NEMO-3 and SuperNEMO

A search for zero neutrino double beta decay

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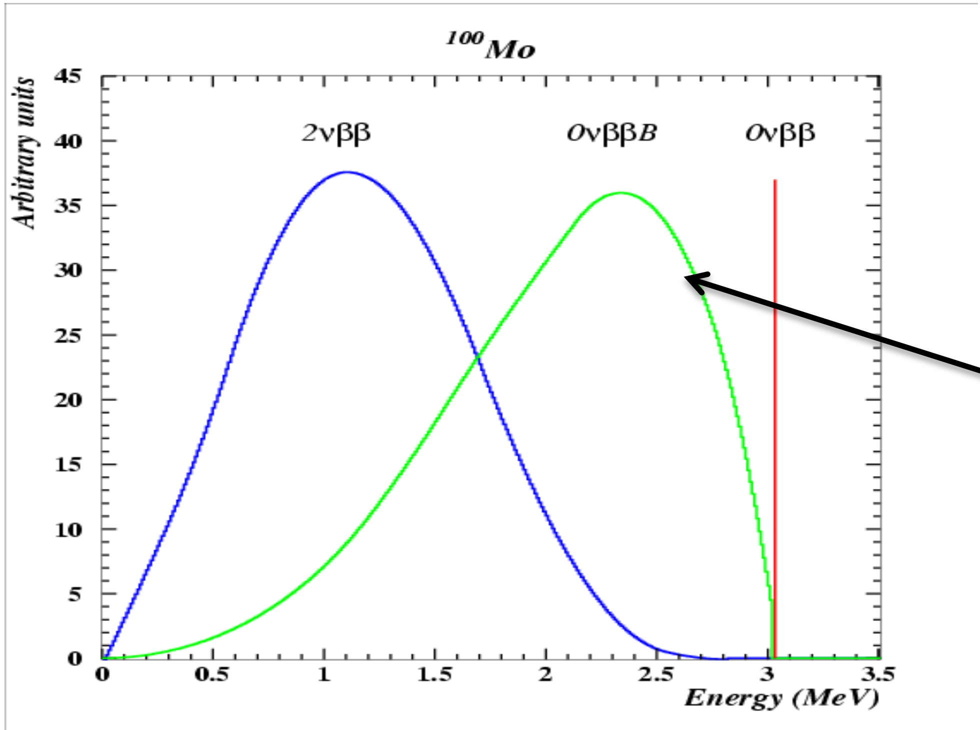
On behalf of the NEMO-3/SuperNEMO collaborations

NOW 2010

Why event reconstruction is useful

<u>2νββ</u>
•Allowed by the standard model
•Irreducible background in the search for 0νββ
•Input into NME calculations



<u>0νββ</u>
•Not allowed by the standard model
•Neutrino must be Majorana
•New physics mechanisms may contribute e.g Majaron
•arXiv: 1005.1241

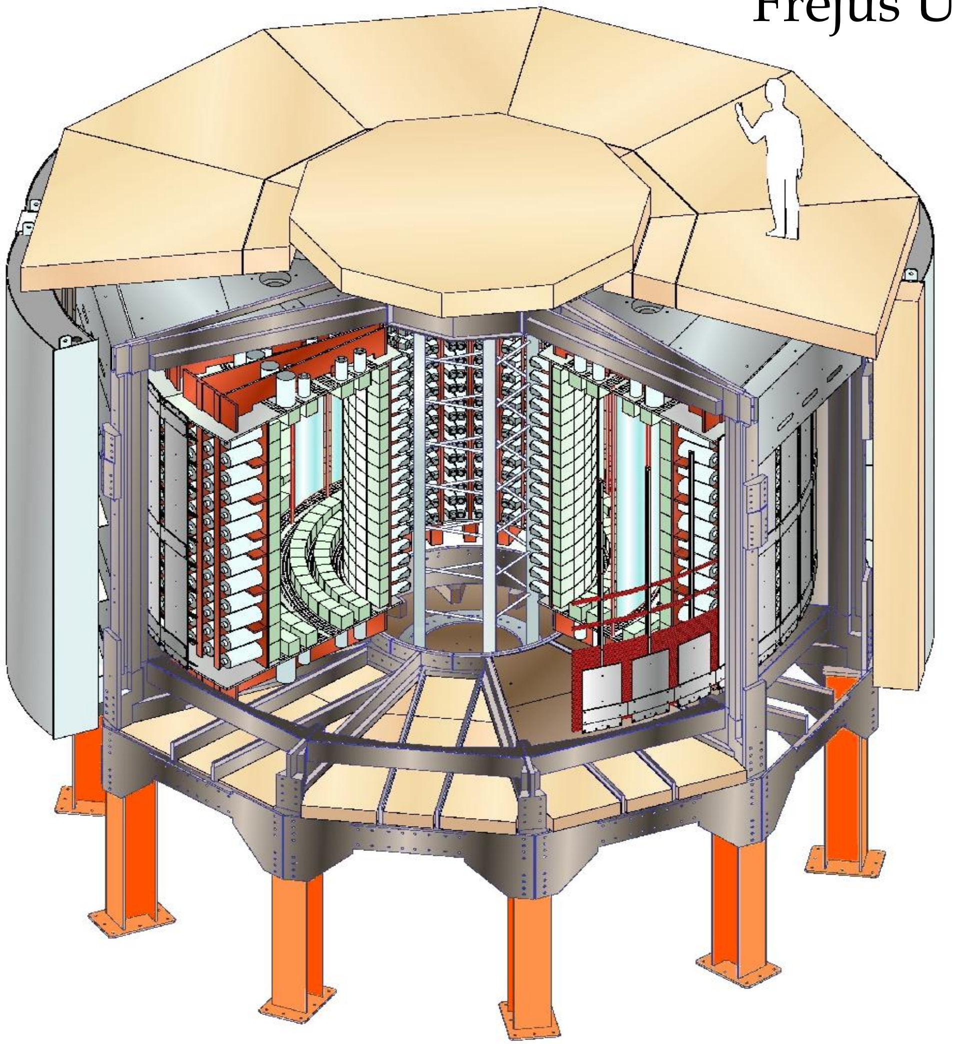
Majaron

•Powerful background rejection tool

•If we observe 0νββ then studying the 2e, 1e energy + angular distributions will give information about the production mechanism.

Neutrino Ettore Majorana Observatory

Fréjus Underground Laboratory : 4800 m.w.e.



Source: 10 kg of ββ isotopes
cylindrical, S = 20 m², d ~ 60 mg/cm²

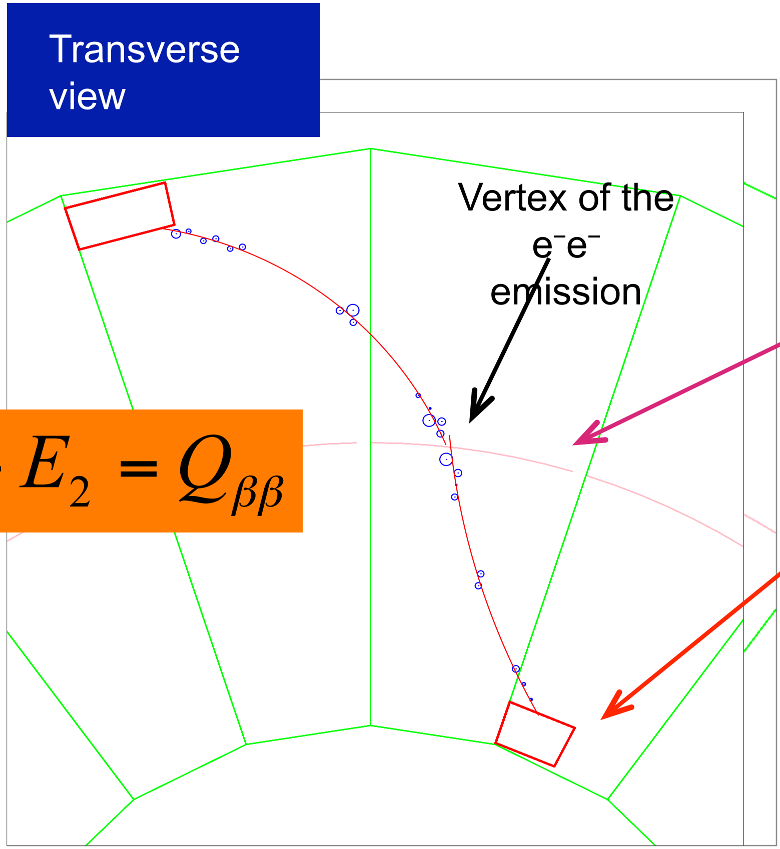
Tracking detector:
drift wire chamber operating
in Geiger mode (6180 cells)
Gas: He + 4% ethyl alcohol + 1% Ar + 0.1% H_2O

Calorimeter:
1940 plastic scintillators
coupled to low radioactivity PMTs

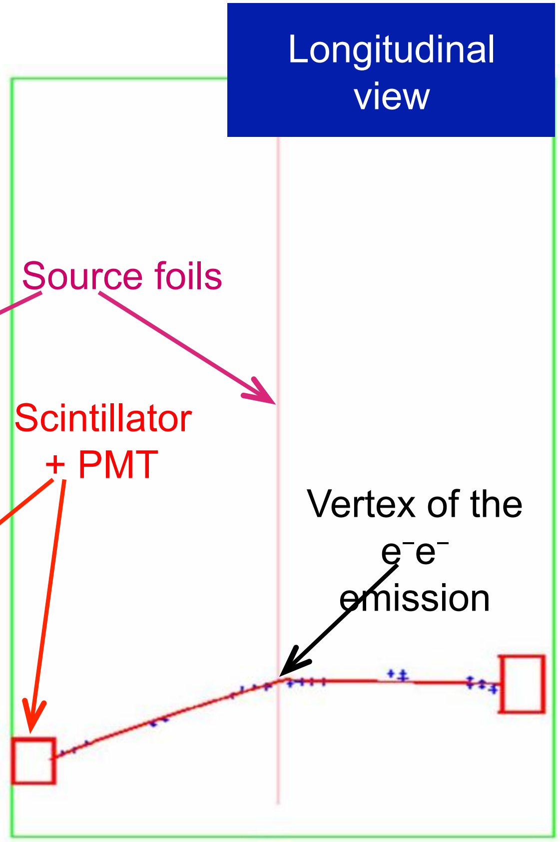
Magnetic field: 25 Gauss
Gamma shield: Pure Iron (d = 18 cm)
Neutron shield: 30 cm water (ext. wall)
40 cm wood (top and bottom)
(since march 2004: water + boron)

