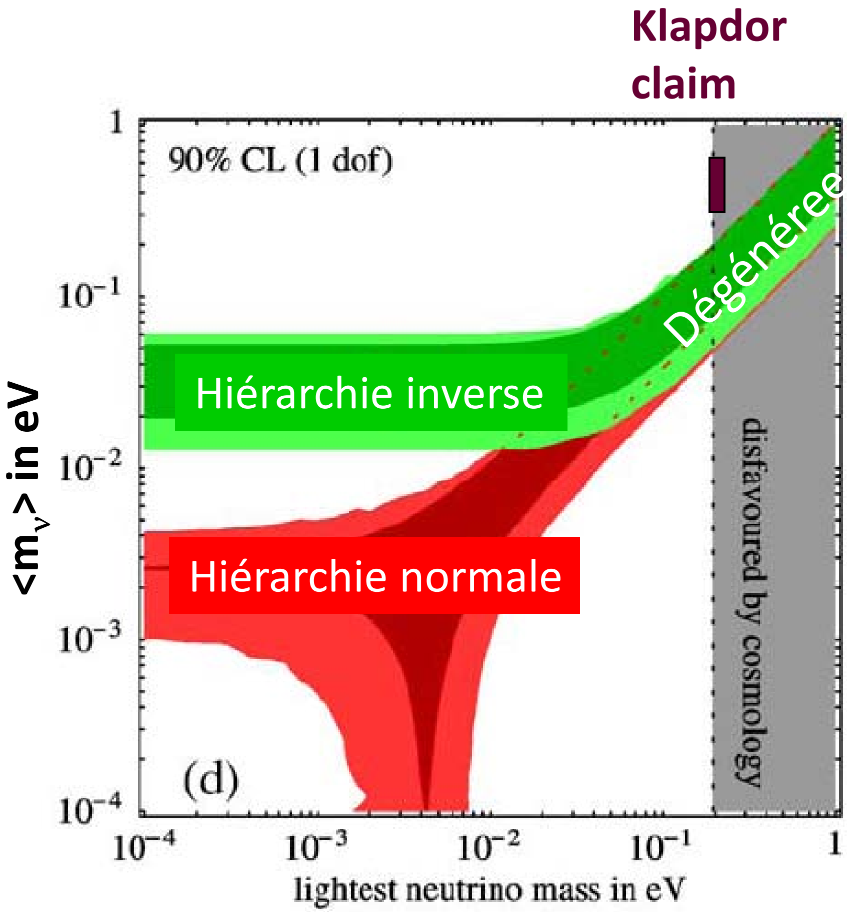
Right-handed current





Masse effective et oscillations de neutrinos

$$|\langle m_\nu \rangle| = |\sum U_{e_i}^2 m_i| = |\cos^2\theta_{13}(m_1\cos^2\theta_{12} + m_2 e^{2i\alpha}\sin^2\theta_{12}) + m_3 e^{2i\beta}\sin^2\theta_{13}|$$



Dégénérée: peut être testée (~10 kg)

Inversée: testée par la prochaine génération d'expérience ββ (~100 kg)

Hiérarchie normale: inaccessible actuellement (~1 tonne)

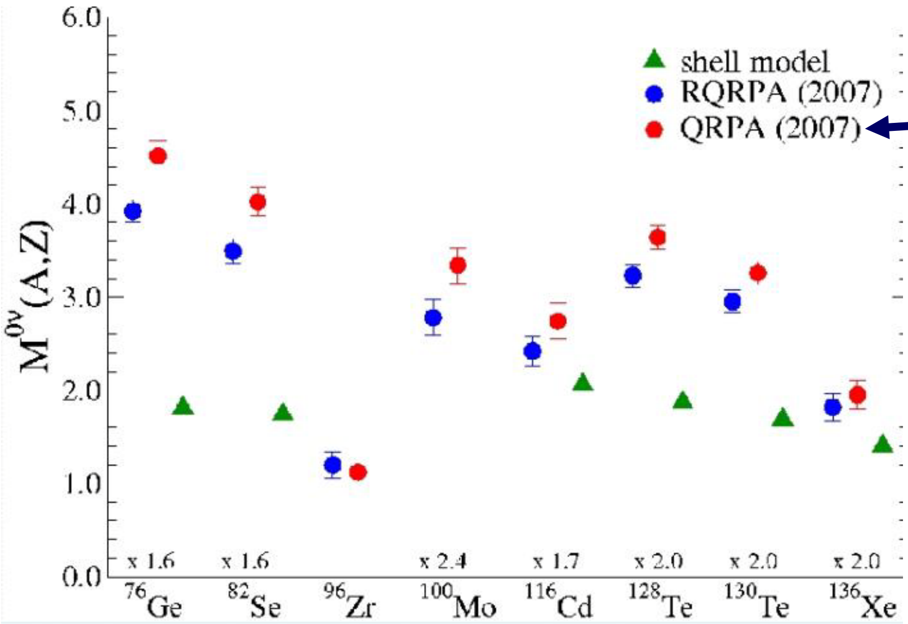
Emetteurs ββ

Isotope	$Q_{\beta\beta}$ (MeV)	abondance isotopique (%)	$G_{0\nu}(an^{-1}) \times 10^{25}$
^{48}Ca	4.271	0.187	2.44
^{76}Ge	2.040	7.8	0.24
^{82}Se	2.995	9.2	1.08
^{96}Zr	3.350	2.8	2.24
^{100}Mo	3.034	9.6	1.75
^{116}Cd	2.802	7.5	1.89
^{130}Te	2.528	33.8	1.70
^{136}Xe	2.479	8.9	1.81
^{150}Nd	3.367	5.6	8.00

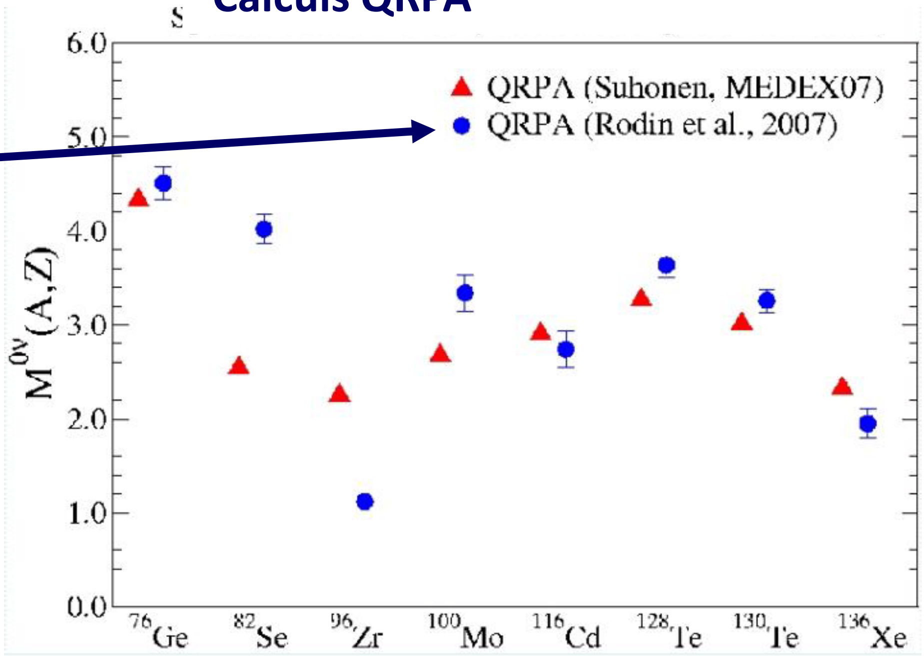
Eléments de matrice nucléaire

$$T_{1/2}^{-1} = F(Q_{\beta\beta}^{5}, Z)\ |M^{0\nu}|^2 \langle m_\nu \rangle^2$$

Shell Model - QRPA



Calculs QRPA



Des améliorations mais encore des incertitudes pour extraction de $\langle m_\nu \rangle$

Techniques expérimentales

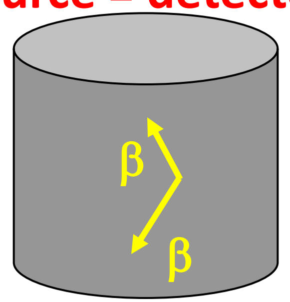
Avec bruit de fond:

$$T^{0\nu}_{1/2}(y) > \frac{\ln 2 \,.\, \mathcal{N}}{k_{C.L.}} \cdot \frac{\varepsilon}{A} \sqrt{\frac{M \,.\, t}{N_{Bckg} \,.\, \Delta E}}$$

M: masse (g)
ε : efficacité »
$\mathbf{K_{C.L.}}$: Confidence level
$\mathcal{N}$: Avogadro number
t: temps (an)
$\mathbf{N_{Bckg}}$: bruit de fond ($keV^{-1}.g^{-1}.an^{-1}$)
ΔE: Résolution en énergie (keV)

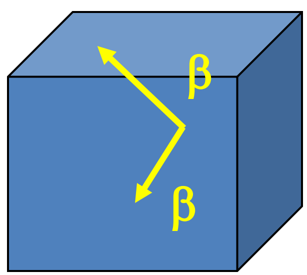
Aucune technique ne peut optimiser tous ces paramètres

Calorimètre
Semi-conducteurs
Bolomètres
Source = détecteur



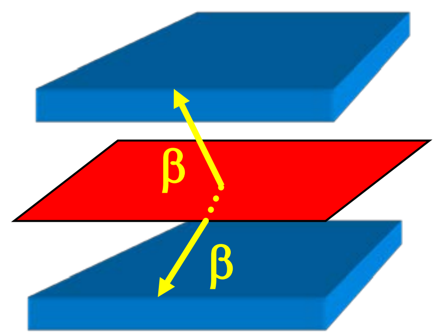
ε, ΔE

Calorimètre
Scintillateur (chargé)
Source = détecteur



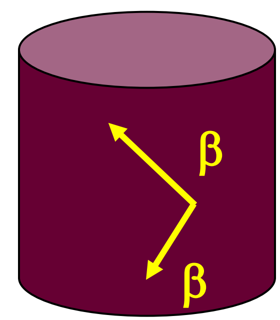
ε, M

Tracko-calo
Source ≠ detector



NBckg, choix isotope

Xe TPC
Source = détecteur



ε,M, (N_{Bckg})

Calorimètre vs Tracko-calo

Calorimètre

Résolution en énergie

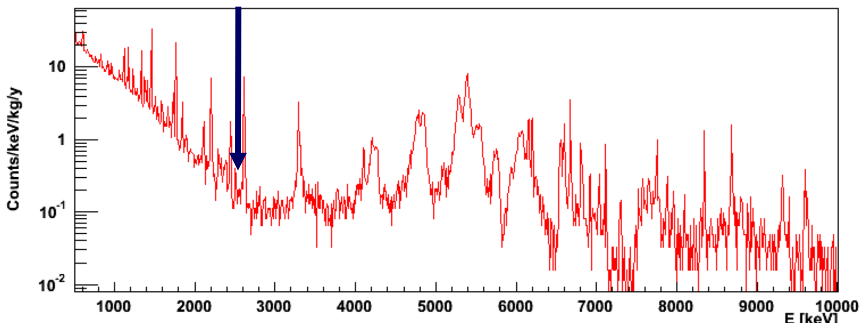
Modeste réjection des fonds

Tracko-calo

Réjection des fonds

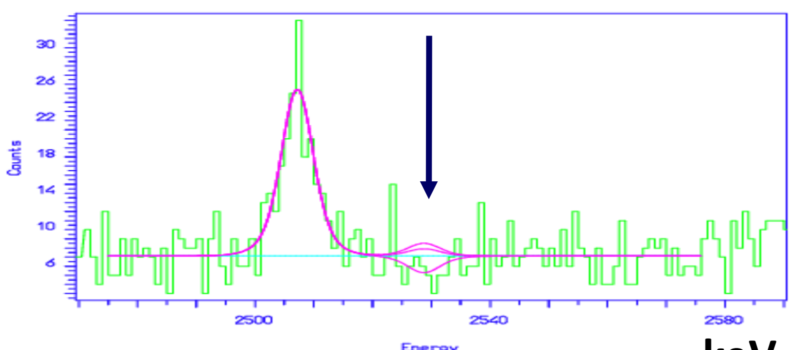
Modeste énergie résolution

ββ(0ν)



keV

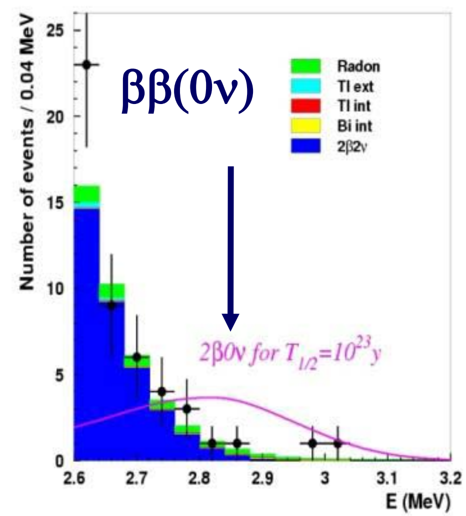
ββ(0ν)



keV

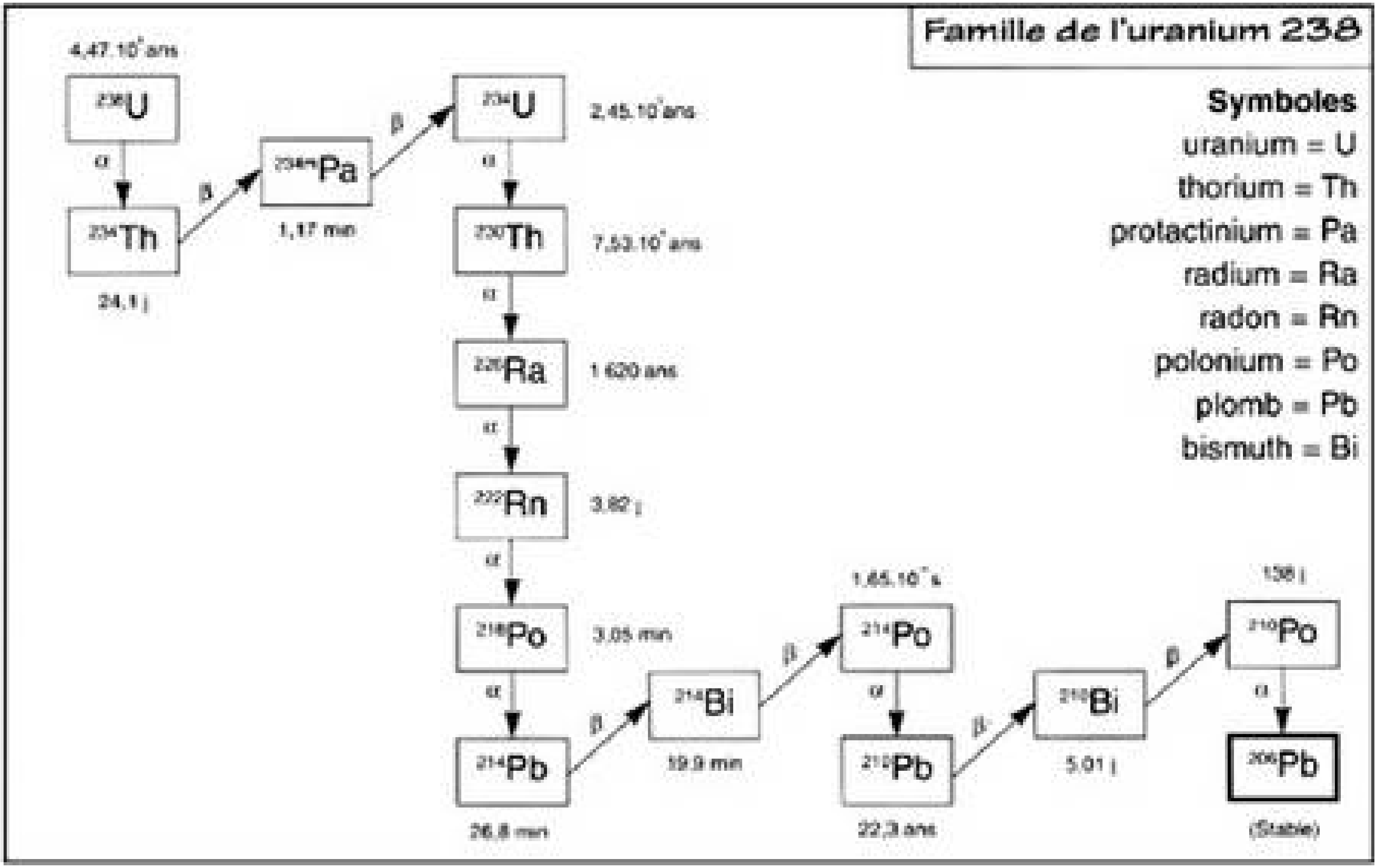
ββ(0ν)

ββ(0ν)



MeV

Radioactivité naturelle: principal bruit de fond



Sélection de tous les matériaux entre 10^3 et 10^6 fois moins radioactifs que les matériaux standard

$Q_{\beta\beta}$ et composantes de bruit de fond

Radioactivité naturelle (^{40}K, ^{60}Co,^{234m}Pa, ^{214}Bi and ^{208}Tl externe…)