Particle ID: e^-, e^+, γ and α

Event reconstruction



$$E_1 + E_2 = Q_{\beta\beta}$$



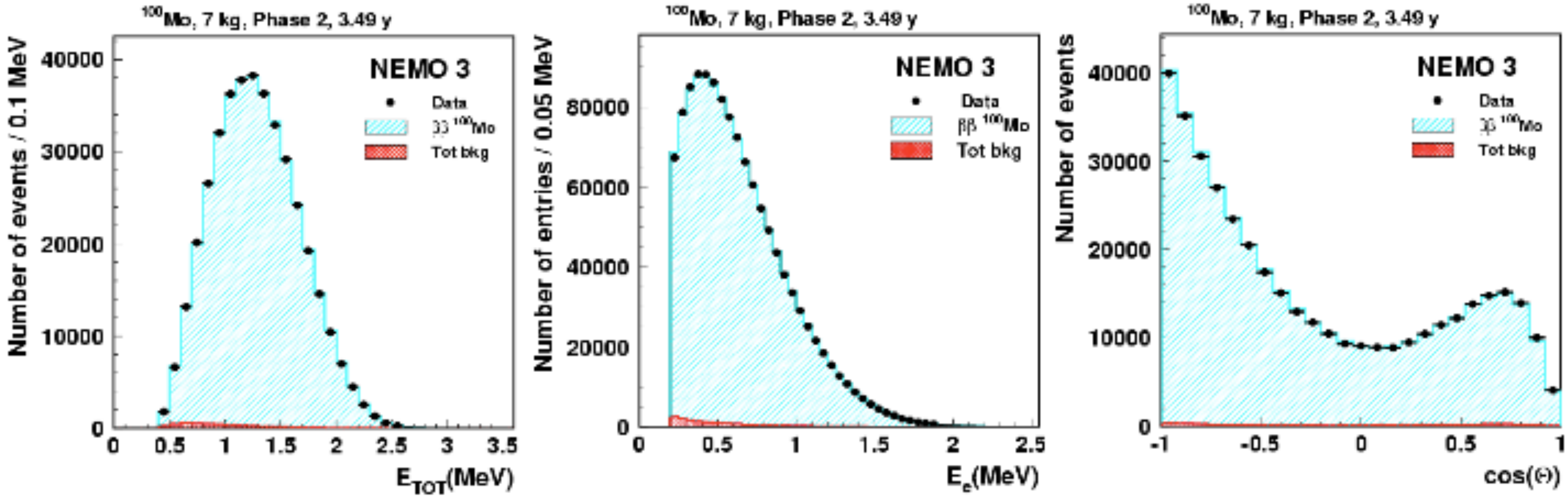
Observables of the final state

- **Trajectories of the 2 electrons**
- **Energies of the 2 electrons**
- **Time of flight**
- **Curvature of the tracks in a B-field (+ or -).**

Backgrounds are measured using event <u>topology</u> and <u>timing</u> to produce a background model for ββ

<u>NIM A606 (2009) 449-465.</u>

^{100}Mo 2νββ updated result



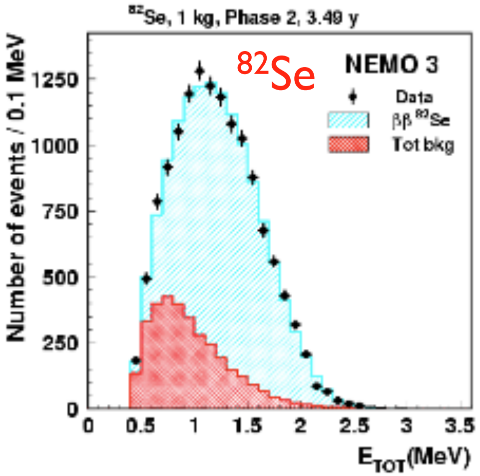
$T_{1/2}(2\nu) = [7.17 \pm 0.01(stat) \pm 0.54(sys)] \times 10^{18}$ yr ⇒ ~3.5 yr, Phase II (low Rn), S/B = 76
$M^{2\nu}(^{100}Mo) = 0.126 \pm 0.006$

This is an update of a previous published result using phase I data

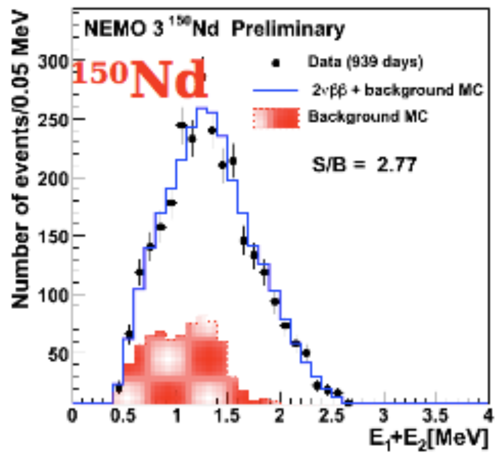
Phys. Rev. Lett. 95 182302 (2005)

$T_{1/2}(2\nu\beta\beta) = 7.11 \pm 0.02$ (stat) ± 0.54 (syst) $\times 10^{18}$ years, S/B = 40

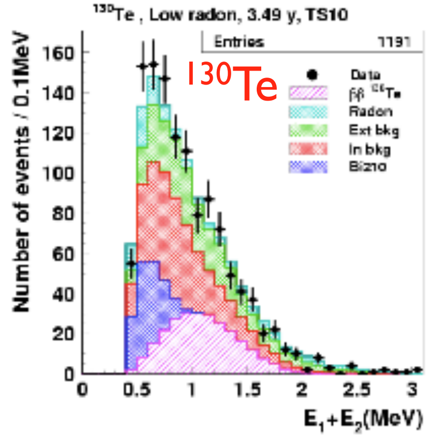
2νββ results for other isotopes (preliminary)



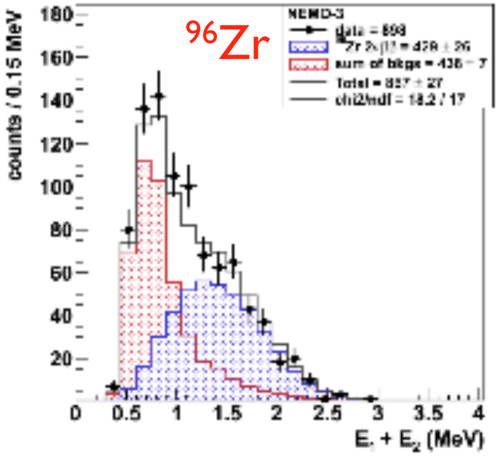
[9.6±0.1(stat)±1.0(sys)]×10^{19} yr
$M^{2\nu}$=0.049±0.004



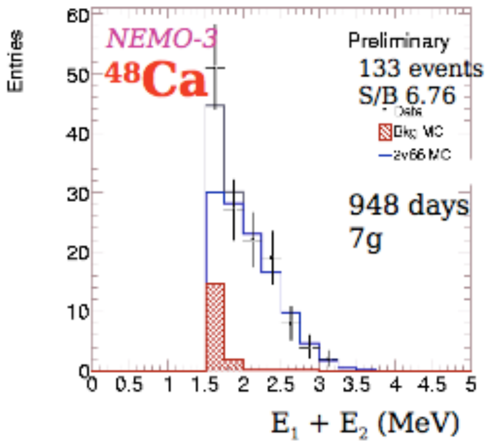
[9.20±0.25(stat)±0.63(sys)]×10^{18} yr
$M^{2\nu}$=0.030±0.002



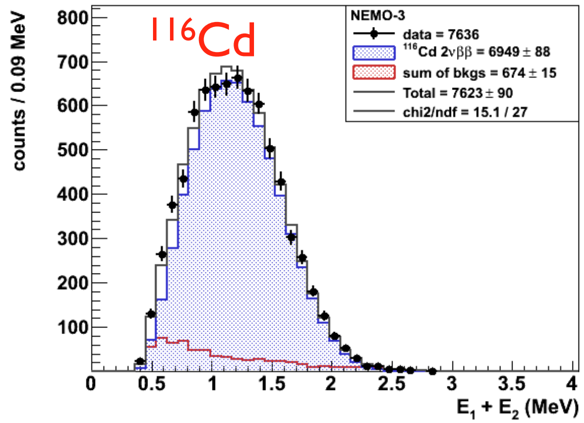
[$7.0^{+1.0}_{-0.8}$(stat) $^{+1.1}_{-0.9}$(sys)]×10^{20} yr
$M^{2\nu}$=0.0173±0.0025



[2.35±0.14(stat)±0.16(sys)]×10^{19} yr
$M^{2\nu}$=0.049±0.002



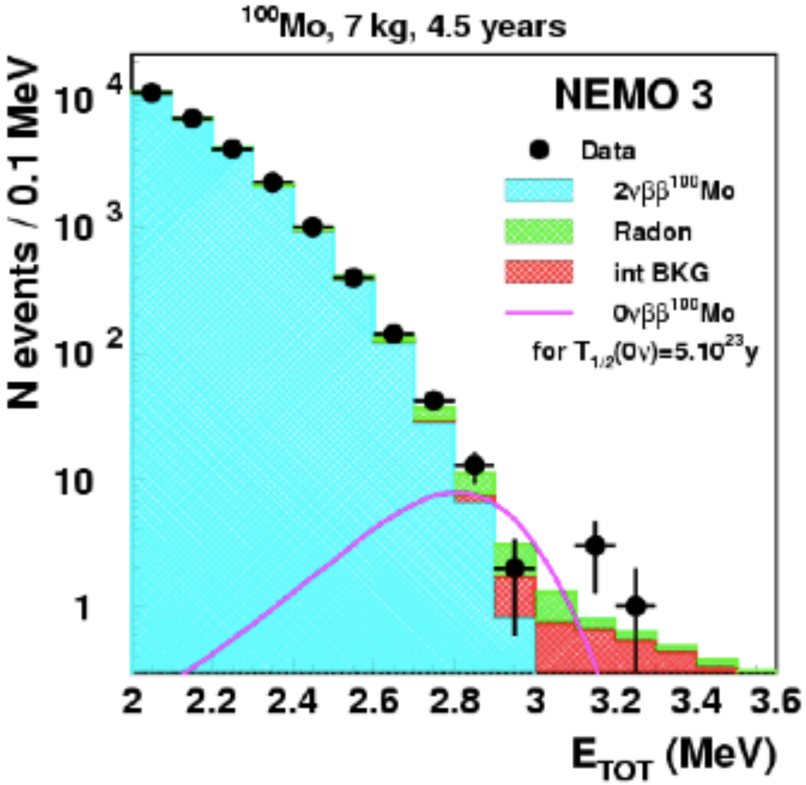
[$4.4^{+0.5}_{-0.4}$(stat)±0.4(sys)]×10^{19} yr
$M^{2\nu}$=0.0238±0.0015