^{214}Bi et Radon

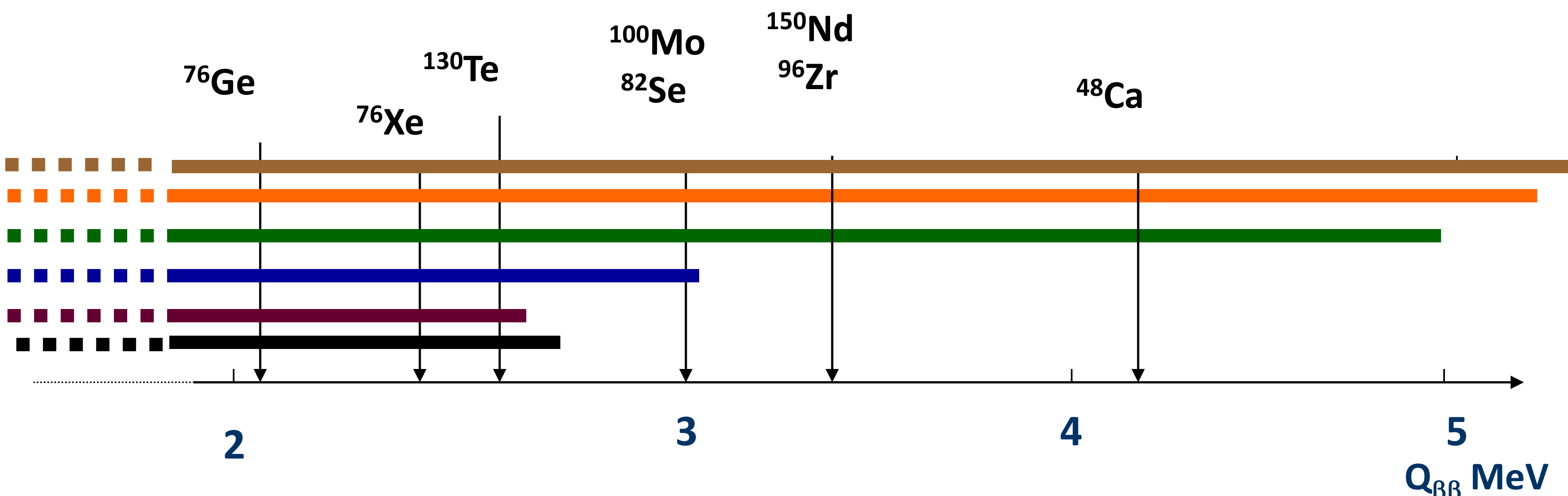
^{208}Tl (2.6 MeV γ line) et Thoron

γ venant des réactions (n,γ) et bremstrahlung des muons

+ spécifique fonds pour les calorimètre

Contamination de surface ou de volume en émetteurs α

Production de cosmogénique



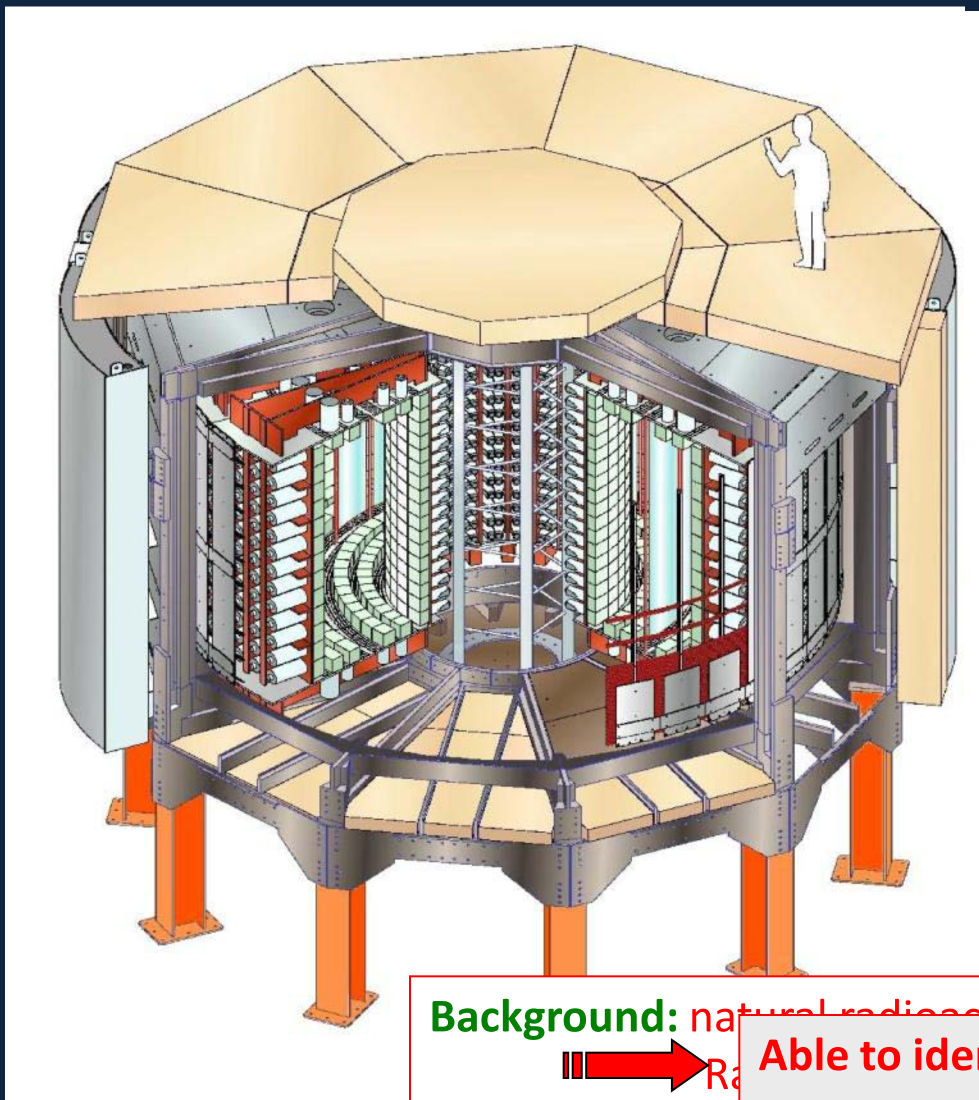
+ $\beta\beta(2\nu)$ pour tracko-calo or calorimètre avec une modeste résolution en énergie

ββ(0ν) : un domaine dynamique

Experiments	Isotopes	Techniques	Main caracteristics
NEMO3	^{100}Mo,^{82}Se	Tracking + calorimeter	Bckg rejection, isotope choice
SuperNEMO	^{82}Se, ^{150}Nd	Tracking + calorimeter	Bckg rejection, isotope choice
Cuoricino	^{130}Te	Bolometers	Energy resolution, efficiency
CUORE	^{130}Te	Bolometers	Energy resolution, efficiency
GERDA	^{76}Ge	Ge diodes	Energy resolution, eficiency
Majorana	^{76}Ge	Ge diodes	Energy resolution, efficiency
COBRA	^{130}Te, ^{116}Cd	ZnCdTe semi-conductors	Energy resolution, efficiency
EXO	^{136}Xe	TPC ionisation + scintillation	Mass, efficiency, final state signature
MOON	^{100}Mo	Tracking + calorimeter	Compactness, Bckg rejection
CANDLES	^{48}Ca	CaF_2 scintillating crystals	Efficiency, Background
SNO++	^{150}Nd	Nd loaded liquid scintillator	Mass, efficiency
XMASS	^{136}Xe	Liquid Xe	Mass, efficiency
CARVEL	^{48}Ca	CaWO4 scintillating crystals	Mass, efficiency
Yangyang	^{124}Sn	Sn loaded liquid scintillator	Mass, efficiency
DCBA	^{150}Nd	Gazeous TPC	Bckg rejection, efficiency

NEMO 3 detector

Fréjus Underground Laboratory : 4800 m.w.e.



Source: 10 kg of ββ isotopes
cylindrical, S = 20 m^2, 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 (18 cm)
Neutron shield: borated water
+ Wood

Background: natural radioactivity, mainly ^{214}Bi et ^{208}Tl (γ 2.6 MeV)
Ra

Able to identify e^-, e^+, γ and α

Un secteur de NEMO 3

Anneau cathodique de la chambre à fils

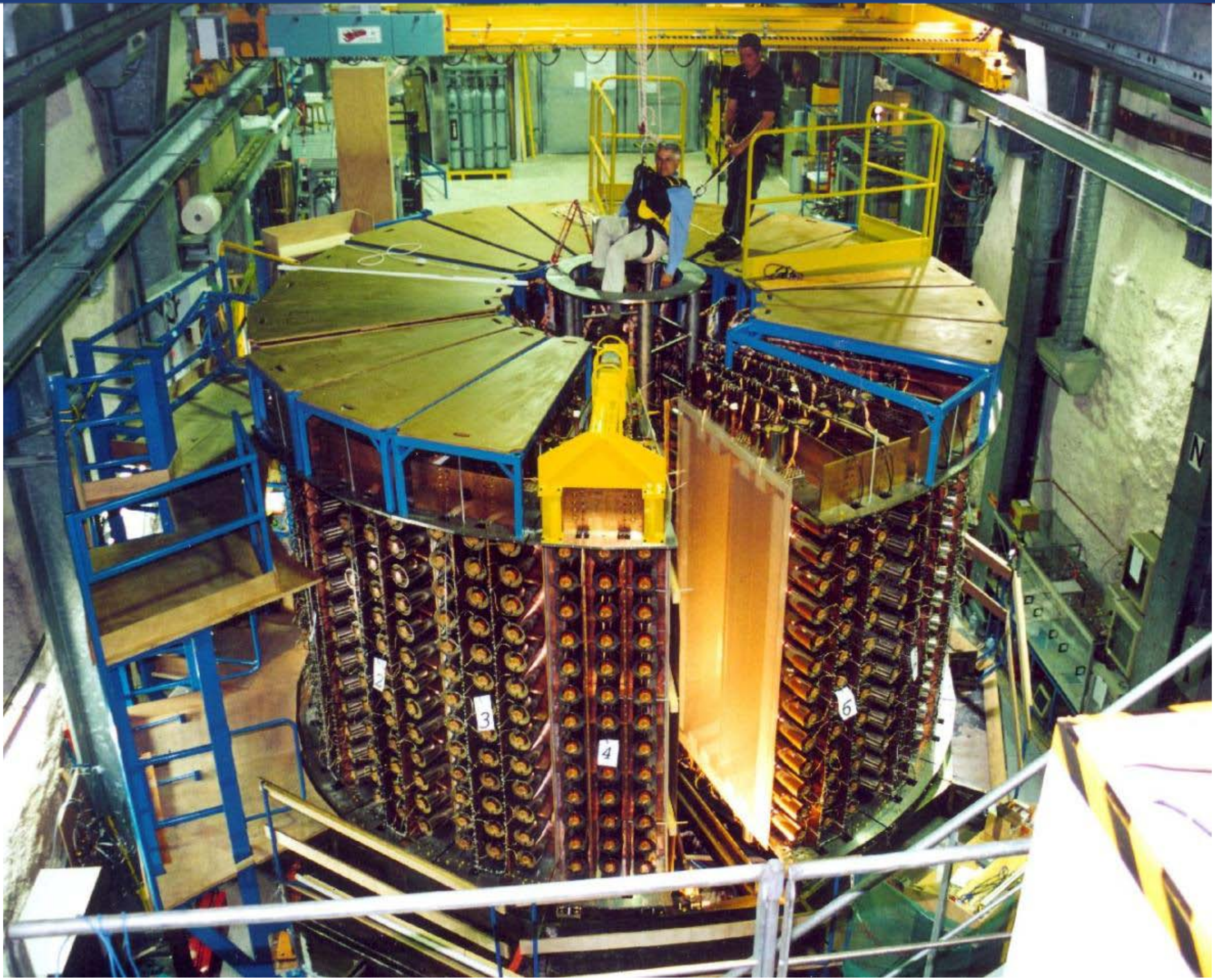
PM

Tube d'étalonnage

Scintillateurs

Feuilles Sources ββ

NEMO 3 detector



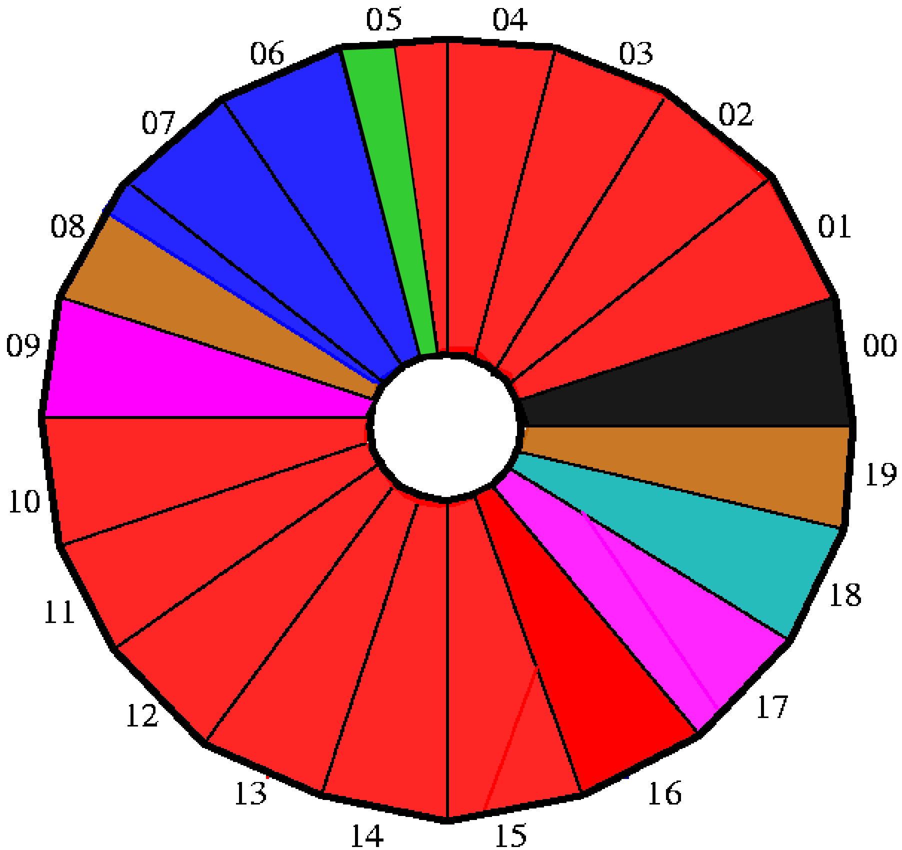
NEMO 3 sources

^{100}Mo 6.914 kg
$Q_{\beta\beta}$ = 3034 keV

&

^{82}Se 0.932 kg
$Q_{\beta\beta}$ = 2995 keV

→ **0νββ decay search**



^{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

2νββ decay measurement

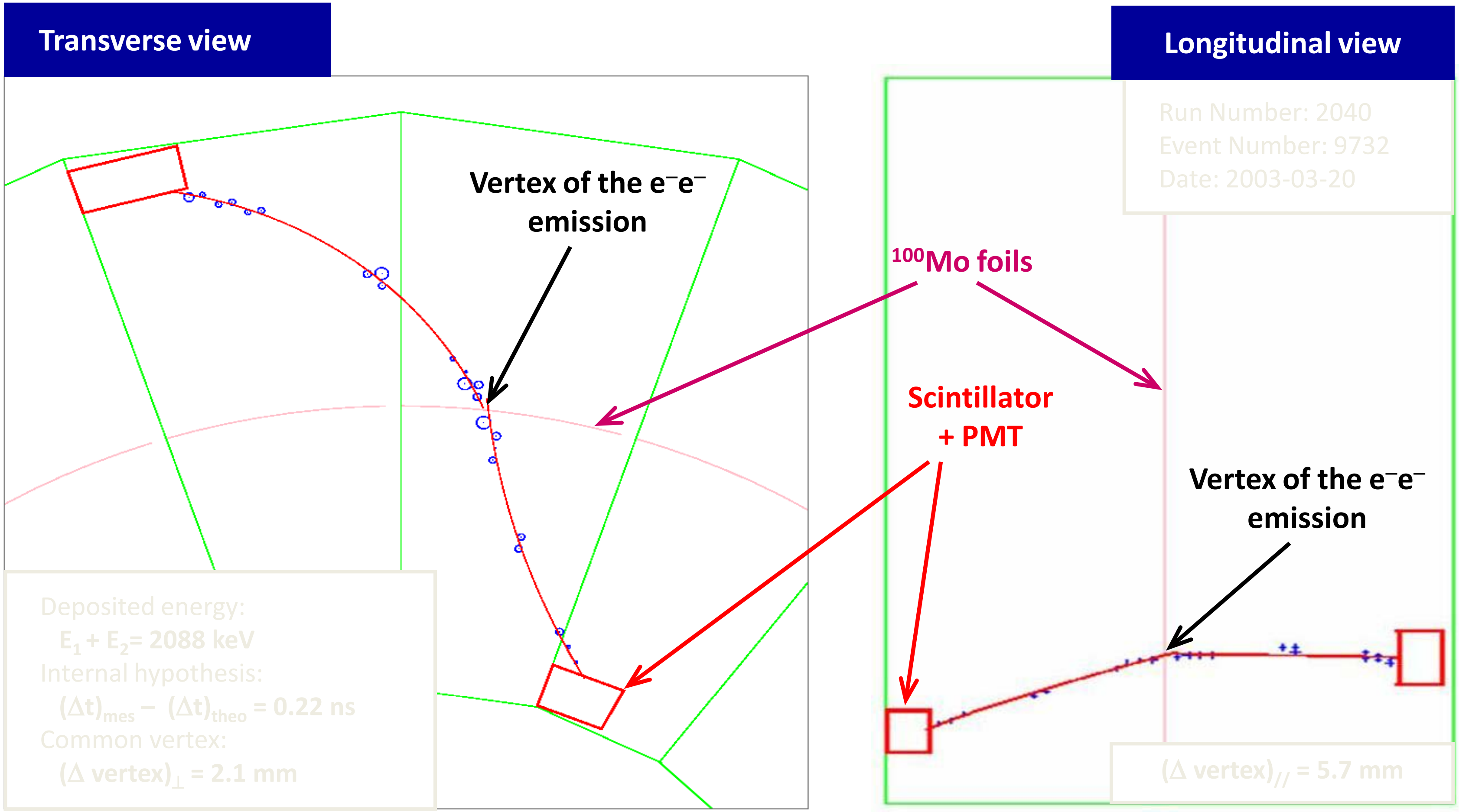
^{nat}Te 491 g

Cu 621 g

External background measurement

All sources produced by centrifugation in Russia

NEMO 3 ββ typical event



Criteria to select ββ events:

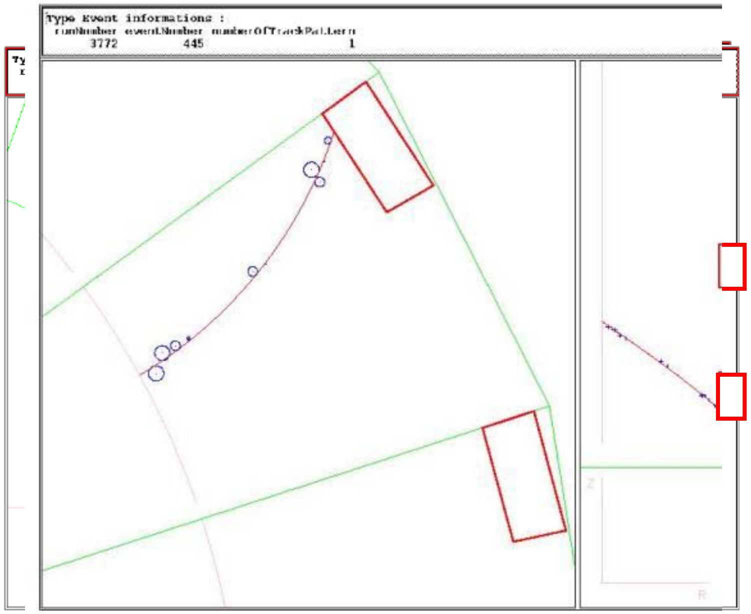
- 2 tracks with charge < 0
- 2 PMTs, each > 200 keV
- PMT-Track association
- Common vertex
- Internal hypothesis TOF (external event rejection)
- No other isolated PMT (γ rejection)
- No delayed α track (^{214}Bi rejection)

NEMO-3 can measure each component of the background

External Background ^{208}Tl (PMTs)

Measured with (e^-, γ) external events

~ 10^{-3} $\beta\beta0\nu$-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV



External Neutrons and High Energy gamma

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

< 0.02 $\beta\beta0\nu$-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV

^{208}Tl impurities inside the foils ~ 60 μBq/kg

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

~ 0.06 $\beta\beta0\nu$-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV

^{214}Bi impurities inside the foils

Measured with (e^-,γ,α) events coming from the foil, dominated by radon in first period

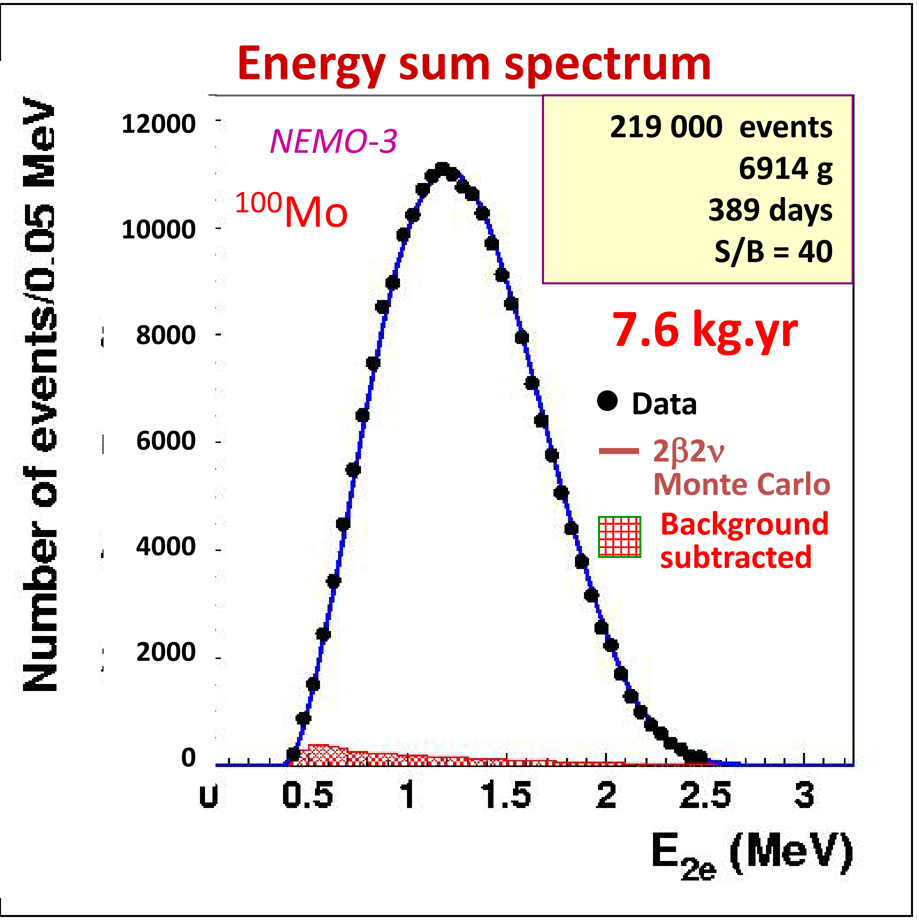
Radon supressed since December 2004, measument in progress. Limits from Ge: A(^{214}Bi)< 400 μBq/kg

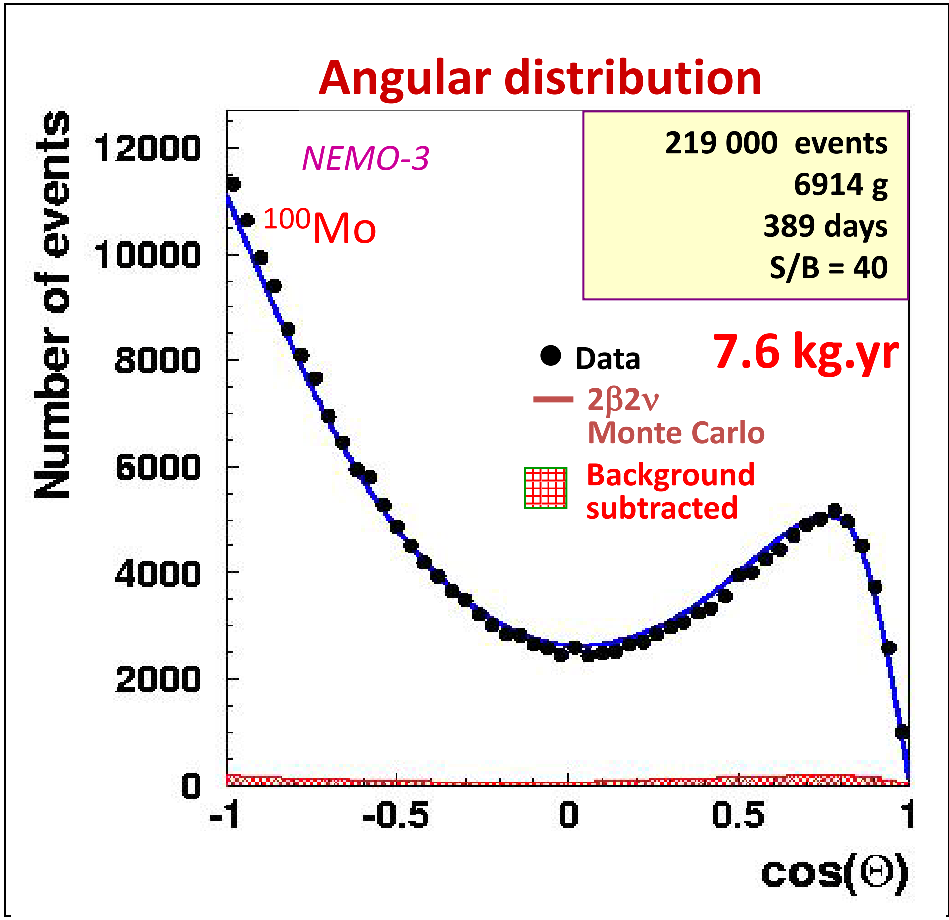
< 0.1 $\beta\beta0\nu$-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV

^{100}Mo $\beta\beta2\nu$ decay $T_{1/2}$ = 7.14 10^{18} y

~ 0.3 $\beta\beta0\nu$-like events year^{-1} kg^{-1} with $2.8<E_1+E_2<3.2$ MeV

NEMO 3: ^{100}Mo ββ2ν results



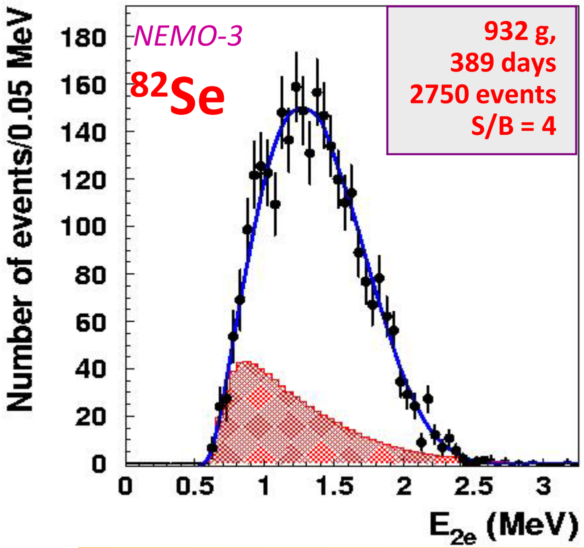


$T_{1/2}(\beta\beta2\nu) = 7.11 \pm 0.02\ (\text{stat}) \pm 0.54\ (\text{syst}) \times 10^{18}$ yr

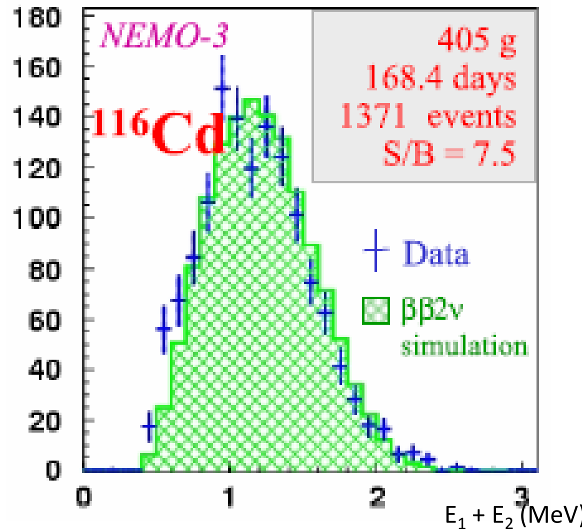
Phys. Rev. Lett. 95 182302 (2005)

«ββ factory» → tool for precision test

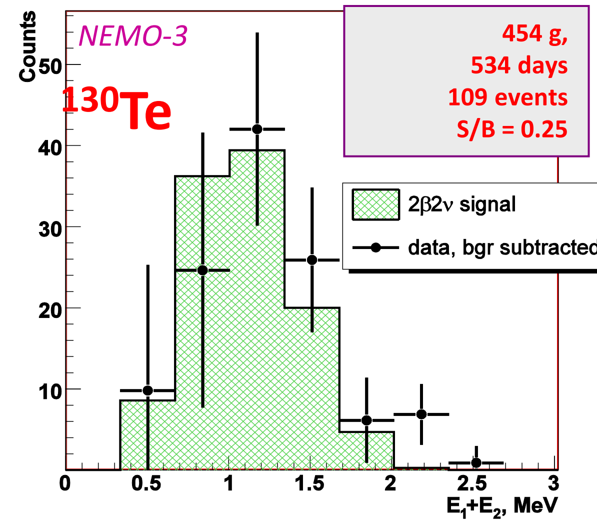
NEMO-3 ββ(2ν) autres résultats



9.6 ± 0.3 (stat) 1.0 (sys) 10^{19} a

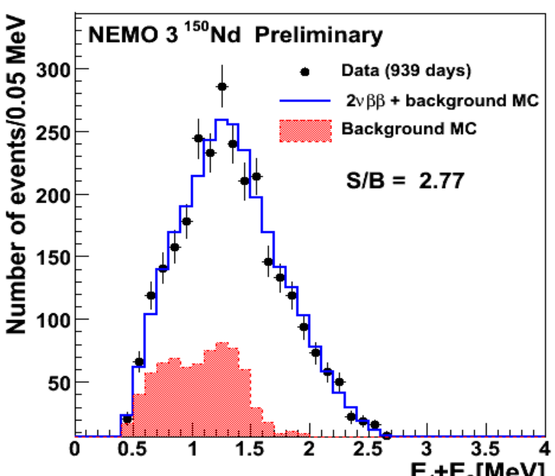


2.8 ± 0.1 (stat) 0.3 (sys) 10^{19} a



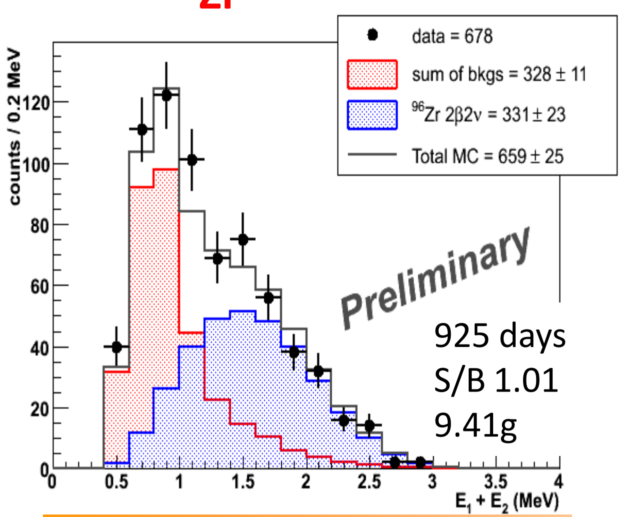
7.6 ± 1.5 (stat) 0.8 (sys) 10^{20} a

^{150}Nd



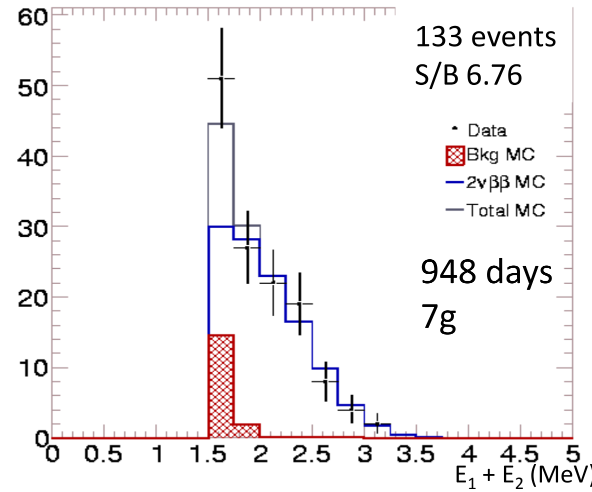
$9.11^{+0.25}_{-0.22}$(stat) ± 0.63 (sys) 10^{18} a

^{96}Zr



2.3 ± 0.2 (stat) 0.3 (sys) 10^{19} a

^{48}Ca



$4.4^{+0.5}_{-0.4}$ (stat)± 0.4 (sys) 10^{19} a

NEMO 3: ^{100}Mo ββ2ν results

The NEMO 3 $\beta\beta$ factory: a tool for precision tests

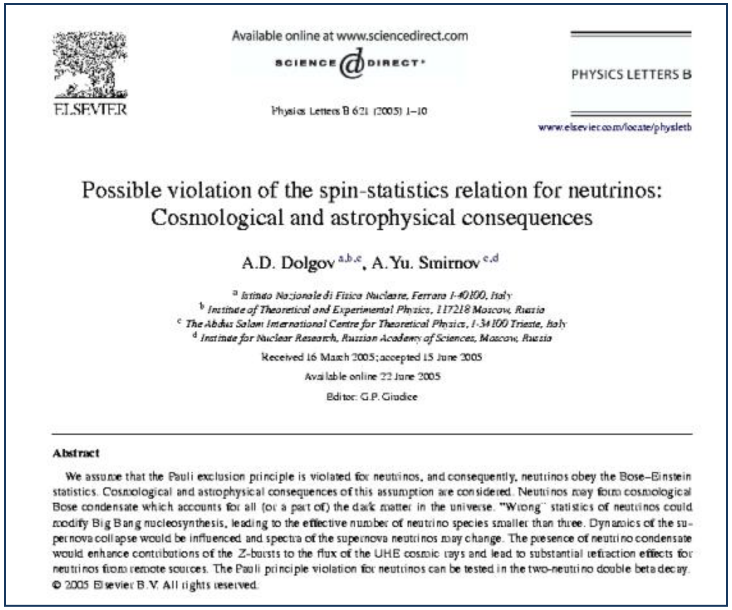
Isotope	$T_{1/2}^{2\nu\beta\beta}$ (y)
^{100}Mo	$[7.11 \pm 0.02(stat) \pm 0.54(syst)] \times 10^{18}$ * (SSD favored)
^{100}Mo(0_1^+)	$[5.7^{+1.3}_{-0.9}(stat) \pm 0.8(syst)] \times 10^{20}$ **
^{82}Se	$[9.6 \pm 0.3(stat) \pm 1.0(syst)] \times 10^{19}$ *
^{116}Cd	$[2.8 \pm 0.1(stat) \pm 0.3(syst)] \times 10^{19}$ **
^{130}Te	$[6.9 \pm 0.9(stat) \pm 1.0(syst)] \times 10^{20}$ ***
^{150}Nd	$[9.20^{+0.25}_{-0.22}(stat) \pm 0.73(syst)] \times 10^{18}$ ***
^{96}Zr	$[2.35 \pm 0.14(stat) \pm 0.19(syst)] \times 10^{19}$ ***
^{48}Ca	$[4.4^{+0.5}_{-0.4}(stat) \pm 0.4(syst)] \times 10^{19}$ ***

* Phase 1 (high radon data), Phys. Rev. Lett. 95 (2005) 182302
(additional statistics are being analysed, to be published soon)

** Phase 1 data

*** Phases 1 and 2, preliminary

Pauli exclusion principle violated by neutrino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Possible violation of the spin-statistics relation for neutrinos: Cosmological and astrophysical consequences

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Abstract

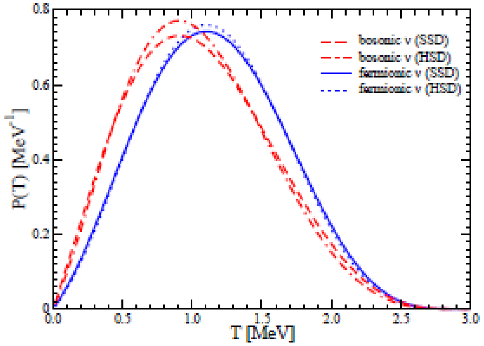
We assume that the Pauli exclusion principle is violated for neutrinos, and consequently, neutrinos obey the Bose–Einstein statistics. Cosmological and astrophysical consequences of this assumption are considered. Neutrinos may form cosmological Bose condensate which accounts for all (or a part of) the dark matter in the universe. "Wrong" statistics of neutrinos could modify Big Bang nucleosynthesis, leading to the effective number of neutrino species smaller than three. Dynamics of the supernova collapse would be influenced and spectra of the supernova neutrinos may change. The presence of neutrino condensate would enhance contributions of the Z-bursts to the flux of the UHE cosmic rays and lead to substantial refraction effects for neutrinos from remote sources. The Pauli principle violation for neutrinos can be tested in the two-neutrino double beta decay.