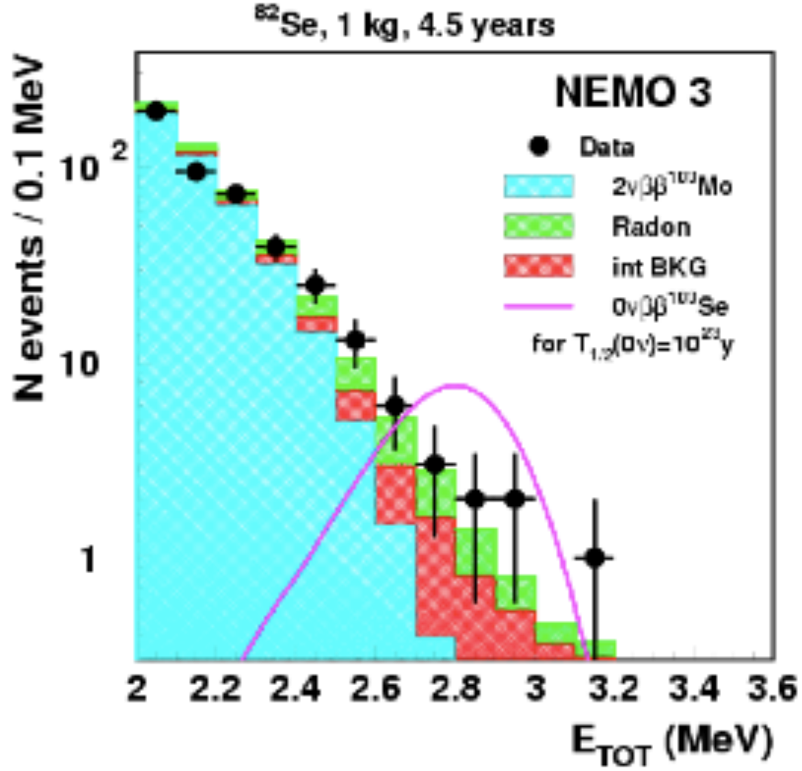


[2.88±0.04(stat)±0.16(sys)]×10^{19} yr
$M^{2\nu}$=0.0685±0.0025

Many more results available. Excited states, 0ν for different mechanisms and isotopes

$0\nu\beta\beta$ for ^{100}Mo(~7kg) and ^{82}Se (~1kg)





[2.8-3.2] MeV: DATA = 18; MC = 16.4±1.4

$T_{1/2}(0\nu) > 1.0\times10^{24}$ yr at 90%CL

$\langle m_\nu\rangle < (0.47 - 0.96)$ eV

[2.6-3.2] MeV: DATA = 14; MC = 10.9±1.3

$T_{1/2}(0\nu) > 3.2\times10^{23}$ yr at 90%CL

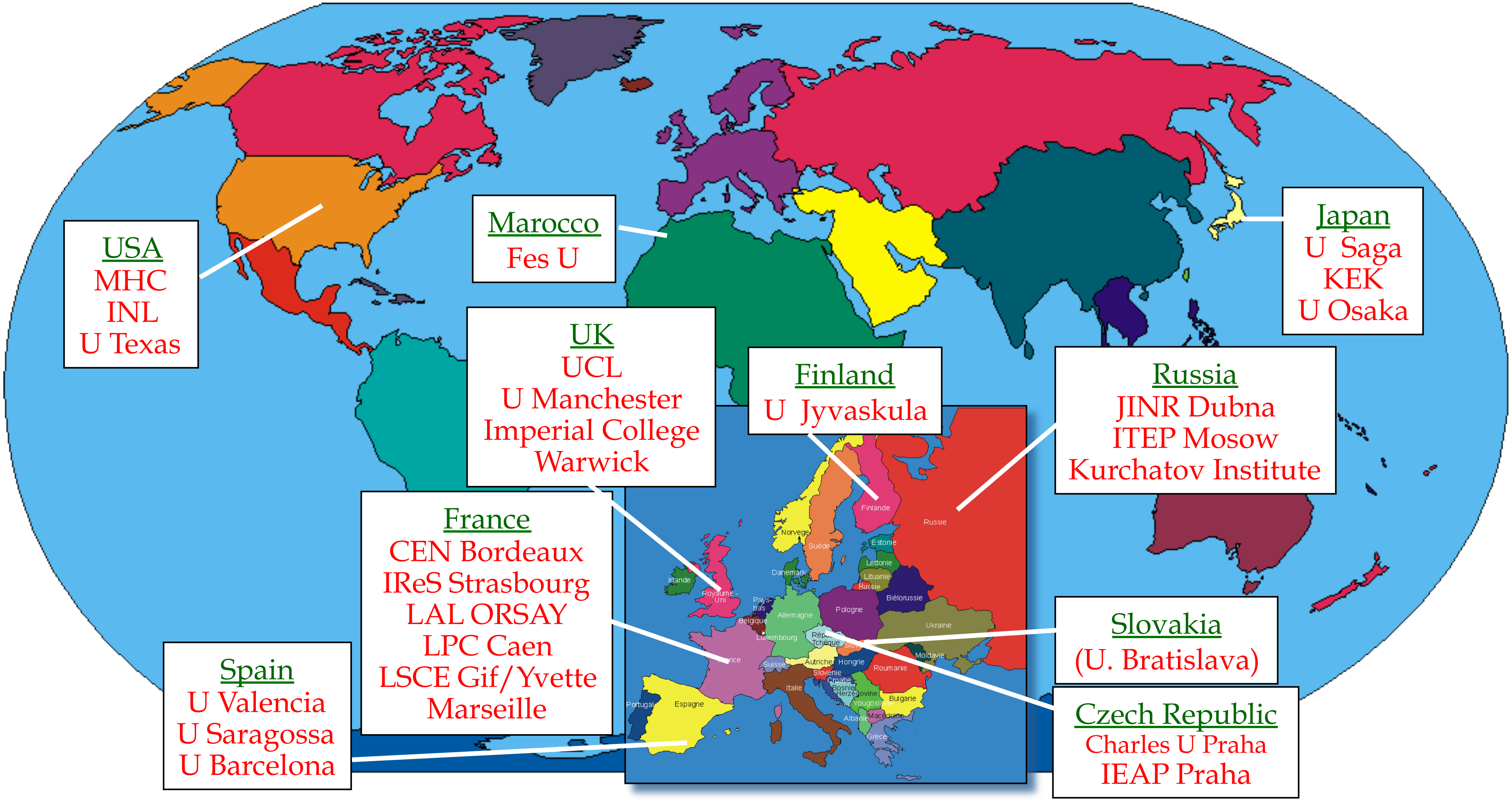
$\langle m_\nu\rangle < (0.94 - 2.5)$ eV

V+A: $T_{1/2}(0\nu) > 5.4\times10^{23}$ yr at 90%CL $\lambda < 1.4\times10^{-6}$

Majoron: $T_{1/2}(0\nu) > 2.1\times10^{22}$ yr at 90%CL $g_{ee} < 0.5\times10^{-4}$ World's best result!

SuperNEMO Collaboration

~ 100 physicists, 10 countries, 27 Institutions



Objectives of the 4 year R&D programme

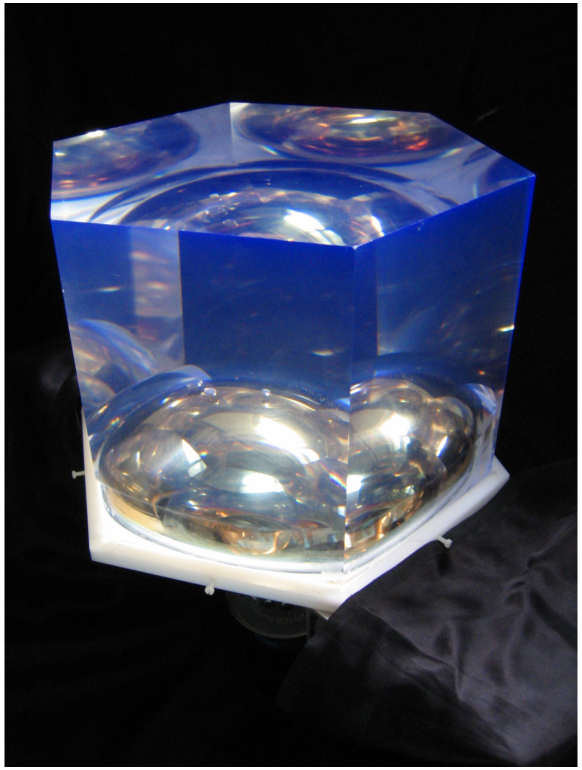
NEMO-3		SuperNEMO
^{100}Mo	isotope	^{82}Se or other
7 kg	isotope mass M	100+ kg
18 %	efficiency ε	~ 30 %
^{208}Tl: ~ 100 μBq/kg ^{214}Bi: < 300 μBq/kg Rn: 5 mBq/m^3	internal contaminations ^{208}Tl and ^{214}Bi in the ββ foil Rn in the tracker	$^{208}Tl \leq 2$ μBq/kg if ^{82}Se: $^{214}Bi \leq 10$ μBq/kg Rn ≤ 0.15 mBq/m^3
8% @ 3MeV	energy resolution (FWHM)	4% @ 3 MeV

$T_{1/2}(\beta\beta0\nu) > 2 \times 10^{24}$ y
$\langle m_\nu \rangle < 0.3 – 0.9$ eV

$T_{1/2}(\beta\beta0\nu) > 1 \times 10^{26}$ y
$\langle m_\nu \rangle < 0.04 - 0.11$ eV

Calorimeter R&D to improve energy and time resolution

Each module will have 550 PMTs + scintillator blocks



Scintillator

- Material
- Shape
- Size
- Coating

PMT

- QE
- Uniformity
- Collection efficiency
- Radiopurity

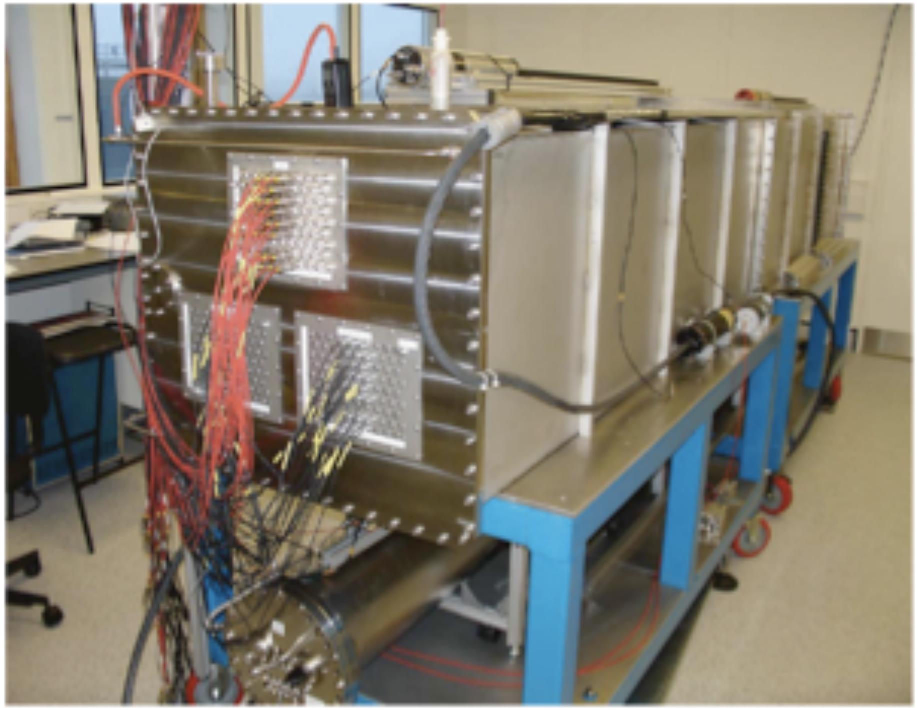
Required resolution demonstrated with 28cm Hex block ($\geq$10cm thick) directly coupled to 8" PMT