Proposed by Dolgov and Smirnov in 2005

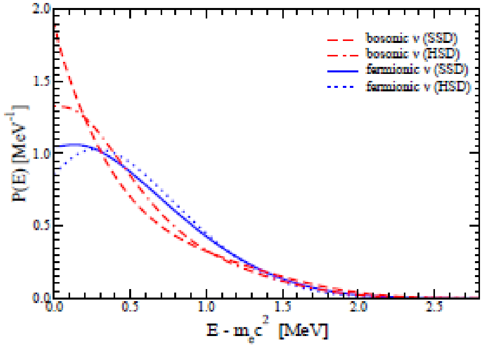
Neutrino would partially obey to Bose-Einstein Statistics and new parameter $\sin\chi$ is introduced to take this effect into account

Effects could be measured on decay rates, energy and angular distribution in particular for $\beta\beta(2\nu)$

Only tracko-calo are able to do it



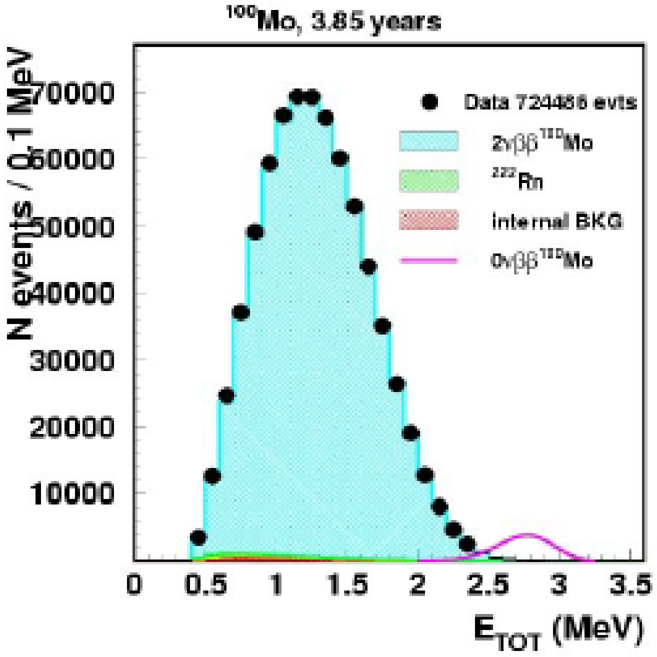
Effect on $\beta\beta(2\nu)$ spectrum of ^{100}Mo

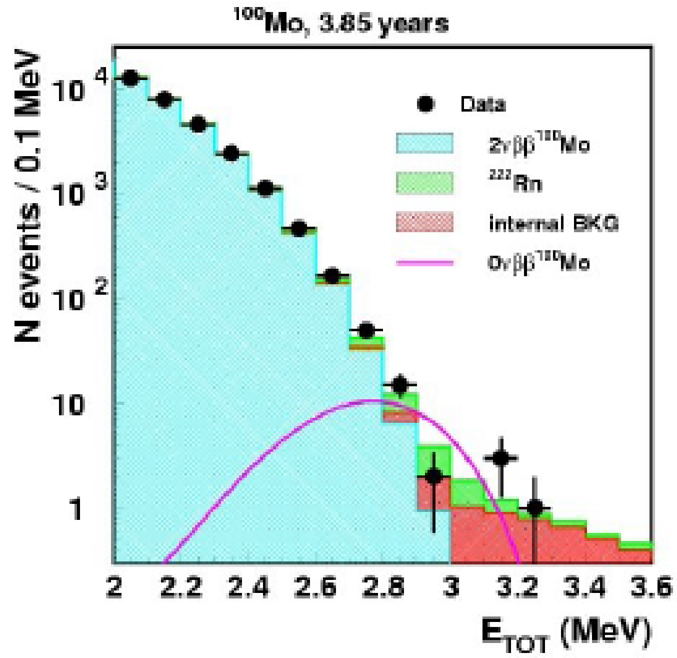


Effect on single energy spectrum of ^{100}Mo

Results of NEMO3 used in
Nucl. Phys. B783: 90-111, 2007
$\sin\chi < 0.6$

$0\nu\beta\beta$ results for ^{100}Mo, 2003-2008 data: 3.85 years





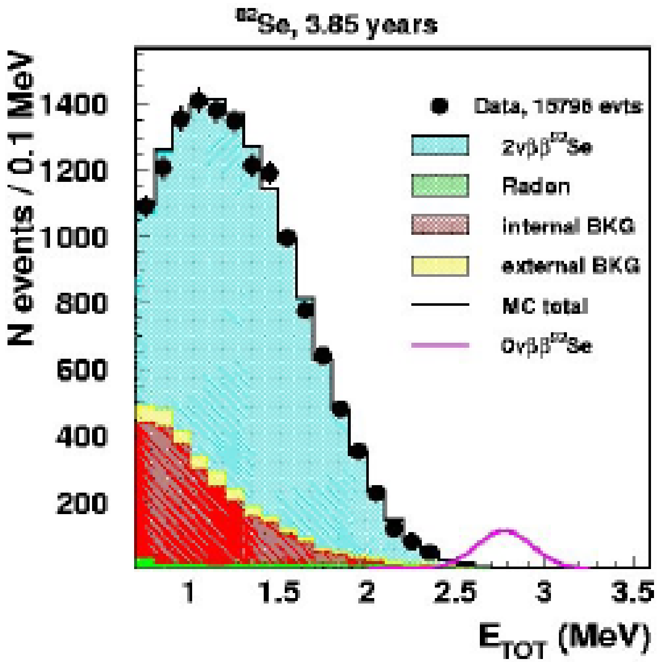
Counting [2.8 – 3.2] MeV

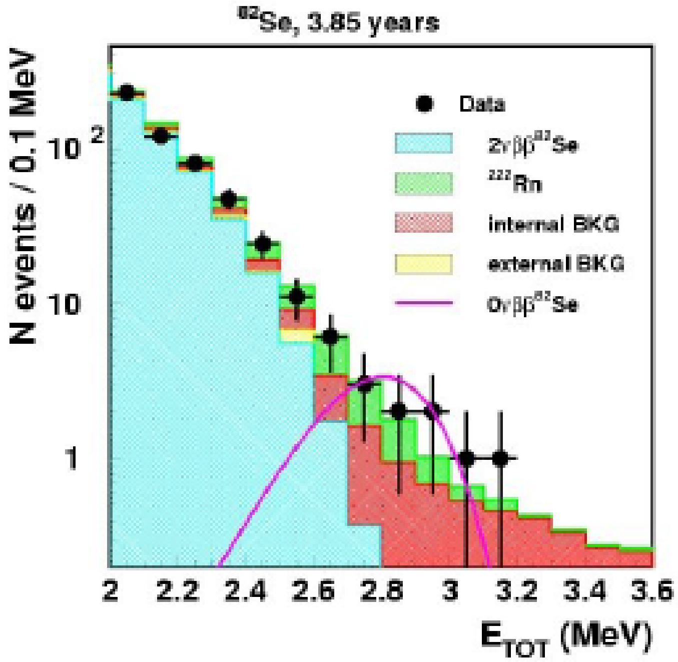
- Data: 20 events
- Expected background: 18.6 events
- Excluded 90% C.L.: 9.6 events
- Efficiency = 0.0726

Likelihood [2.0 – 3.2] MeV

- Excluded 90% C.L.: 18 events
- Efficiency = 0.174
  $T_{1/2}^{0\nu\beta\beta} > 1.1\ 10^{24}$ y @ 90 %C.L.
  $< m_\nu > < 0.45$–0.93 eV

$0\nu\beta\beta$ results for ^{82}Se, 2003-2008 data: 3.85 years





	V+A*	Majoron(s) emission **			
Isotope	$T_{1/2}^{0\nu\beta\beta}$ (y)	n=1	n=2	n=3	n=7
^{100}Mo	$> 5.7\ 10^{23}$ $\lambda < 1.4\ 10^{-6}$	$> 2.7\ 10^{22}$ $g_{ee} < (0.4 - 1.8)10^{-4}$	$> 1.7\ 10^{22}$	$> 1.0\ 10^{22}$	$> 7\ 10^{19}$
^{82}Se	$> 2.4\ 10^{23}$ $\lambda < 2.0\ 10^{-6}$	$> 1.5\ 10^{22}$ $g_{ee} < (0.7 - 1.9)10^{-4}$	$> 6\ 10^{21}$	$> 3.1\ 10^{21}$	$> 5\ 10^{20}$

From NEMO-3 to SuperNEMO… challenges

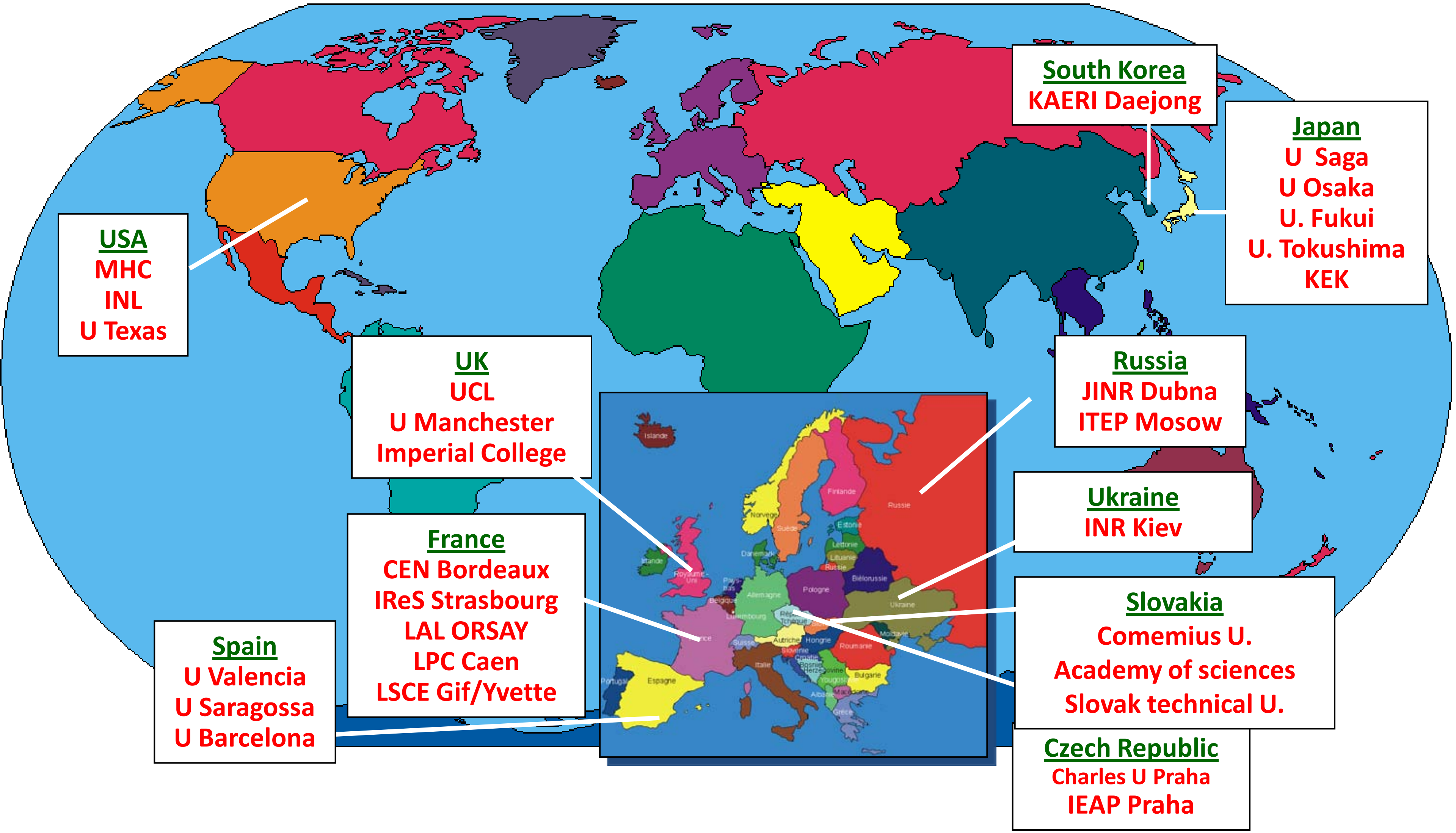
$$T_{1/2}(\beta\beta0\nu) > \ln 2 \times \frac{N_A}{A} \times \frac{M \times \varepsilon \times T_{obs}}{N_{90}}$$

NEMO-3		SuperNEMO
^{100}Mo	isotope	^{82}Se , ^{150}Nd or ^{48}Ca
7 kg	isotope mass M	100 kg
8 %	efficiency ε	~ 30 %
^{208}Tl: < 20 μBq/kg ^{214}Bi: < 300 μBq/kg	internal contaminations ^{208}Tl and ^{214}Bi in the ββ foil	^{208}Tl < 2 μBq/kg *if* ^{82}Se: ^{214}Bi < 10 μBq/kg
8% @ 3MeV	energy resolution (FWHM)	4% @ 3 MeV

$T_{1/2}(\beta\beta0\nu) > 2 \times 10^{24}$ y $\langle m_\nu \rangle < 0.3 – 1.3$ eV	$T_{1/2}(\beta\beta0\nu) > 10^{26}$ y $\langle m_\nu \rangle < 50$ meV

SuperNEMO collaboration

~ 80 physicists, 10 countries, 28 laboratories

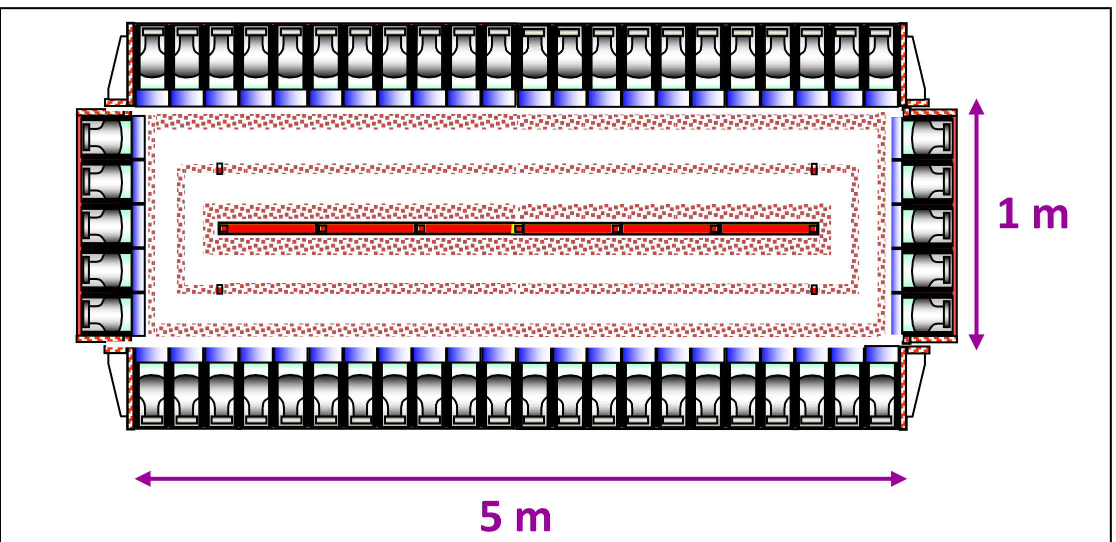


SuperNEMO conceptual design

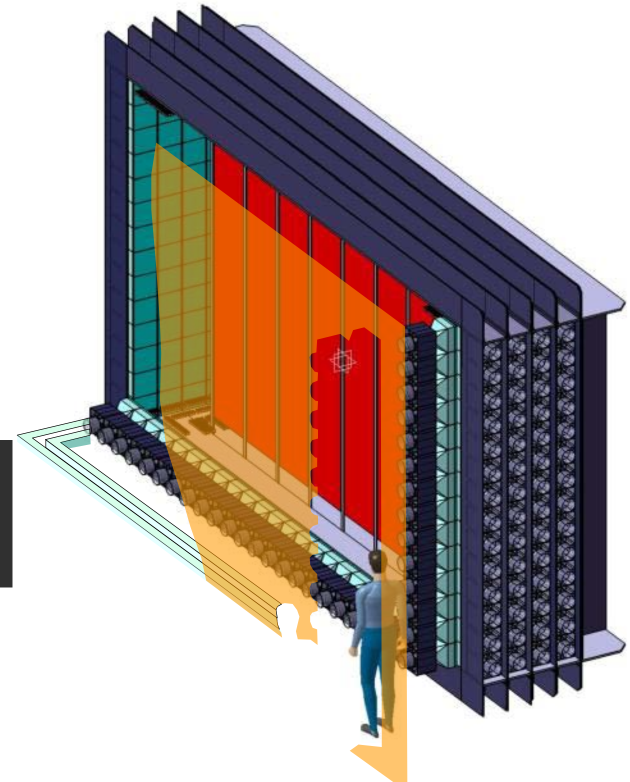
20 modules for 100 kg

Source (40 mg/cm²) 12m²
Tracking (~2-3000 Geiger cells).
Calorimeter (600 channels)