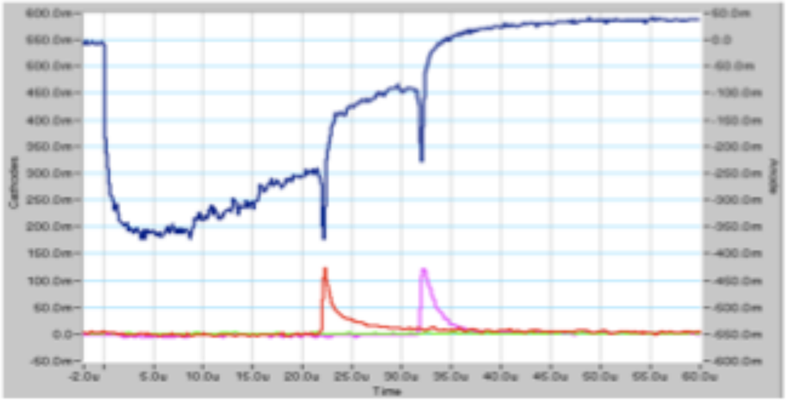
FWHM = 4% @ $Q_{\beta\beta}$ = 3 MeV

Tracker R&D

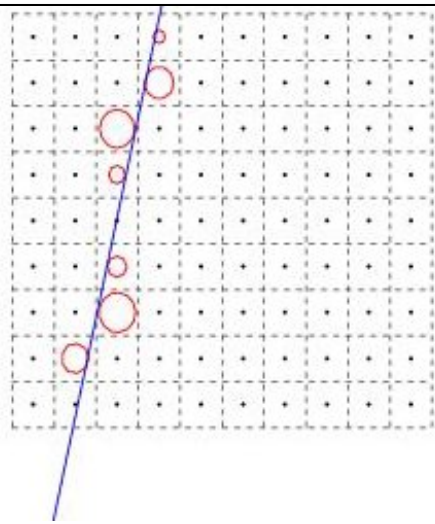
To optimise the length, diameter, material for the wire, readout and gas mixture

Constructed several prototype single cells of differing lengths and diameters.
Then progressed to a 9-cell to look at the configuration of the fields and cross-talk.
From this work a 90-cell prototype was constructed.





Cosmic muon used for testing of reconstruction algorithm



Transverse 0.7mm, longitudinal 1cm
Overall cell efficiency of >98%

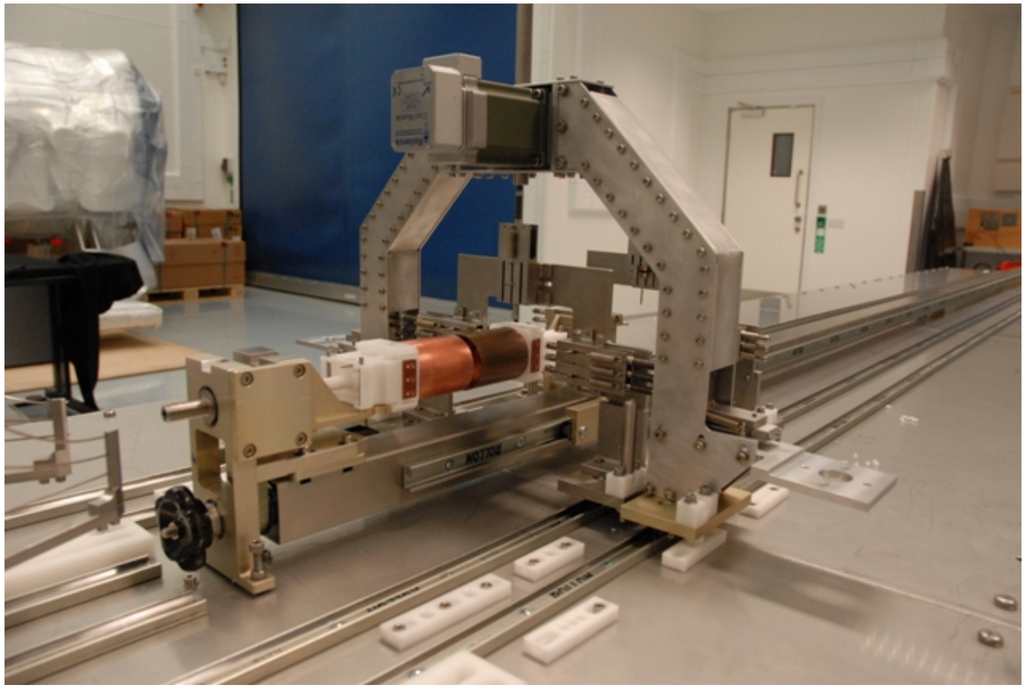
Wiring robot

For the full 20 modules in excess of 0.5M wires will need to be strung.

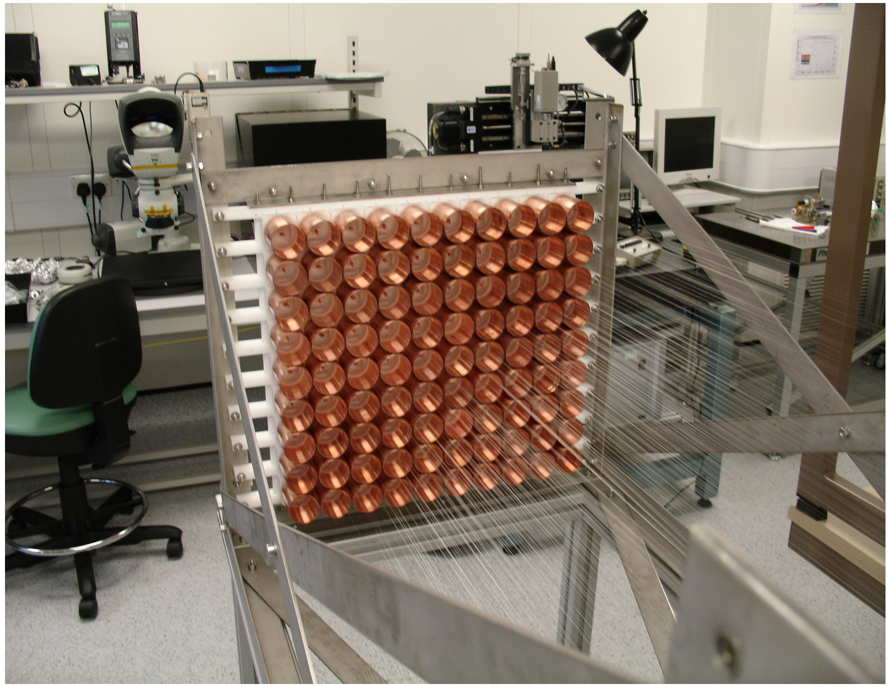
A wiring robot is being developed at the Mullard Space Science Laboratory.

The wiring will be carried out in a clean-room environment with as little human intervention as possible.

Protoype robot being developed at MSSL



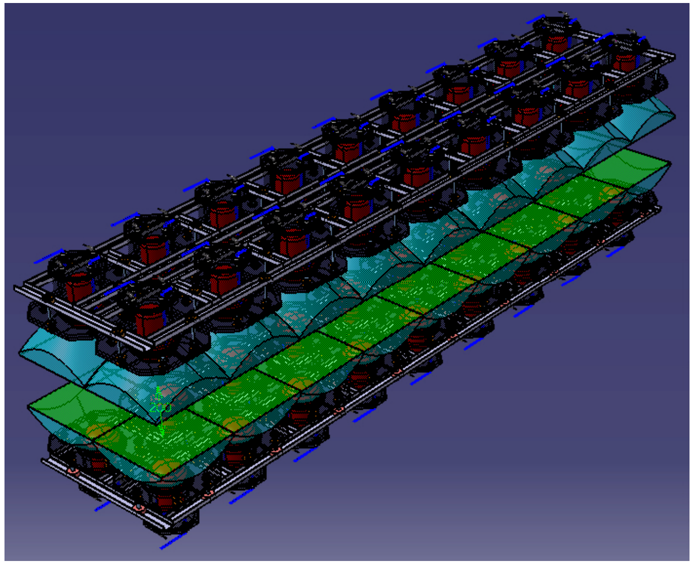
90-cell opened up

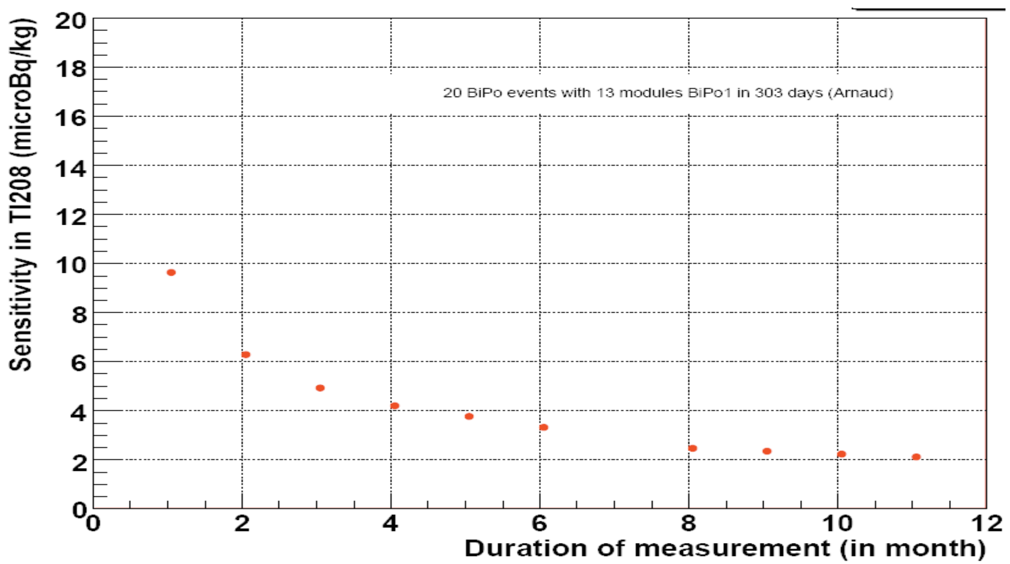


Production of the ββ Source Foil

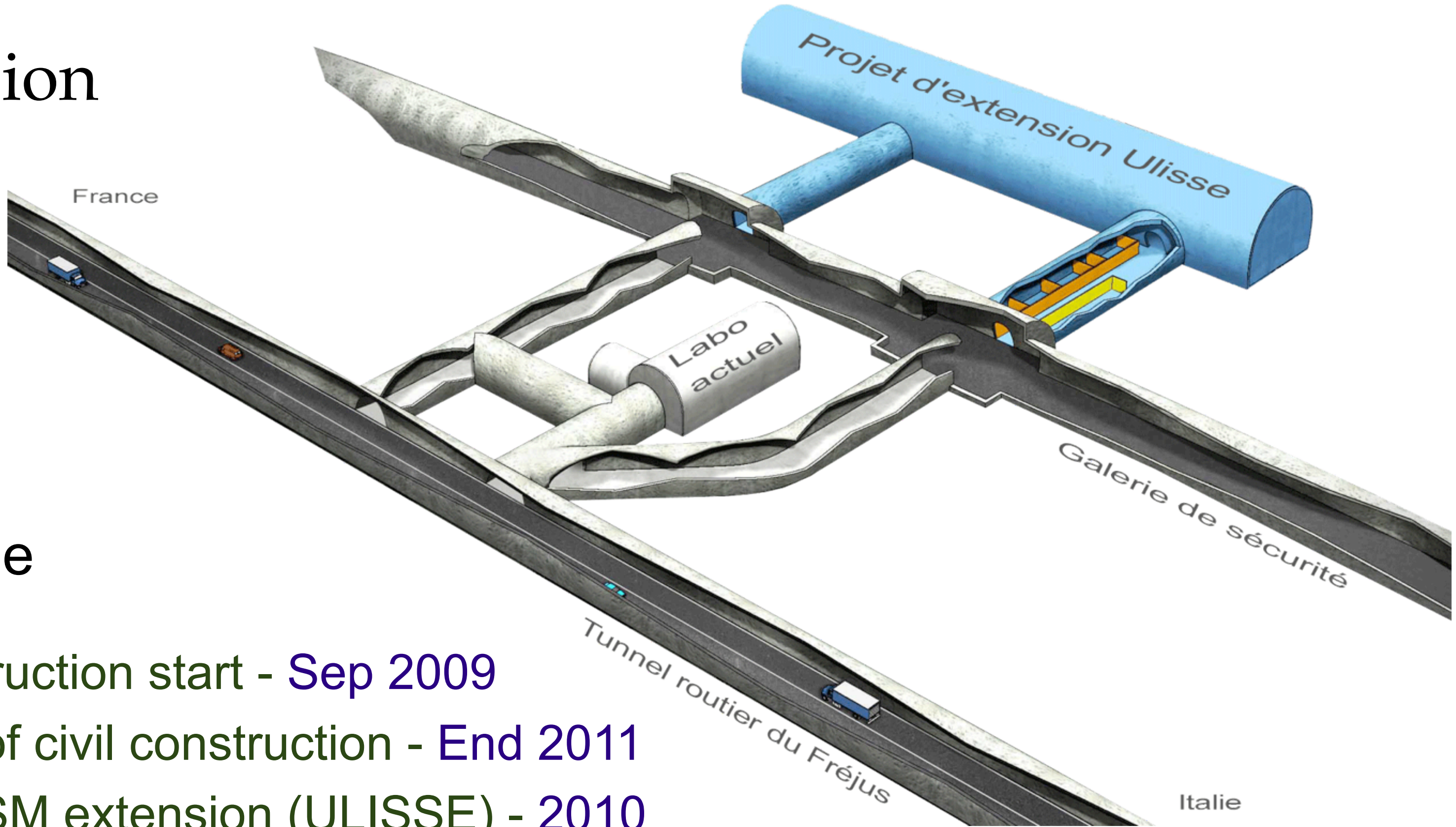
- Preferred candidate for the source is ^{82}Se (others being investigated).
- Enrichment of 100 kg by centrifugation is possible.
- The density on the foil is 40-50 mg/cm^2.
- Radio-purity: $^{208}Tl < 2\ \mu Bq/kg$, $^{214}Bi < 10\ \mu Bq/kg$
- Chemical and physical purification methods

Dedicated BiPo detector to measure low radio-purity levels





LSM Extension



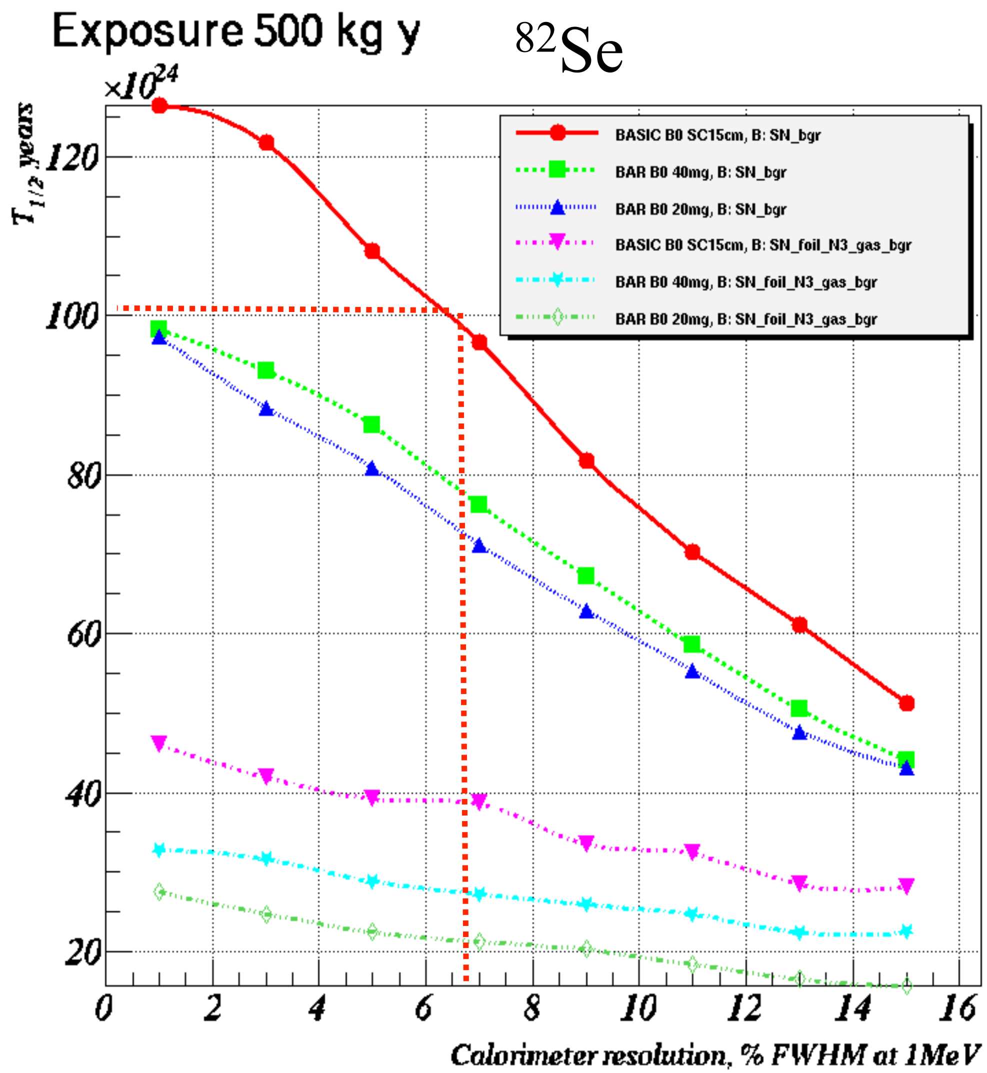
Schedule

- Safety tunnel construction start - Sep 2009
- Safety tunnel, end of civil construction - End 2011
- Detailed study of LSM extension (ULISSE) - 2010
- Deadline for final decision/money commitment - May 2011
- Excavation of new Lab completed - mid-2012
- Outfitting completed, Lab ready to host experiments - 2013

Minimal scenario: 45,000m^3 (100m long), 12M€ excavation + 3M€ outfitting

2d ULISSE workshop in October. 11 LOIs received.

Detector sensitivity



Using a GEANT-4 based model of the detector combined with NEMO-3 experience.

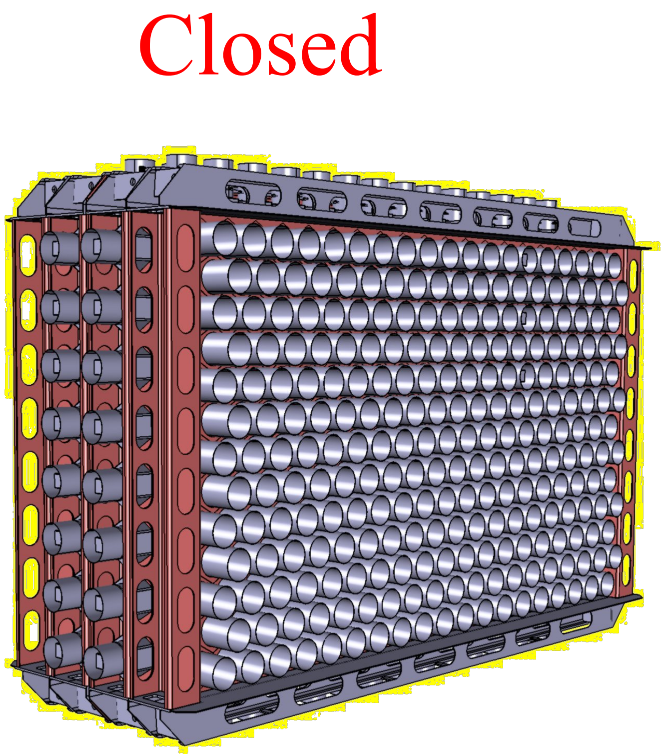
5yrs with 100kg ^{82}Se:

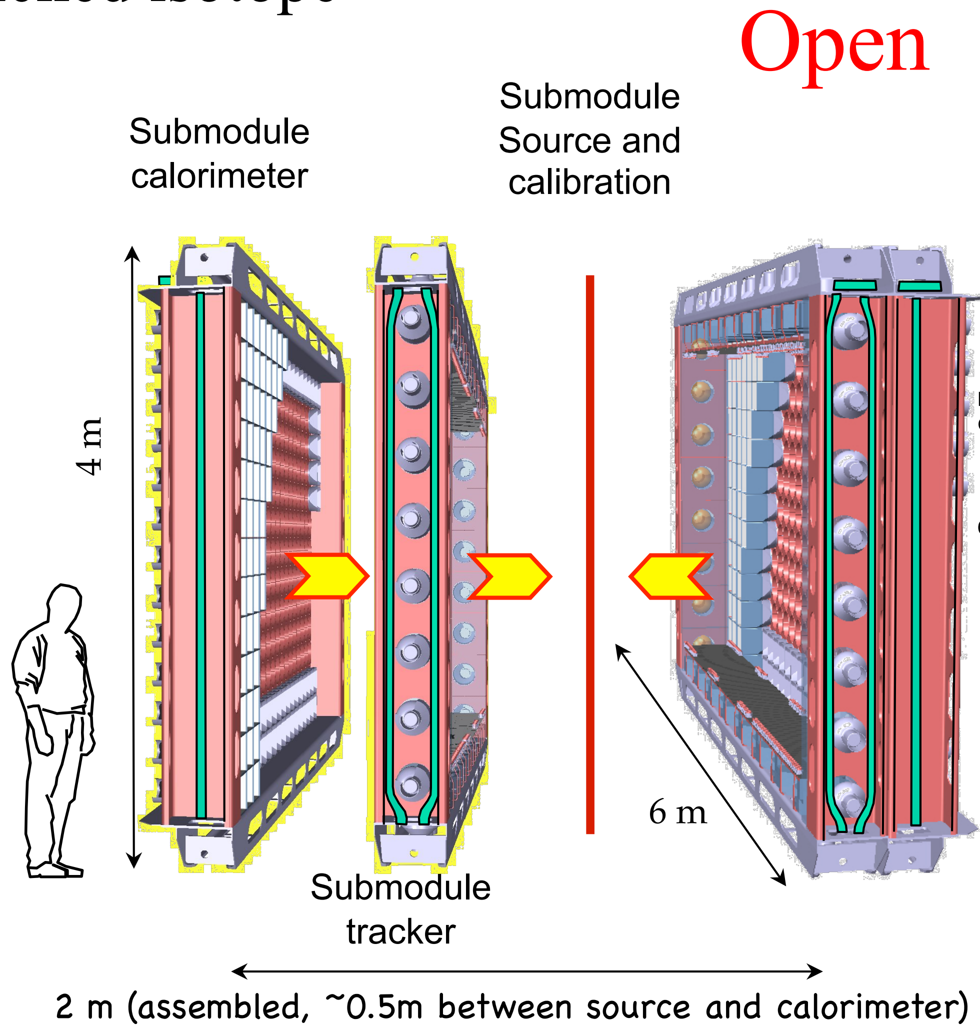
$T_{1/2}(\beta\beta 0\nu) > 1 \times 10^{26}$ y

$\langle m_\nu \rangle < 0.05 - 0.1$ eV

A SuperNEMO module

20 modules having a Planar design:
Each module will have 5kg of enriched isotope
Making a total of 100 kg.