Total:~ 40 000 – 60 000 geiger cells channels
~ 12 000 PMT



Top view



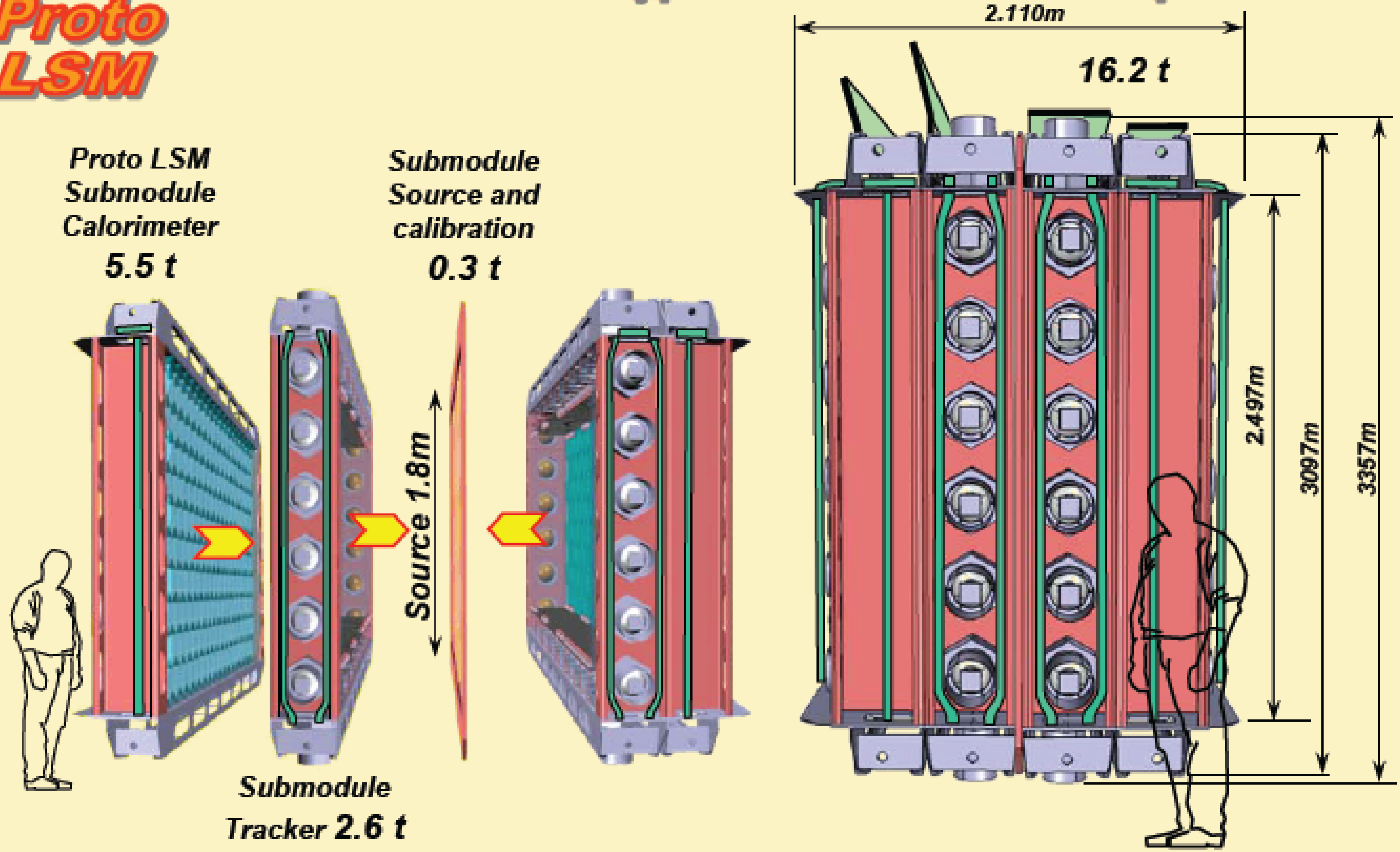
Module 0 : 7 kg of ^{82}Se

$\langle m_\nu \rangle < 0.2 – 0.5$ eV (1 year of data)

LABORATOIRE DE L'ACCÉLÉRATEURLINÉAIRE
IN2P3-CNRS et Université PARIS-SUD Centre Scientifique d'Orsay - Bât 200 - B.P. 34 91898 ORSAY Cedex (France)

Three submodules types with standard components

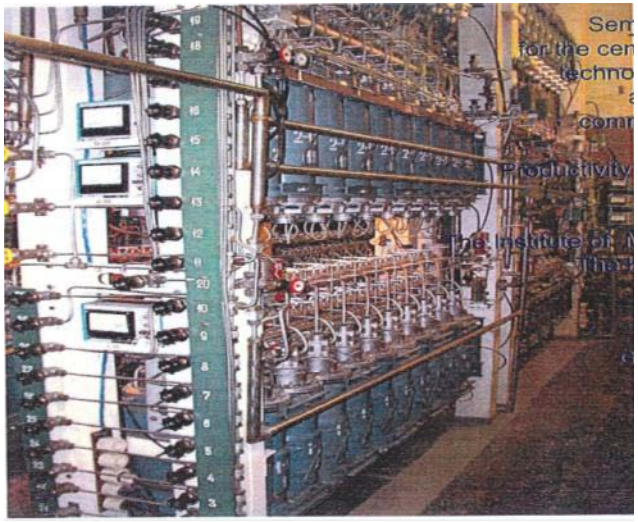
Proto LSM



SuperNEMO Sources

Guideline: ^{82}Se

- **Can be produced by centrifugation**
- **Already 5 kg in the collaboration**
- **(3,5 kg from ILIAS, 1 kg in NEMO3, 0,5 from ITEP)**
- **2,5 kg more will be provided by Russian groups**
- **No problem to order 100 kg**
- **Several possibilities for purification**



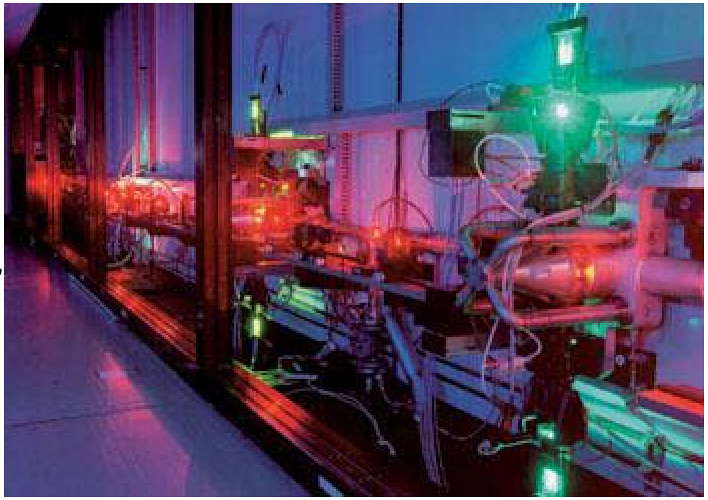
Possibility of ^{150}Nd enrichment ($Q_{\beta\beta}$ = 3,37 MeV No background from ^{214}Bi, phase space factor)

-**Laser isotopique separation possible in India or Russia ?**

- **(was possible in France but facilityhas been dismantled in 2009)**

-**Possibility to use centrifugation ?**

Common investigations with SNO++ (also for purification)



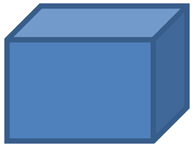
^{48}Ca enrichment ($Q_{\beta\beta}$ = 4,27 MeV No background from ^{214}Bi,

- **Laser isotopique separation developed in KOREA (patent)**

-**Support of Korean government for production of 1 kg (enr: 25%) within 3 years**

SuperNEMO Calorimeter

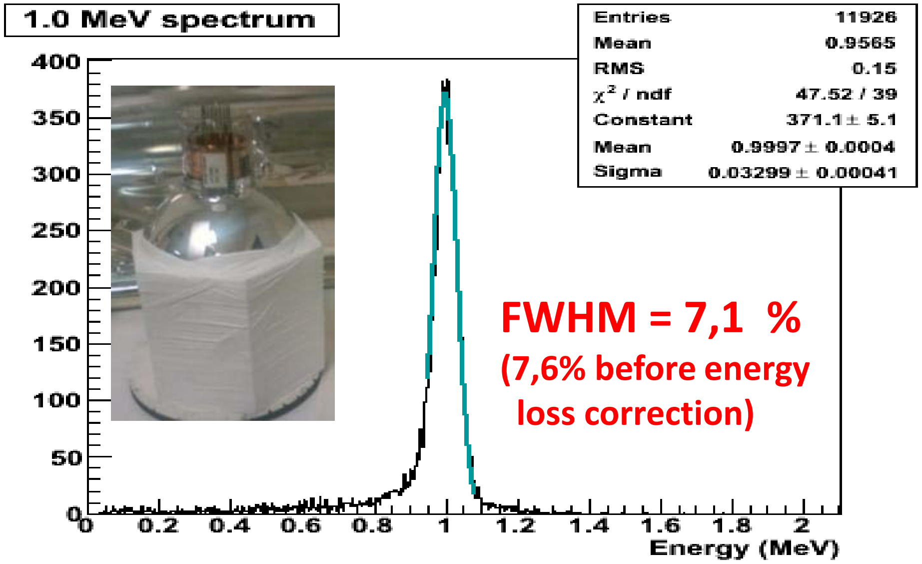
NEMO3



Vol: 4 l
5'' PMT
ΔE/E ~16%

SuperNEMO

Vol: 8 l
8'' PMT
ΔE/E 6.5 – 8 %



PMT	PHOTONIS XP1886	HAMAMATSU R5912MOD
FWHM @ 1 MeV with 10 cm high hexagonal PVT	6.7 %	7.8 %

Photonis and Hamamatsu PMTs "fight"

Use of PVT instead of Polystyren, improvements of QE of PMT (8'')
Use of Polystyren still possible

SuperNEMO… BiPo

Objectives :to mesure ^{208}Tl < 2 μBq/kg & ^{214}Bi < 10 μBq/kg in ββ source foil in 1 month

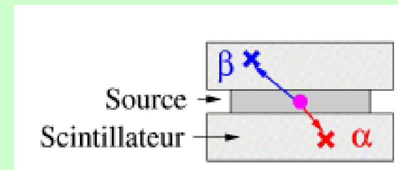
Principle: Detection of BiPo coïncidence : β + α retardé

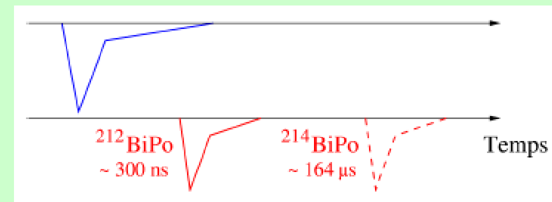
^{238}U → ^{214}Bi (19.9 mn) $\xrightarrow{\beta}$ ^{214}Po (164 μs) $\xrightarrow{\alpha}$ ^{210}Pb 22.3 y

^{214}Bi $\xrightarrow{0.021\%}$ ^{210}Tl (1.3 mn) → ^{210}Pb

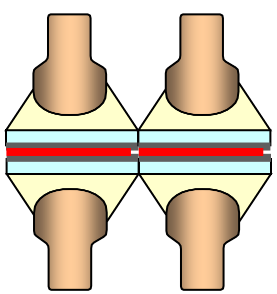
^{232}Th → ^{212}Bi (60.5 mn) $\xrightarrow{\beta}$ ^{212}Po (300 ns) $\xrightarrow{\alpha}$ ^{208}Pb (stable)

^{212}Bi $\xrightarrow{36\%}$ ^{208}Tl (3.1 mn) → ^{208}Pb



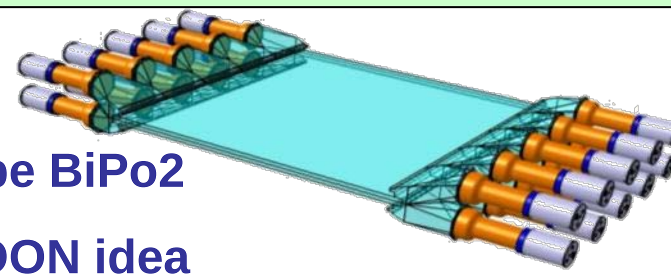


Prototype BiPo 1



Prototype BiPo2

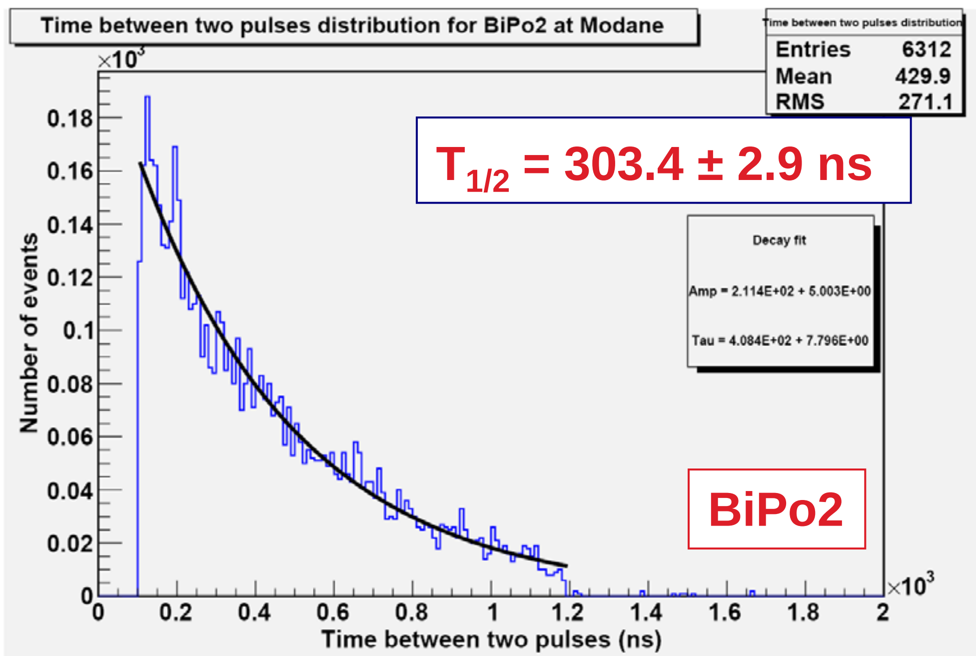
from MOON idea

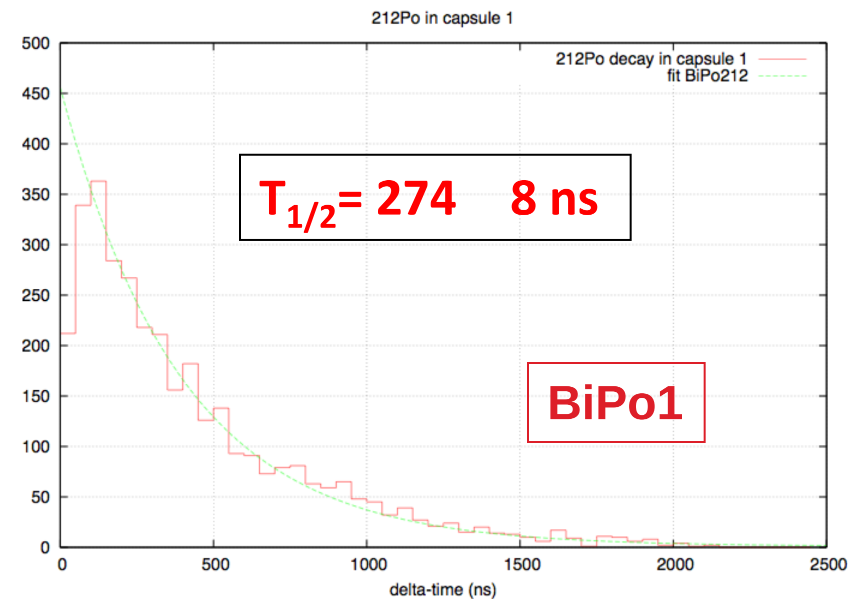


SuperNEMO BiPo results

❖ **^{212}Po decay constant measurement :**

The lifetime of the ^{212}Po (299 ns) has been measured in BiPo1 (2 scintillator versions) and BiPo2 using a calibrated Aluminium foil.





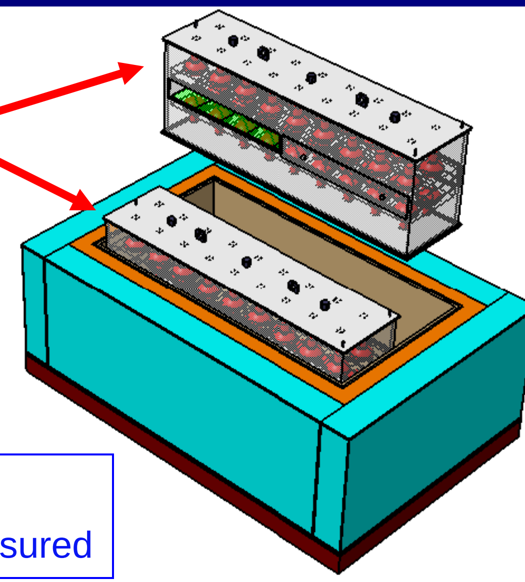
The Bi-Po events measurement principle has been validated with the prototypes

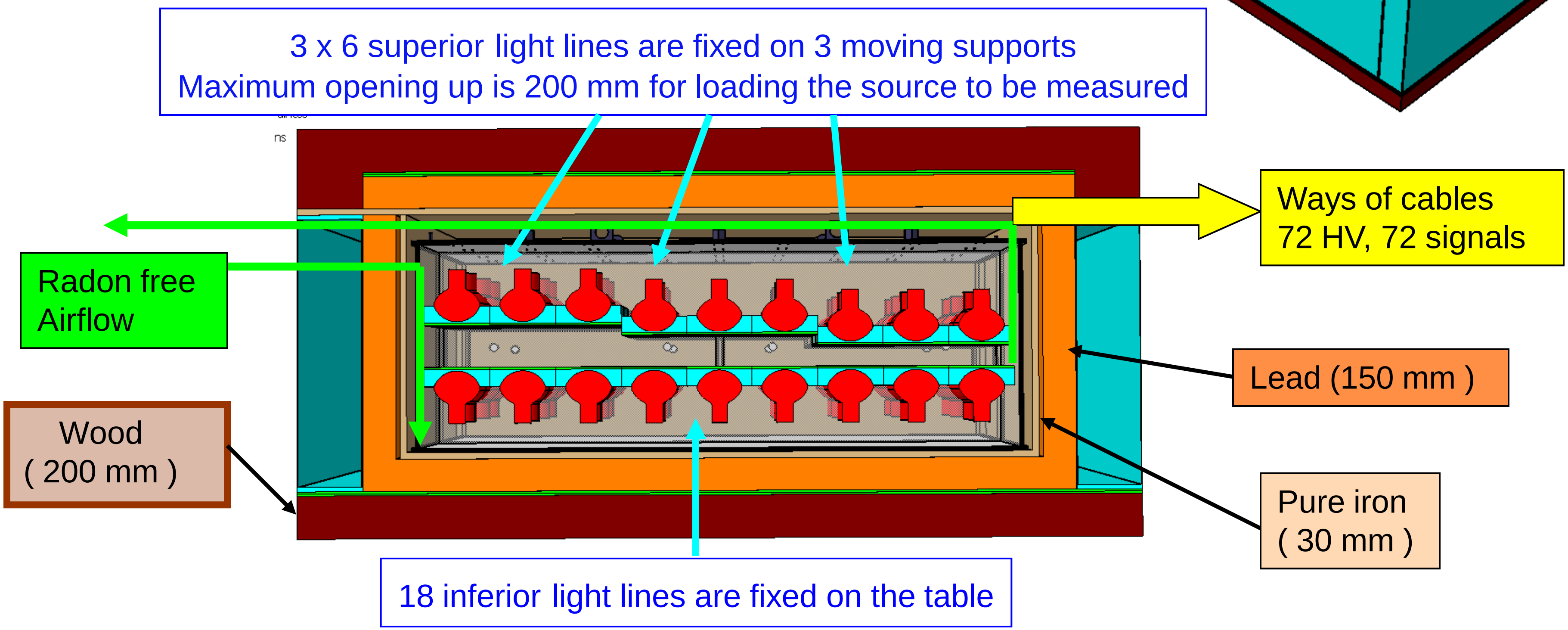
SuperNEMO BiPo 1 results

2 modules composed of 2 rows of 9 scintillator pairs (face-to-face, 30×30 cm^2) coupled to 5’’PMTs.