1st SuperNEMO module - Demonstrator

- Demonstrate that mass production is possible.

- Study the backgrounds with an emphasise on radon emanation.

- Make a competitive physics measurement

0.3 expected bkg events in 2.8 - 3.2 MeV with 7kg of ^{82}Se in 2 yr

Sensitivity by 2015: $6.5 \cdot 10^{24}$ yr (90% CL)

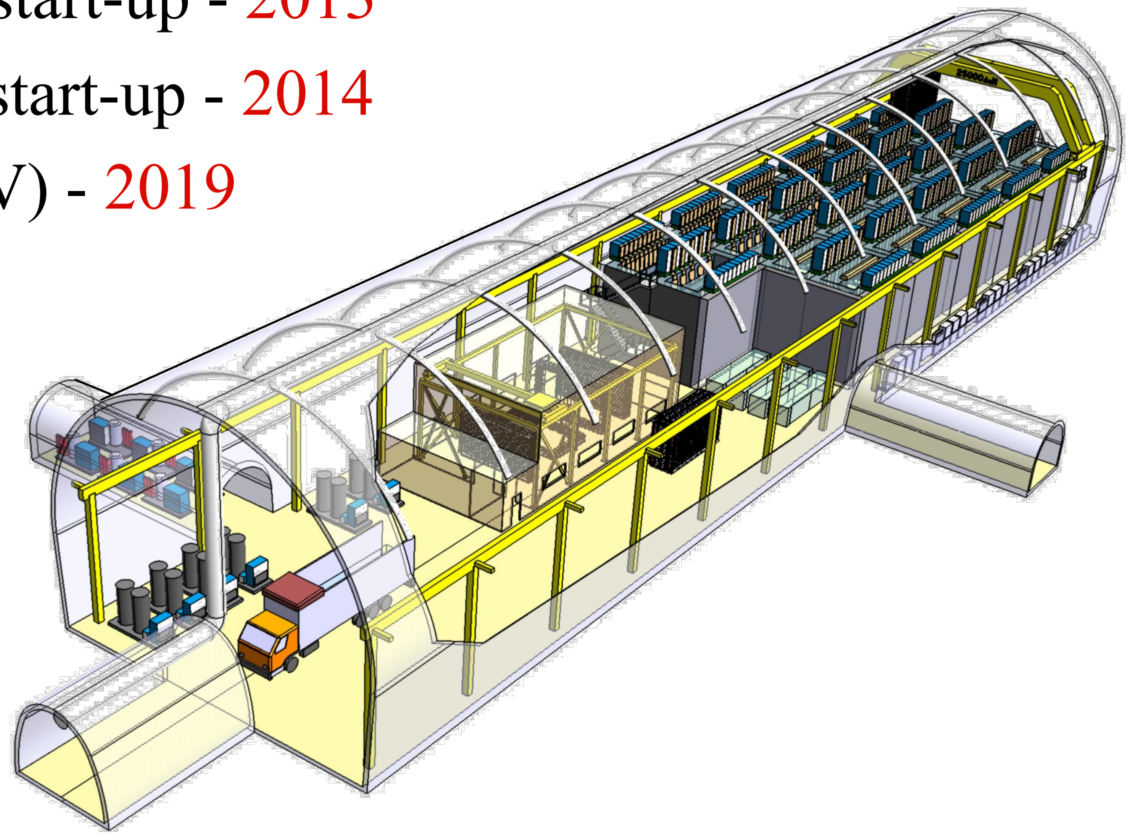
Equivalent to $3 \cdot 10^{25}$ **yr** for ^{76}Ge (using phase space ratio only)

or ~4 expected "golden events" if KK claim is correct

SuperNEMO schedule highlights

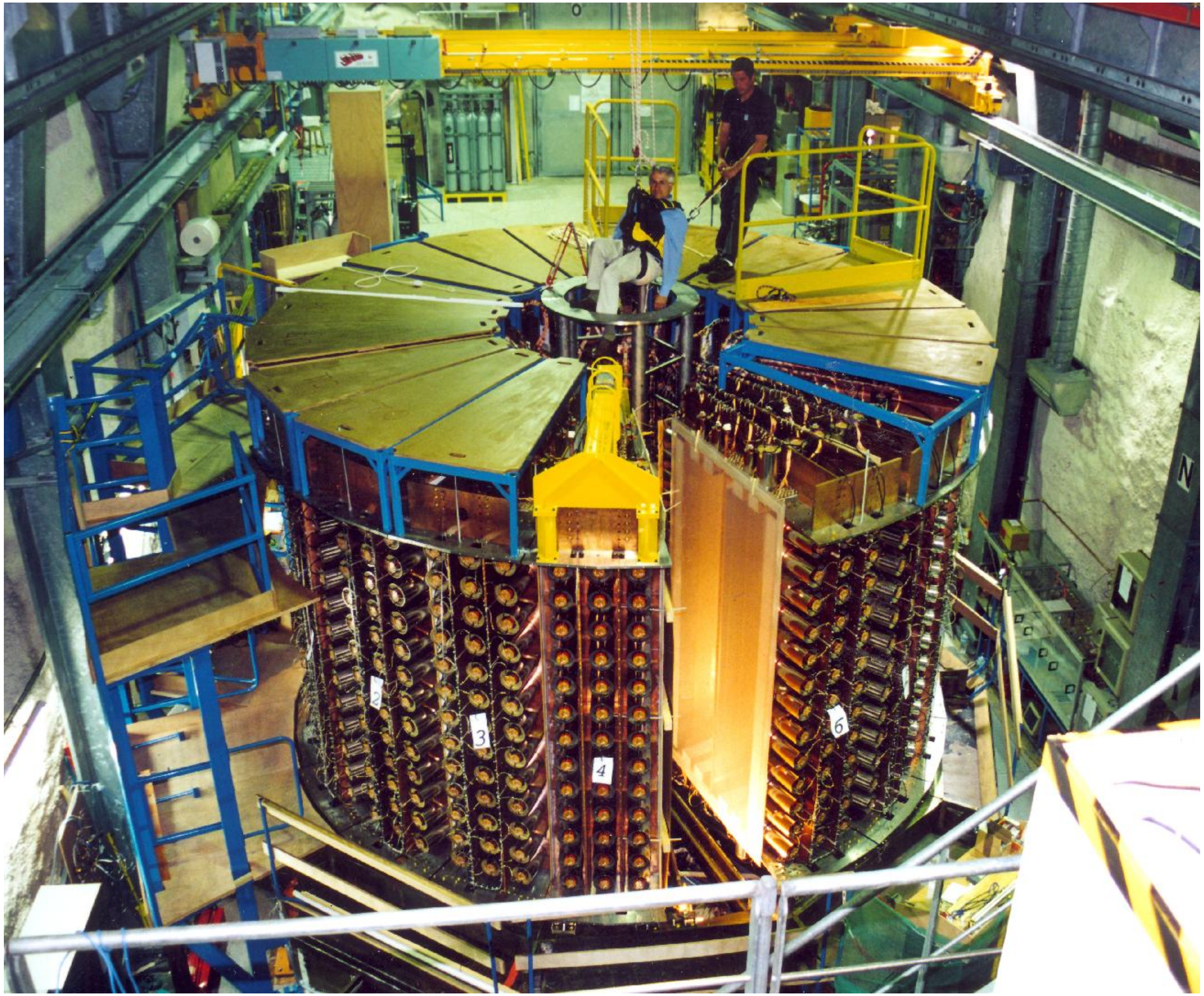
- NEMO-3 decommissioning - early 2011
- Demonstrator construction - 2010-2012
- Demonstrator physics run start-up - 2013
- Full detector construction start-up - 2014
- Target sensitivity (~0.05 eV) - 2019