Total number of PMT channels : **72**

Surface of measurement : 0.3 x 0.3 x (18 x 2) = **3.24 m^2**

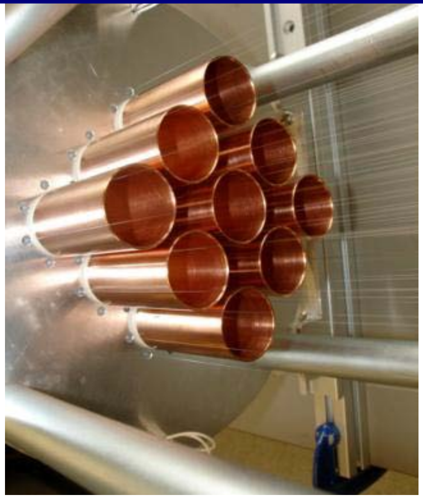


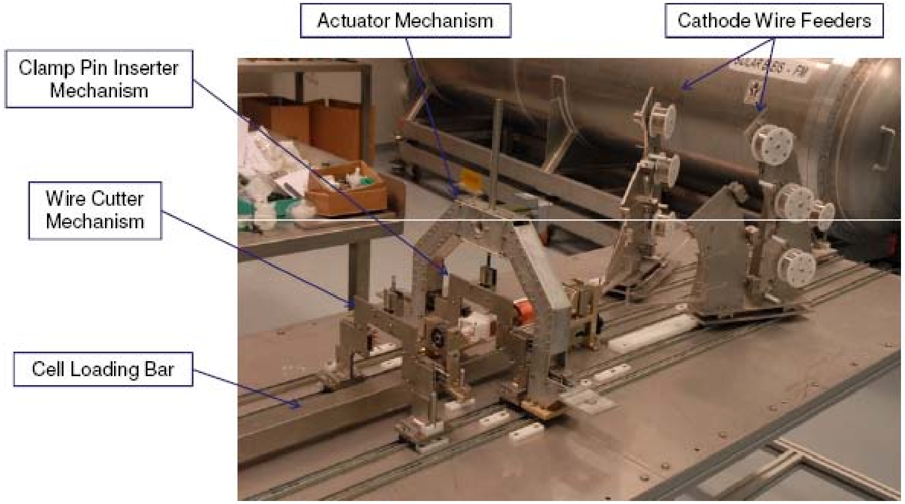


SuperNEMO Tracking

Wiring Robot

prototype 90 cells prototype

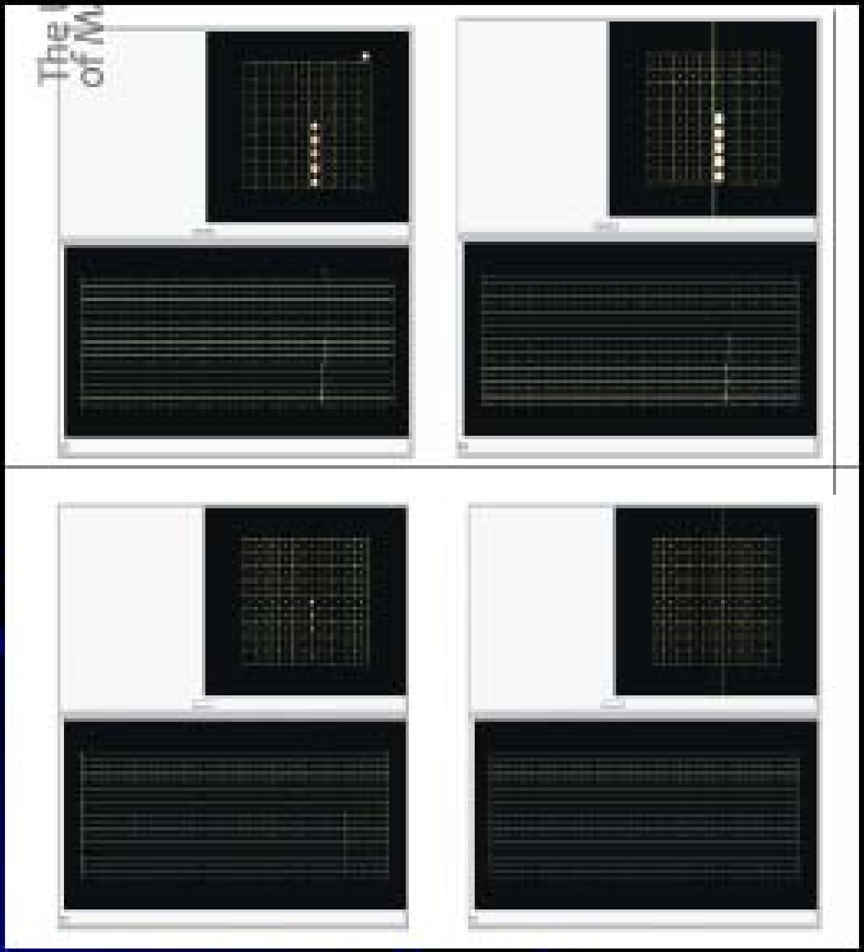




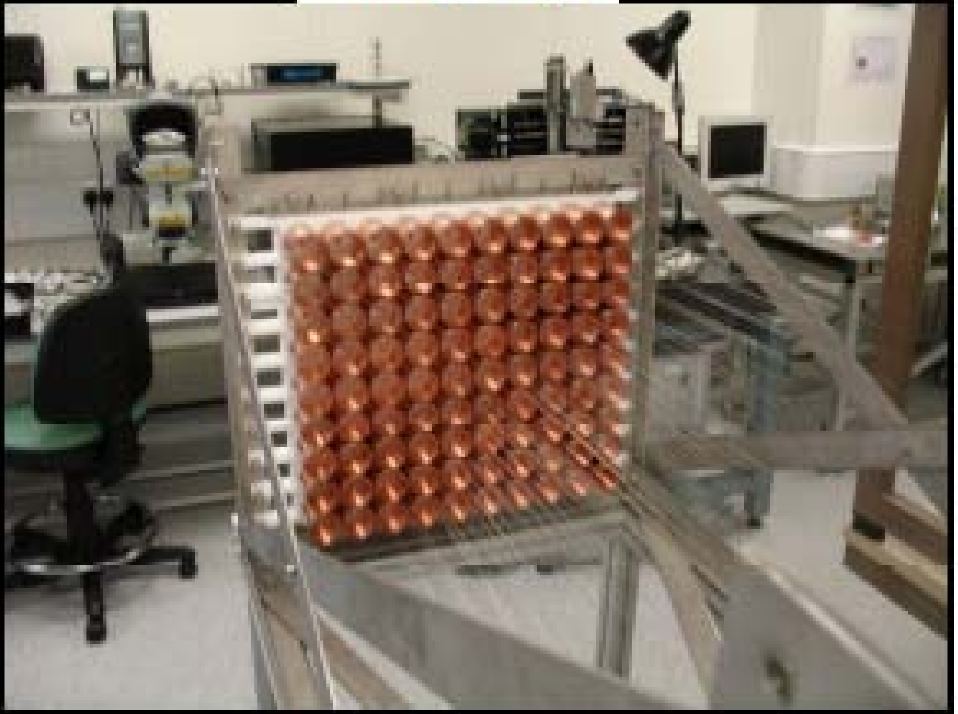
Wiring robot

90 cells prototype

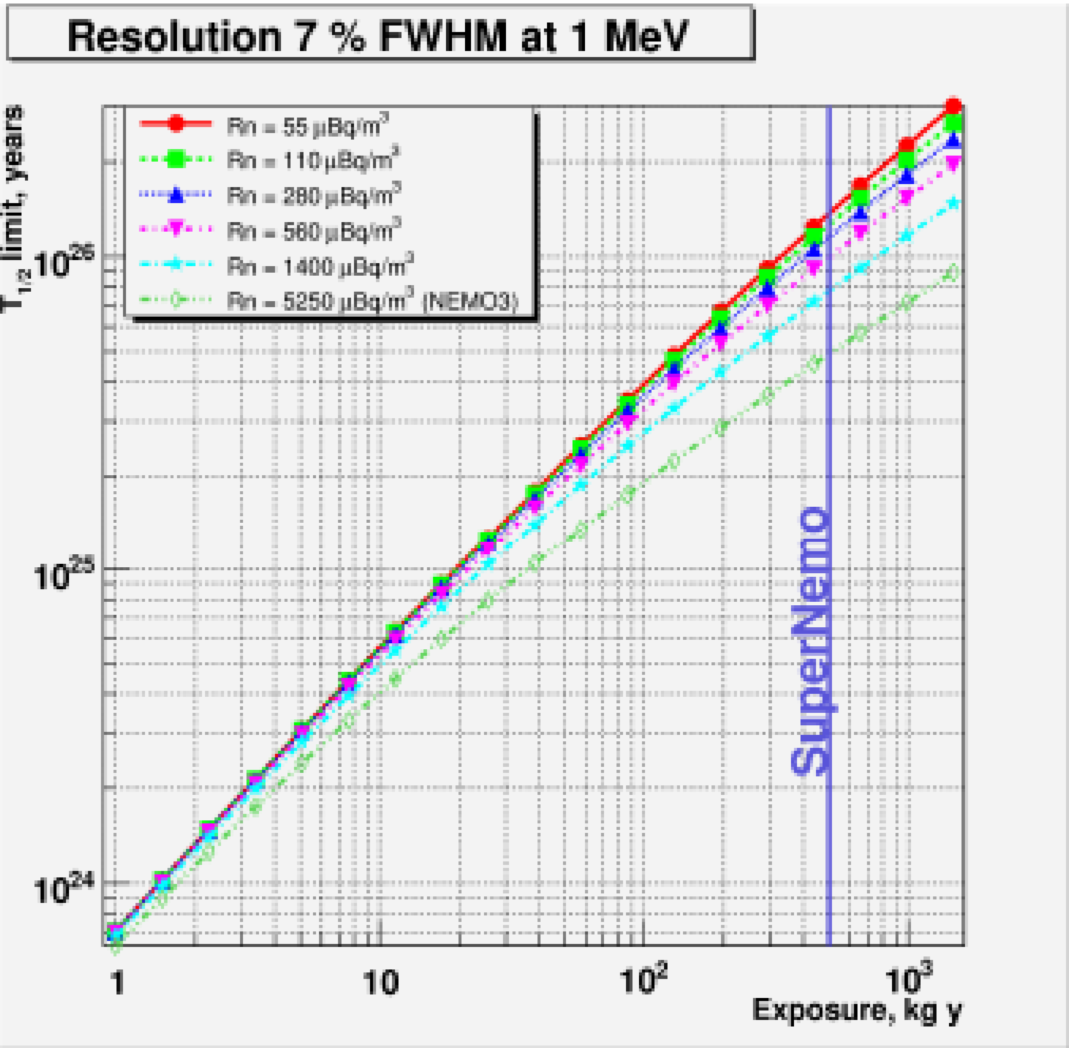
Tracking 90 cells first tracks



90-cell prototype



SuperNEMO Radon



Strategy to reduce radon:

Tracker separated from calorimeter

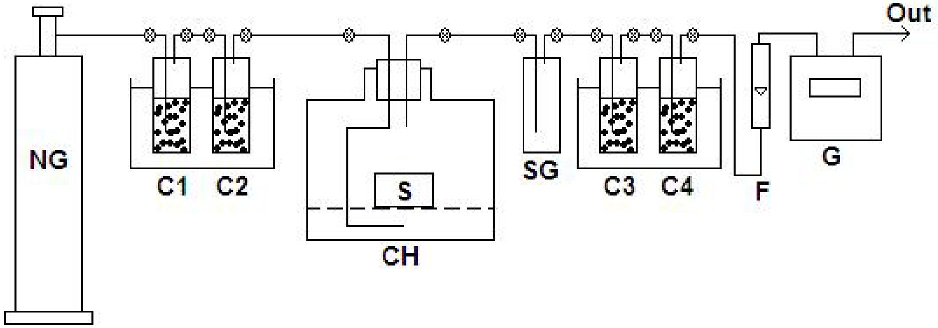
Sealing of the setup → planar geometry

More radiopure materials

Monitoring of the gaz

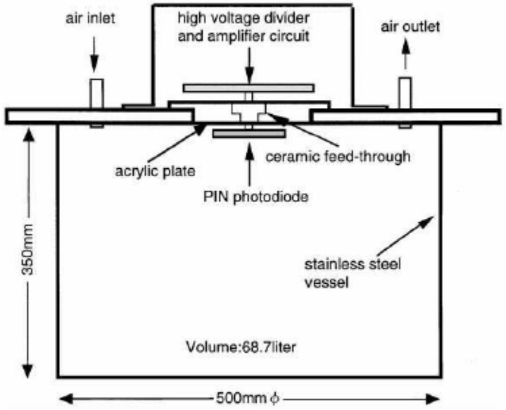
SuperNEMO Radon

Prague : setup to measure permeability of materials



Bratislava, UCL : setups to measure radon emanation of materials or gas

CENBG: setup to measure radon emanation with liquid scintillator

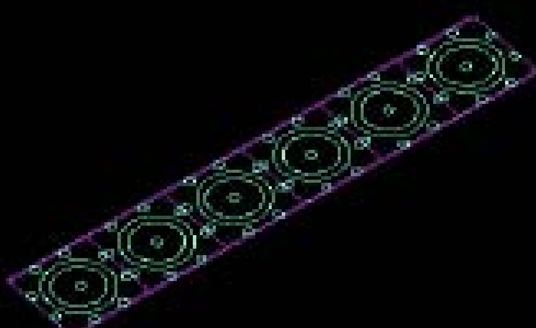


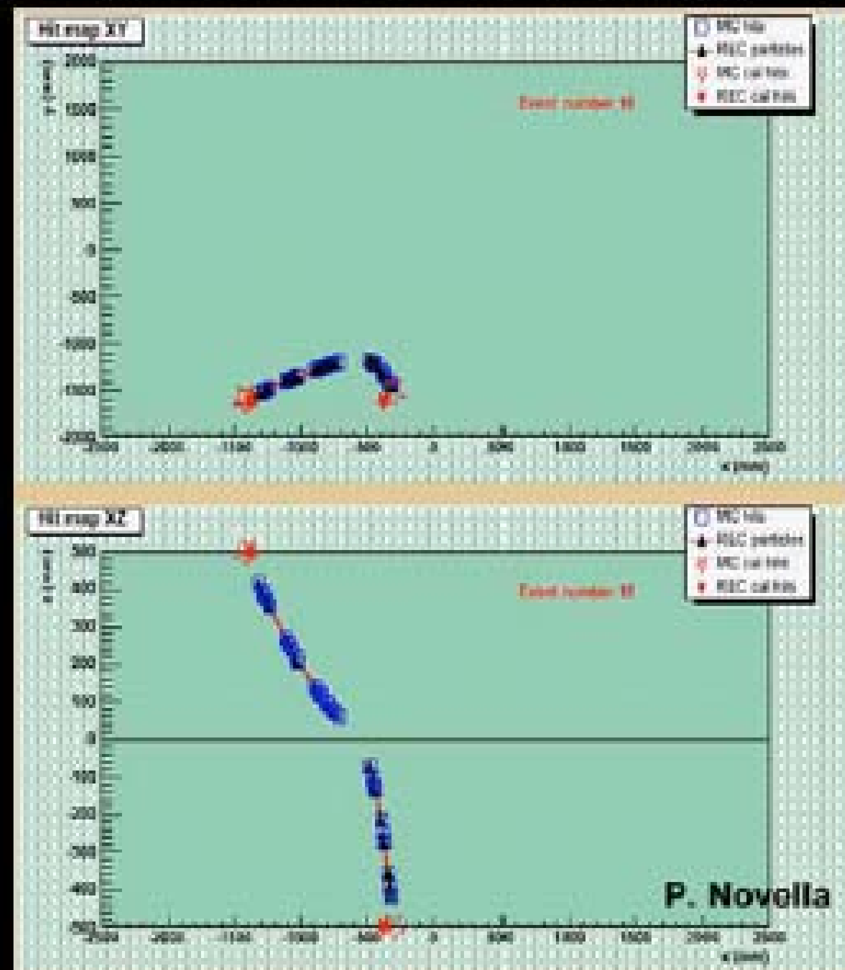
CENBG, Marseille, Saga U: Electrostatic detectors for gaz measurement