KK claim to be verified with Demonstrator by 2015

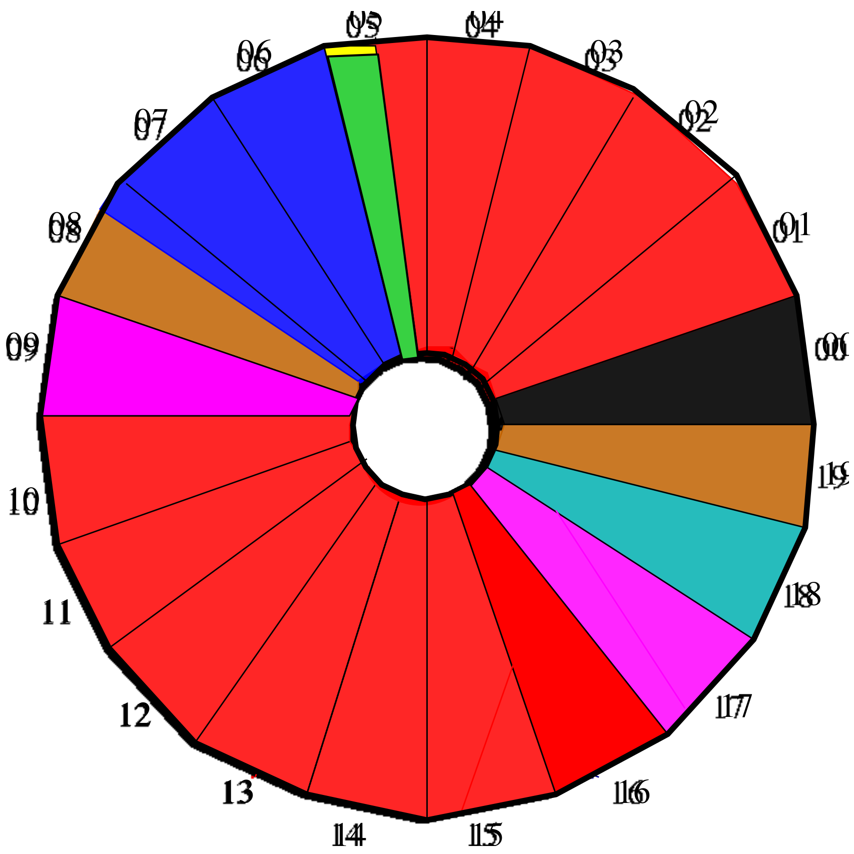


BACKUP

NEMO 3 under construction at the LSM



$\beta\beta$ 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

$\beta\beta0\nu$ search

$\beta\beta2\nu$ 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

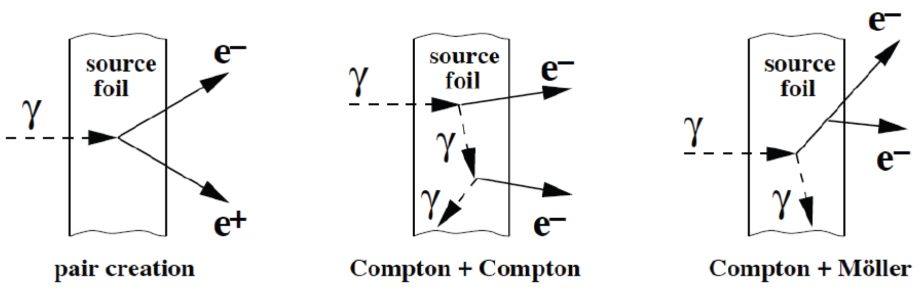
Cu 621 g

External bkg measurement

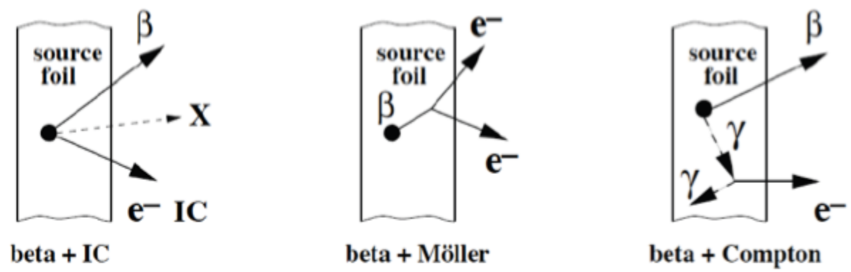
(Enriched isotopes produced by centrifugation in Russia)

NEMO-3 Backgrounds for ββ

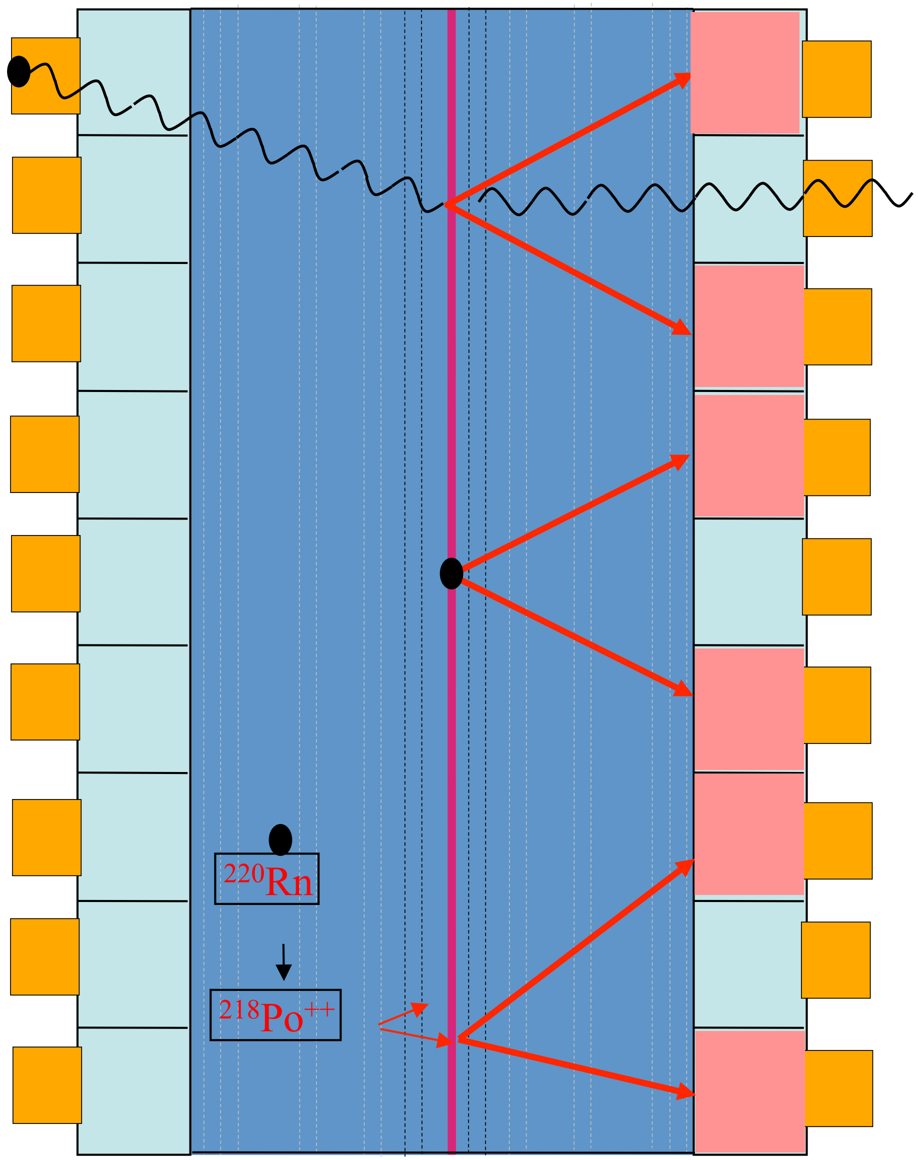
- External γ (if the γ is not detected in the scintillators)
  Origin: natural radioactivity of the detector or neutrons
  Main bkg for ββ2ν but negligeable for ββ0ν
  (^{100}Mo and ^{82}Se $Q_{\beta\beta}$~ 3 MeV > Eγ(^{208}Tl) ~ 2.6 MeV)



- ^{232}Th (^{208}Tl) and ^{238}U (^{214}Bi) contamination inside the ββ source foil



- Radon (^{214}Bi) inside the tracking detector
  - deposits on the wire near the ββ foil
  - deposits on the surface of the ββ foil

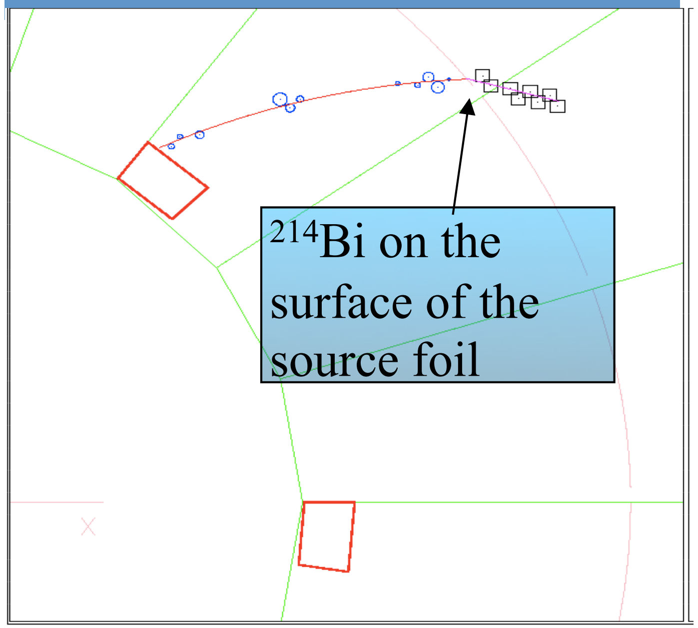


Each bkg is measured using the NEMO-3 data

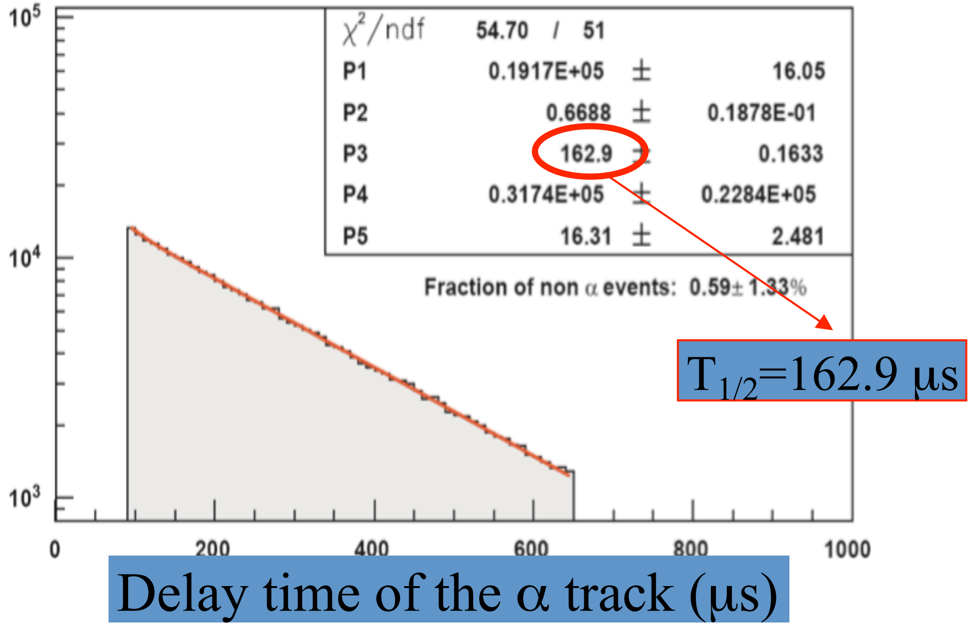
Example: Radon inside the tracking detector

$^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Pb$

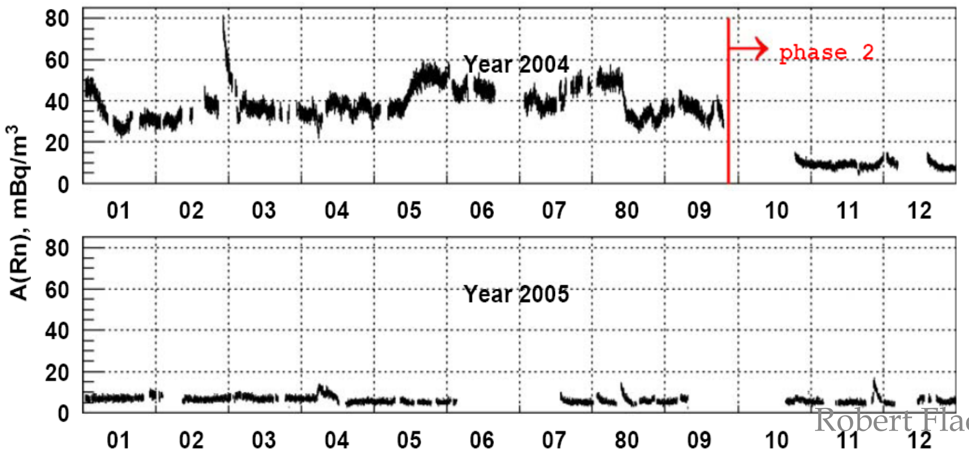
(164 μs)