SuperNEMO MC simulations

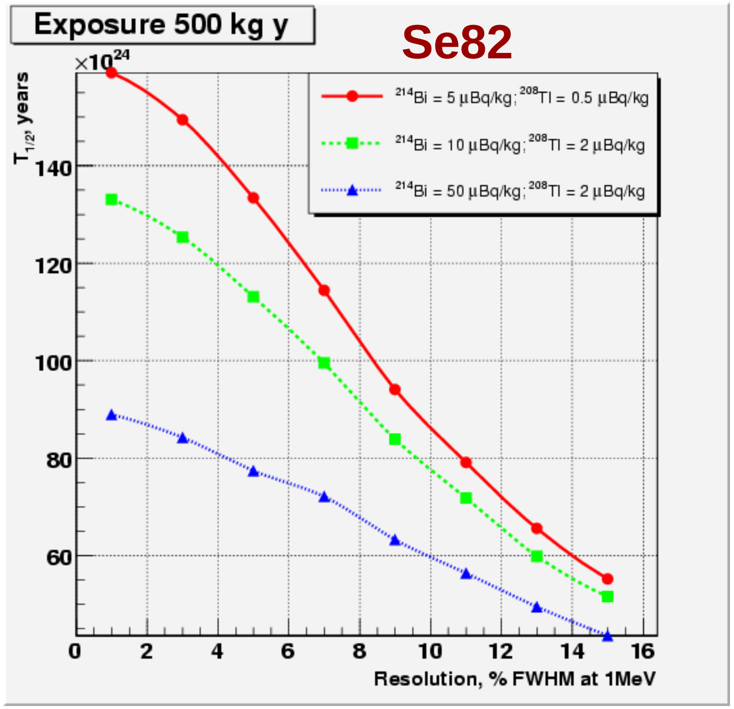
Large scale simulations are performing in GRID

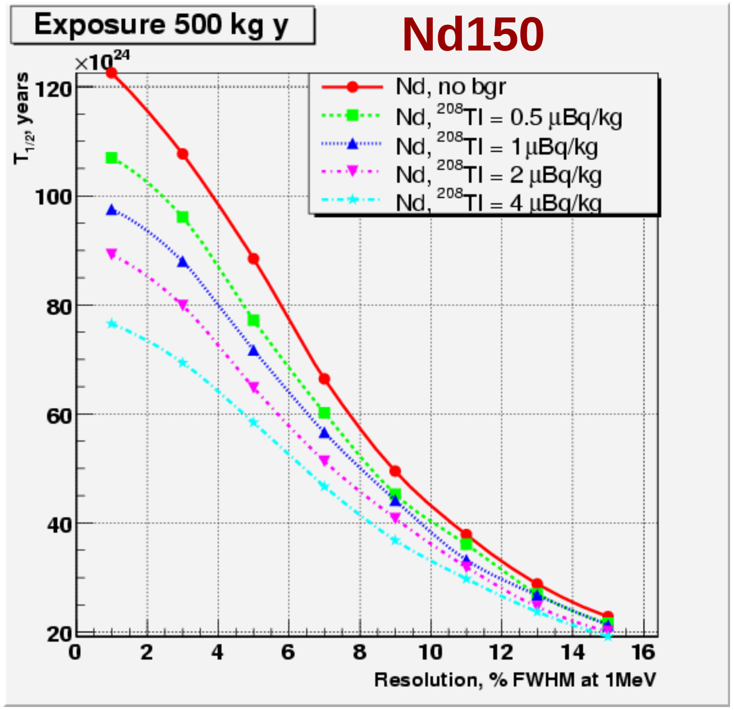
Top view





SuperNEMO sensitivity 100 kg 5 years





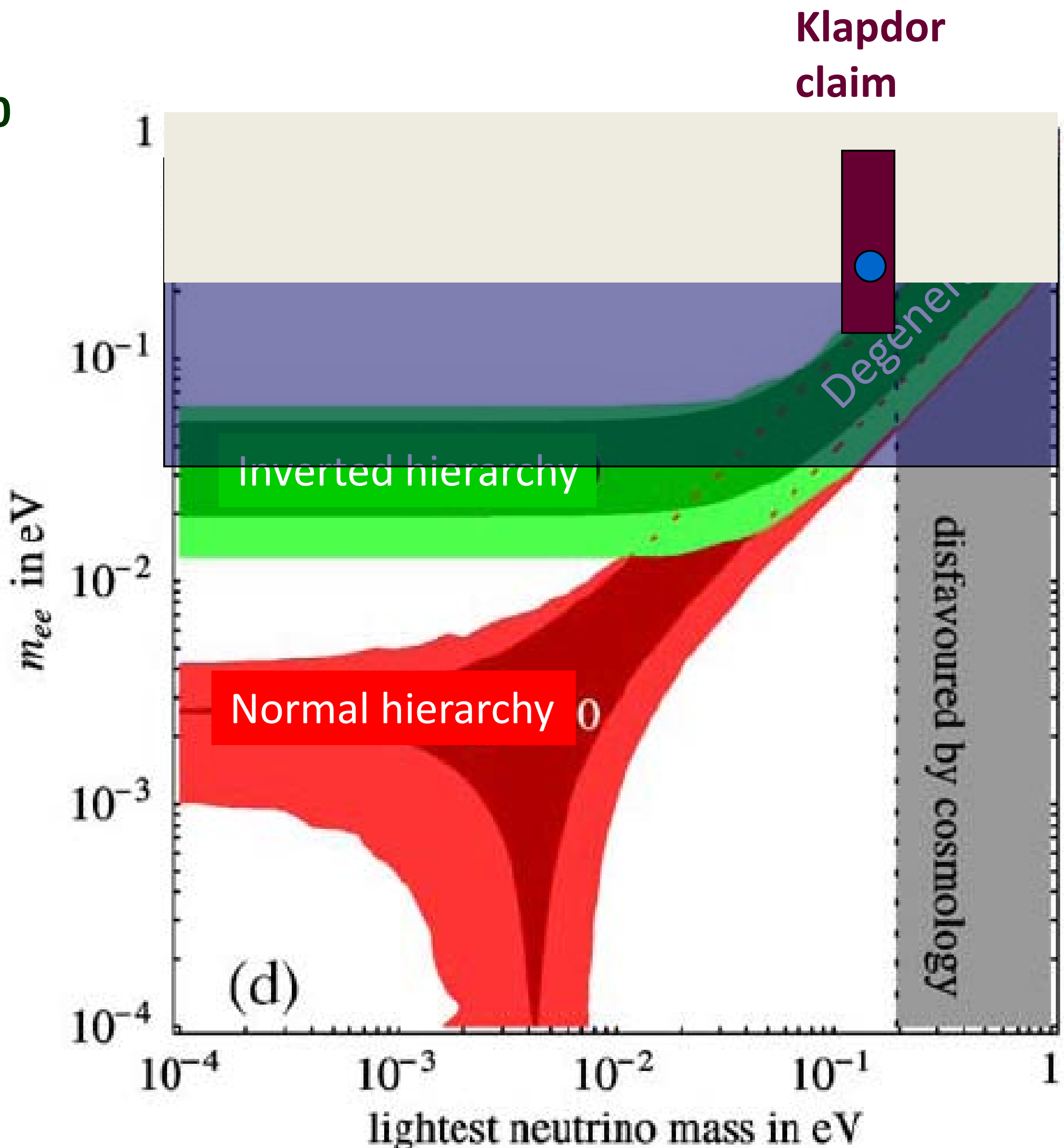
3 candidates :

^{82}Se	$T_{1/2} < 10^{26}$ y	$\langle m_\nu \rangle < 0.07 – 0.12$ eV
^{150}Nd	$T_{1/2} < 4.\ 10^{25}$ y	$\langle m_\nu \rangle < 0.05$ eV
^{48}Ca (IE 50%)	$T_{1/2} < 1.9\ 10^{26}$ y	$\langle m_\nu \rangle < 0.03$ eV

<m_ν> current and future limits

Limits in 2010

HM,NEMO3,
Cuoricino



Expected limits
2013 – 2018

CUORE,GERDA,
Majorana,
SuperNEMO,
EXO,….

Use of « latest NME » for all experiments

SuperNEMO Module 0

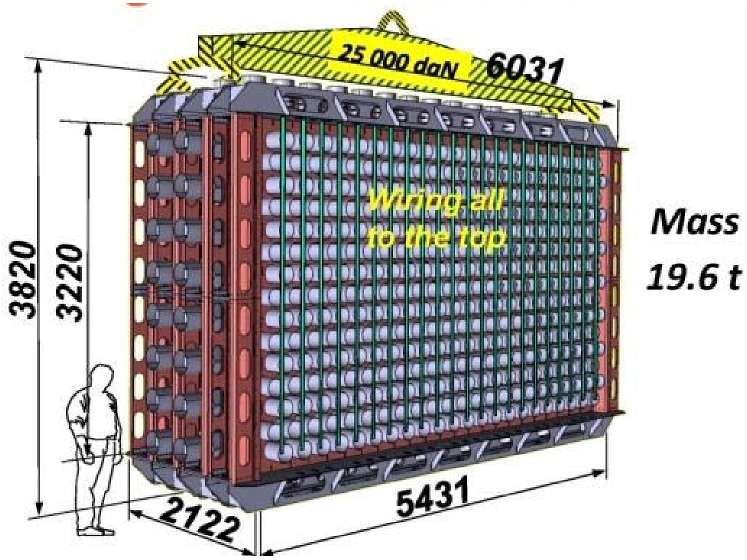
SuperNEMO phase I : 2011 – 2014

A demontrator module with 7 kg of ^{82}Se (1 kg of ^{48}Ca ?)

Sensitivity in 1 year: ~5 10^{24} y $\langle m_\nu \rangle < 0{,}2 - 0{,}6$ meV

Sensibility equivalent to GERDA I

Tracker already funded by UK



Calendar:

- Construction in labs: 2011 – 2012
- Installation, commissioning and running in LSM: 2013
- Few months to qualify the backgroud level
- Results 2014

SuperNEMO Demonstrator

SuperNEMO phase II: 2014 - 2018

20 modules, total 100 kg (82Se or 150Nd or 48Ca)

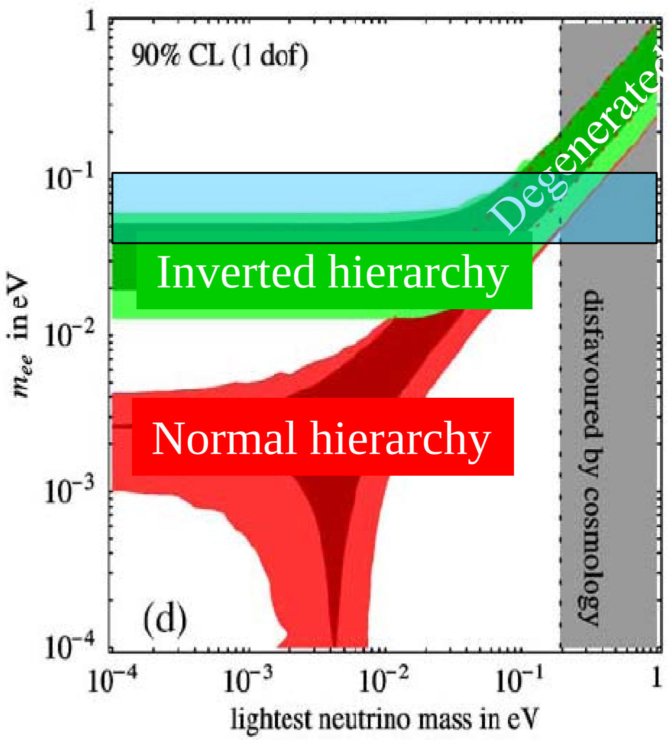
Contruction: 2015 – 2016

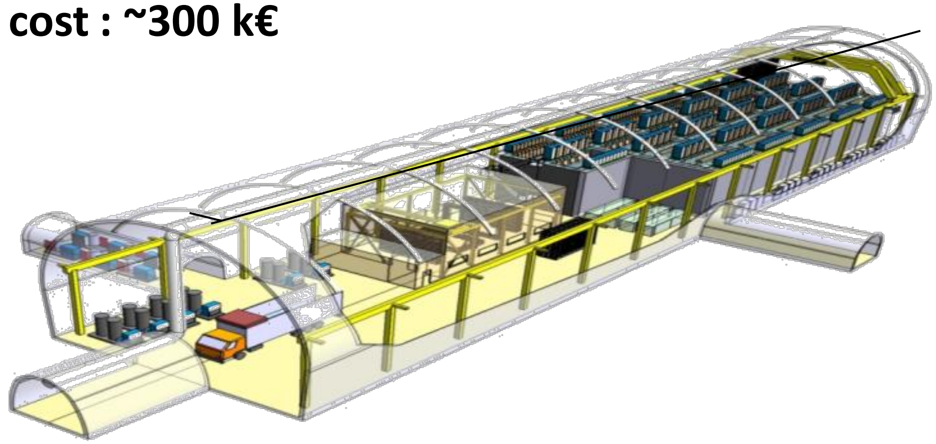
Commissioning and running: 2015 – 2020

^{82}Se Sensitivity: 53 – 145 meV

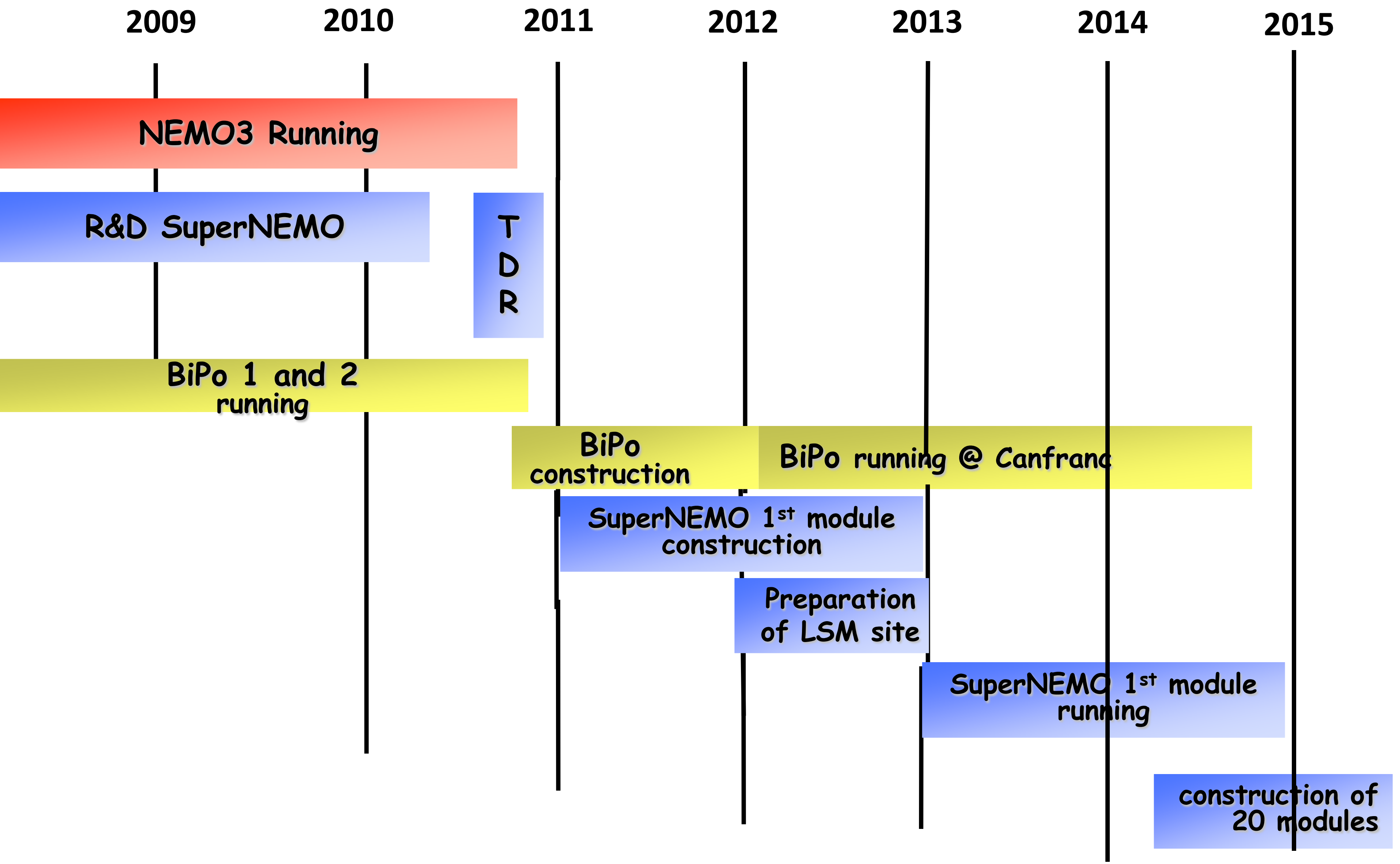
Total cost : 40 M€   (2/3 for Europe)

Running cost : ~300 k€





SuperNEMO schedule summary



SuperNEMO summary

In case of signal, it must be confirmed on other isotope and by:
- identification of electrons
- measure of both angular and single energy distributions

Tracko-calo à la NEMO is the only multi-isotope detector available for such measurement

NEMO3 has been a successful experiment at the level of the best limits and has provided data for nuclear matrix element calculations

Final sensitivity for NEMO3 : $T_{1/2} > 2\ 10^{24}$ years $\quad <m_\nu> < 0.3 – 0.7$ eV

SuperNEMO R&D has reached most of the requirements , especially on energy resolution (limits on radiopurity to be checked)

Could be possible in the future to obtain several tens of kg of ^{150}Nd and ^{48}Ca

Expected sensitivity for SuperNEMO : $T_{1/2} > 10^{26}$ years $\quad <m_\nu> < 50 – 120$ eV