Pure sample of ^{214}Bi – ^{214}Po events



Monitoring of the Radon bkg every day



- Phase 1: Feb. 2003 → Sept. 2004
  Radon Contamination
- Phase 2: Dec. 2004 → Today
  A (Radon) ≈ 5 mBq/m³

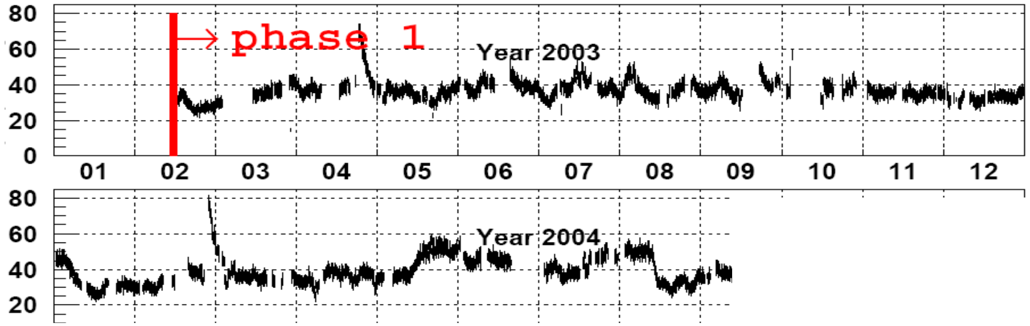
Radon trapping facility

(First developed for SuperKamiokande)

Phase I : February 2003 – September 2004 (radon background in data)

~ 1 $0\nu\beta\beta$-like event/y/kg with $2.8 < E_1+E_2 < 3.2$ MeV

Phase II : since October 2004 (radon level reduced by a factor of 6)



1 ton of charcoal @ –50°C, 9 bars

air flux = 150 m^3/h

Input: A(^{222}Rn) 15 Bq/m^3

Output: A(^{222}Rn) < 15 mBq/m^3 !!!

reduction factor of 1000

Inside the NEMO 3 tent: factor of 100 – 300

Inside NEMO 3: almost factor of 10 A(^{222}Rn) ≈ 6 mBq/m^3

Neutrinos are massive and they mix

What else do we want to know?

- Number of neutrinos: Are there sterile neutrinos?
- θ_{13}, Precision values of mixing angles and Δm^2's
- Absolute neutrino mass value. Only limits so far.
  Tritium: $m_{\bar{\nu}_e} < 2.3$ eV Cosmology: $\sum m_{\nu_i} < 1$ eV
- Neutrino mass spectrum: Normal ($m_1 < m_2 < m_3$)
  Inverted ($m_3 < m_1 < m_2$) or Quasi-degenerate ($m_1 \approx m_2 \approx m_3$)?
- Origin of matter-antimatter asymmetry.
  CP-violation in lepton sector: $\delta \neq 0,\pi$ and/or $\alpha,\beta \neq 0,\pi$?
- Nature of Neutrinos: Majorana ($\nu =$ anti-ν) or Dirac ($\nu \neq$ anti-ν)?
  Full lepton number violation (required in most Grand Unification Theories) .

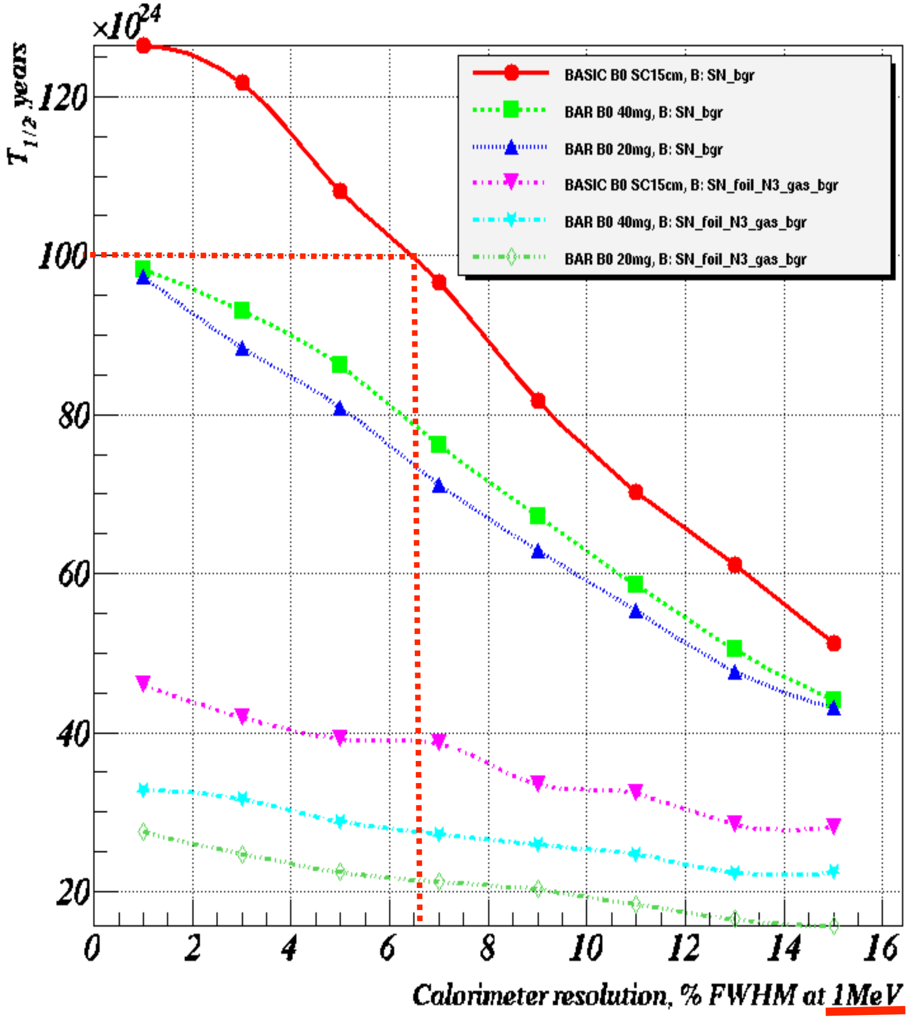
addressed by $0\nu\beta\beta$ decay

Physics Studies

Full chain of GEANT-4 based software + detector effects

+ NEMO3 experience

Exposure 500 kg y ^{82}Se



5 yr with 100kg of ^{82}Se:
$T_{1/2} > 10^{26}$ yr, $\langle m_\nu \rangle < 50\text{-}100$ meV at 90%CL
with target detector parameters

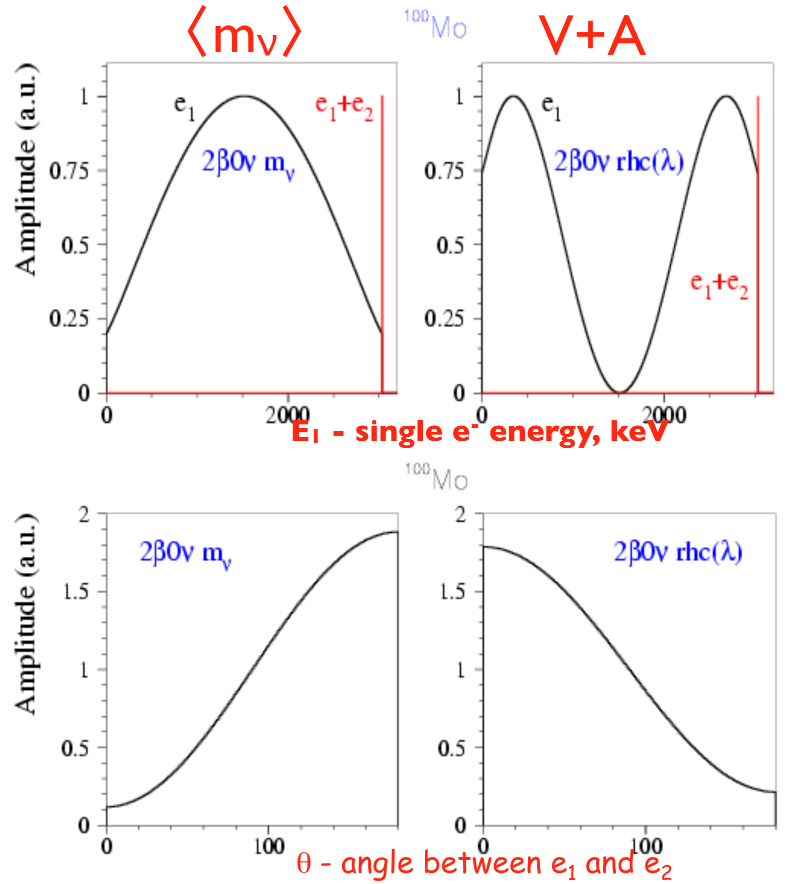
Much more than 1 result!

- Other mechanisms: V+A, Majoron, etc
- Disentangling $\langle m_\nu \rangle$ and V+A:
  arXiv: 1005.1241
- $\beta\beta 0\nu$(and 2ν) to excited states

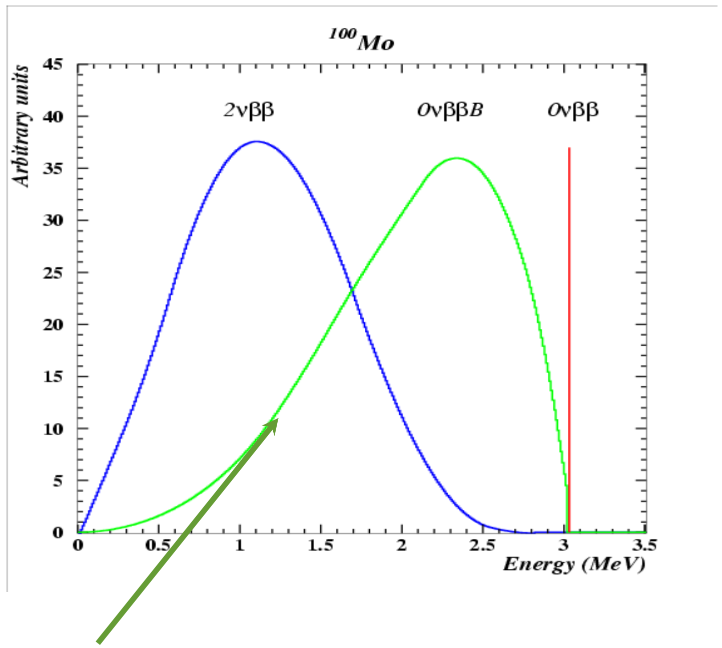
Open-minded search for any 0νββ mechanism

$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}(Q_{\beta\beta}, Z)\left|M^{0\nu}\right|^2 \eta^2$$

η can be due to $\langle m_\nu \rangle$,V+A, Majoron, SUSY, H^- or a combination of them



Topology can be used to disentangle underlying physics mechanism



Majoron

Topology detection is a more sensitive method for
phenomena with continuous spectra, e.g.
2νββ, 0νββB (Majoron)