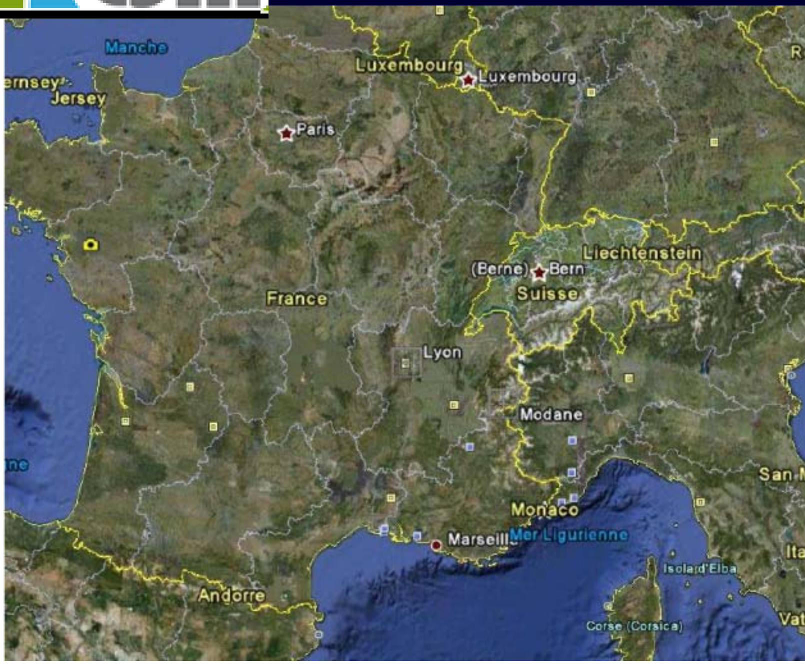
LSM extension has good chance to be done and to be able to host the next generation of both double beta decay and dak matter experiments

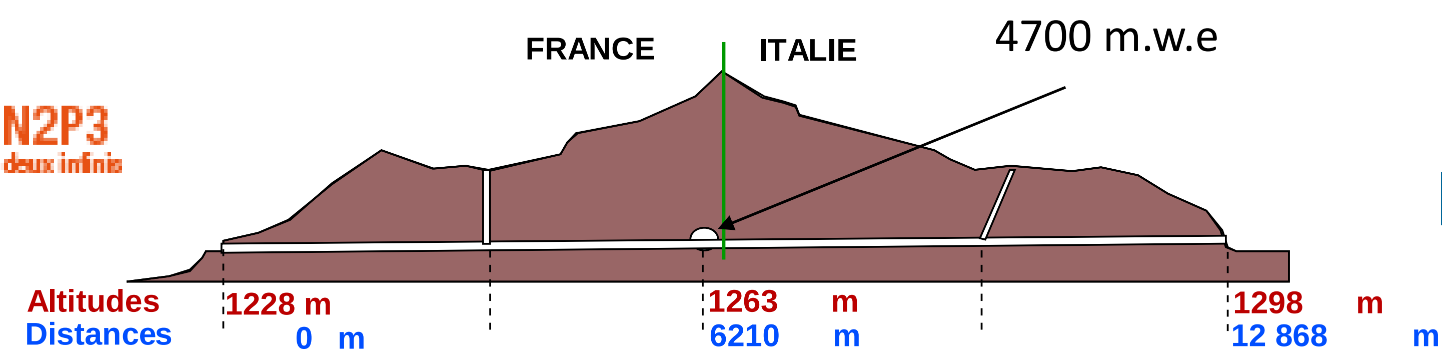
Summary

Experiment	Isotope	Enriched isotope mass (kg)	$T_{1/2}$ (yr)	$<m_\nu>$ (eV)	Start	Status
CUORE	^{130}Te	203	$2.1\ 10^{26}$	0.03 - 0.07*	2012	Funded
GERDA phase I phase II	^{76}Ge	17.9 40	$3.\ 10^{25}$ $2.\ 10^{26}$	0.2 – 0.5* 0.07 – 0.2*	2010 2012	Funded Funded
Majorana	^{76}Ge	30 - 60	1.10^{26}	0.1 – 0.3*	2011	Funded
EXO-200	^{136}Xe	200	$6.4\ 10^{25}$	0.2 - 0.7*	2008	Funded
SuperNEMO	^{82}Se ^{150}Nd	100 100	$2.\ 10^{26}$ 10^{26}	0.05- 0.09* 0.07	2013	Module 0 Partially funded
CANDLES	^{48}Ca	0.5		~0.5	2010	Funded
MOON II	^{100}Mo	120		0.09 – 0.13	?	R&D
DCBA	^{150}Nd	20			?	R&D
SNO++	^{150}Nd	500		0.03	?	R&D
COBRA	116Cd, ^{130}Te	420	?	?	?	R&D

* Calculation with NME from Rodim et al., Suhonen et al., Caurier et al. PMN07

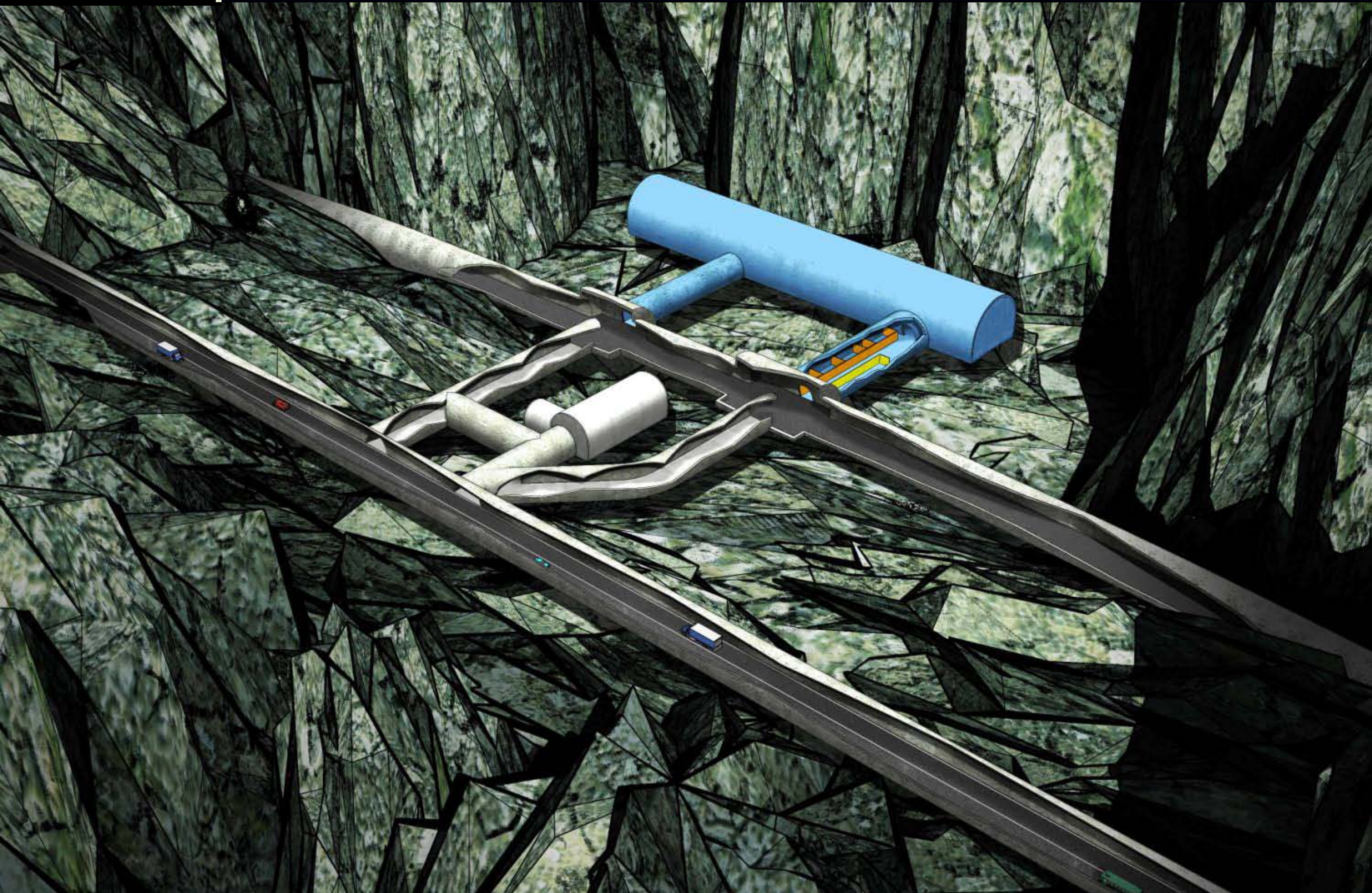
Modane Underground Laboratory



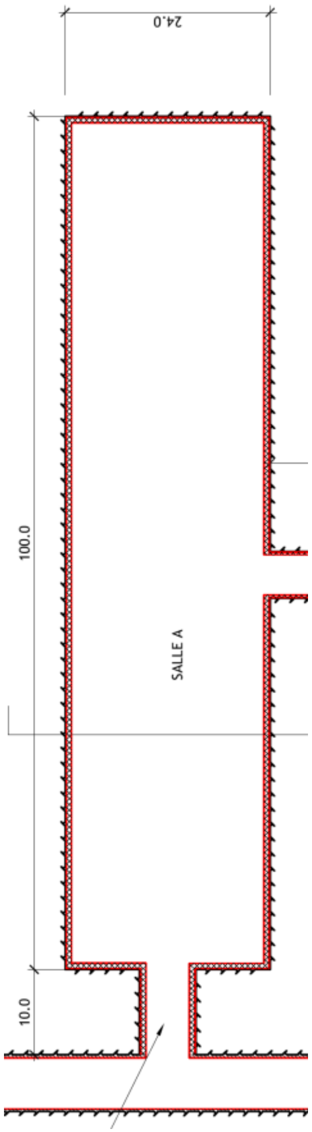


Muons flux reduced by a factor 2. 10^6 → 4 muons/m^2/day

LSM EXTENSION



LSM extension



COUPE TYPE SALLE A

SECTION EXCAVEÉ 375 m²

SECTION UTILE 320 m²

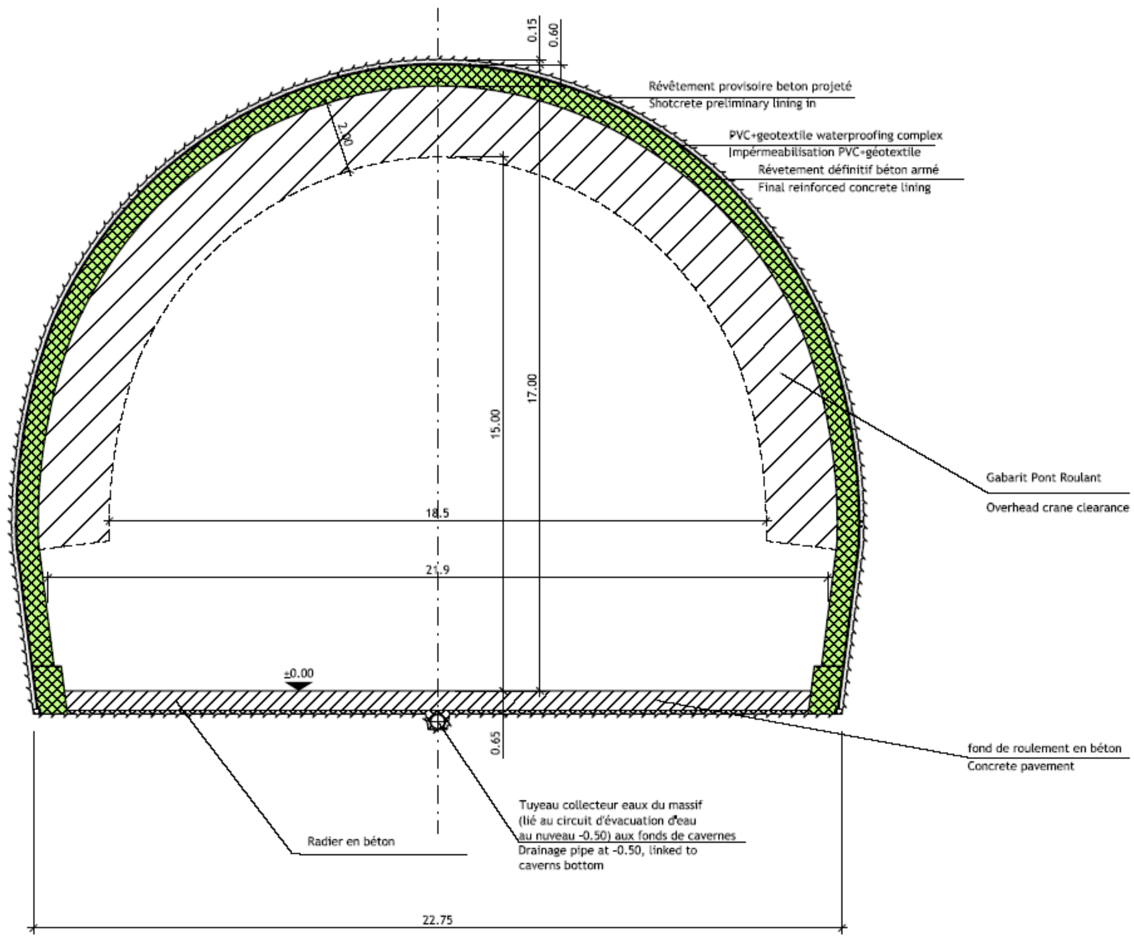
1:100

CAVERN A CROSS SECTION

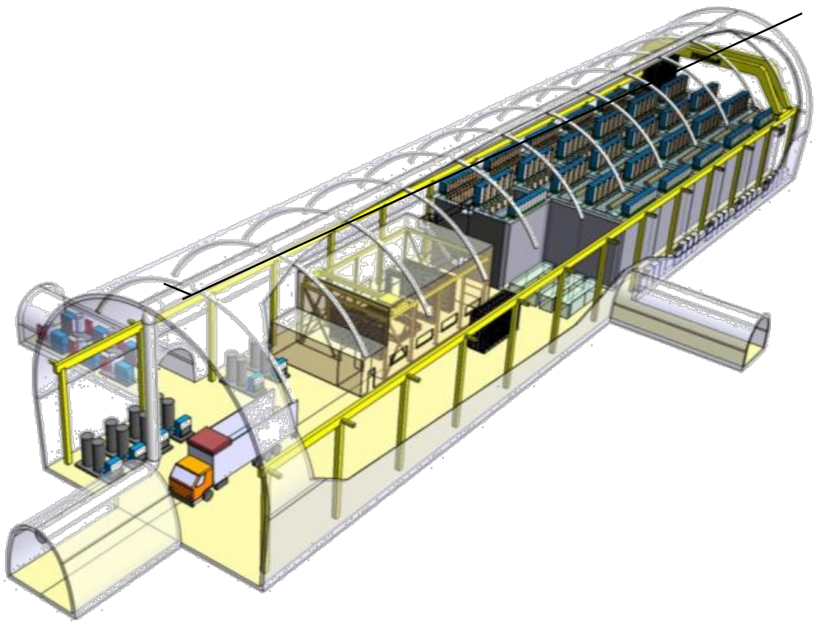
EXCAVATED AREA 375 m²

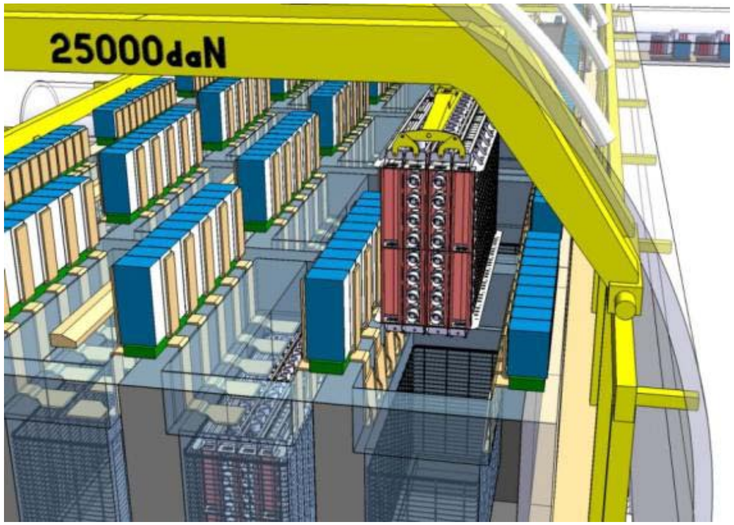
INTERNAL CLEARANCE 320 m²

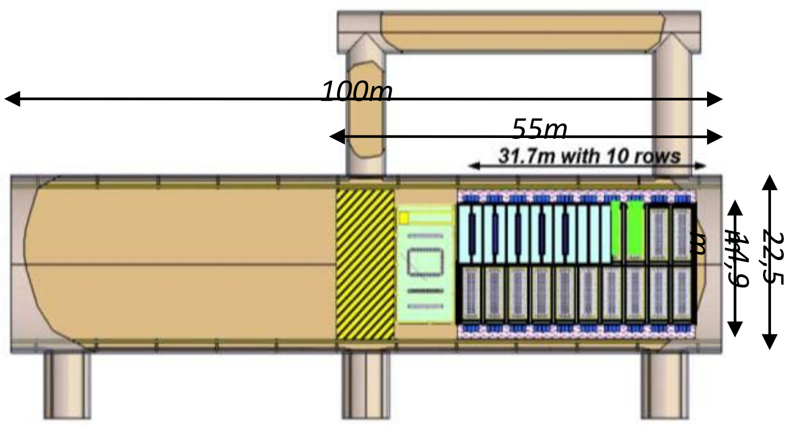
1:100



SuperNEMO @ LSM







Space requirements: 32 m X 15 m

Minimum height: 13 m

Clean room : 7 m X 6 m

Electrical power : 80 kW

Free radon air : 15 mBq/m3

Water shielding

LSM extension

- Safety galery work started in September 2009
- Excavation of the extension end 2011.
- In operation in 2013.
- Pre-study funded by LSM and UK in 2006. Preliminary design to host SuperNEMO and EURECA
- Detailed studies funded by Savoie departement and Rhone-Alpes Region
- Review of project and LoI's by an indepeandent Scientific Advisory Committee
- Estimated cost : 10 M€ for civil work
  3 M€ for equipment (ventilation, cooling, electrical power)
- Open to international partner (contribution to scienific equipements, experiments)

Funding in progress