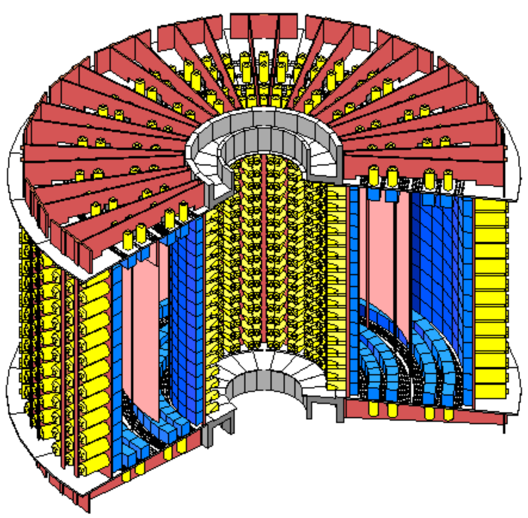
Double beta decay with NEMO3 and SuperNEMO

supernemo collaboration



Stefano Torre

University College London

for NEMO3 and SuperNEMO collaborations

Workshop on
Double Beta Decay and Neutrinos
Osaka, 14-17 Nov 2011

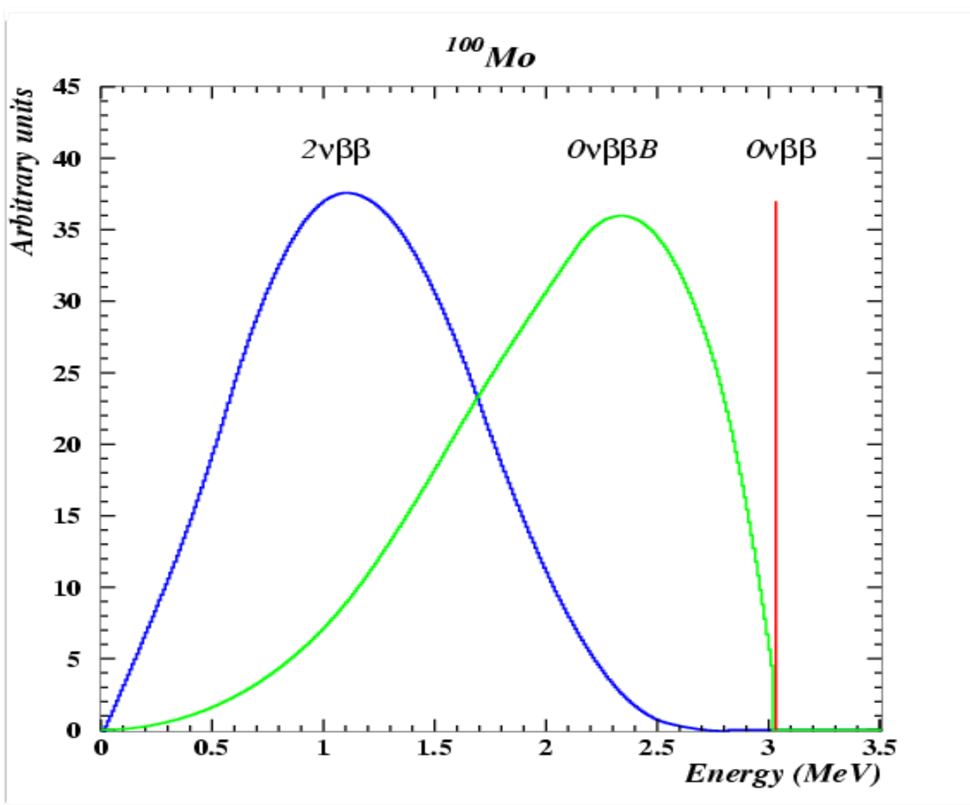
Outline

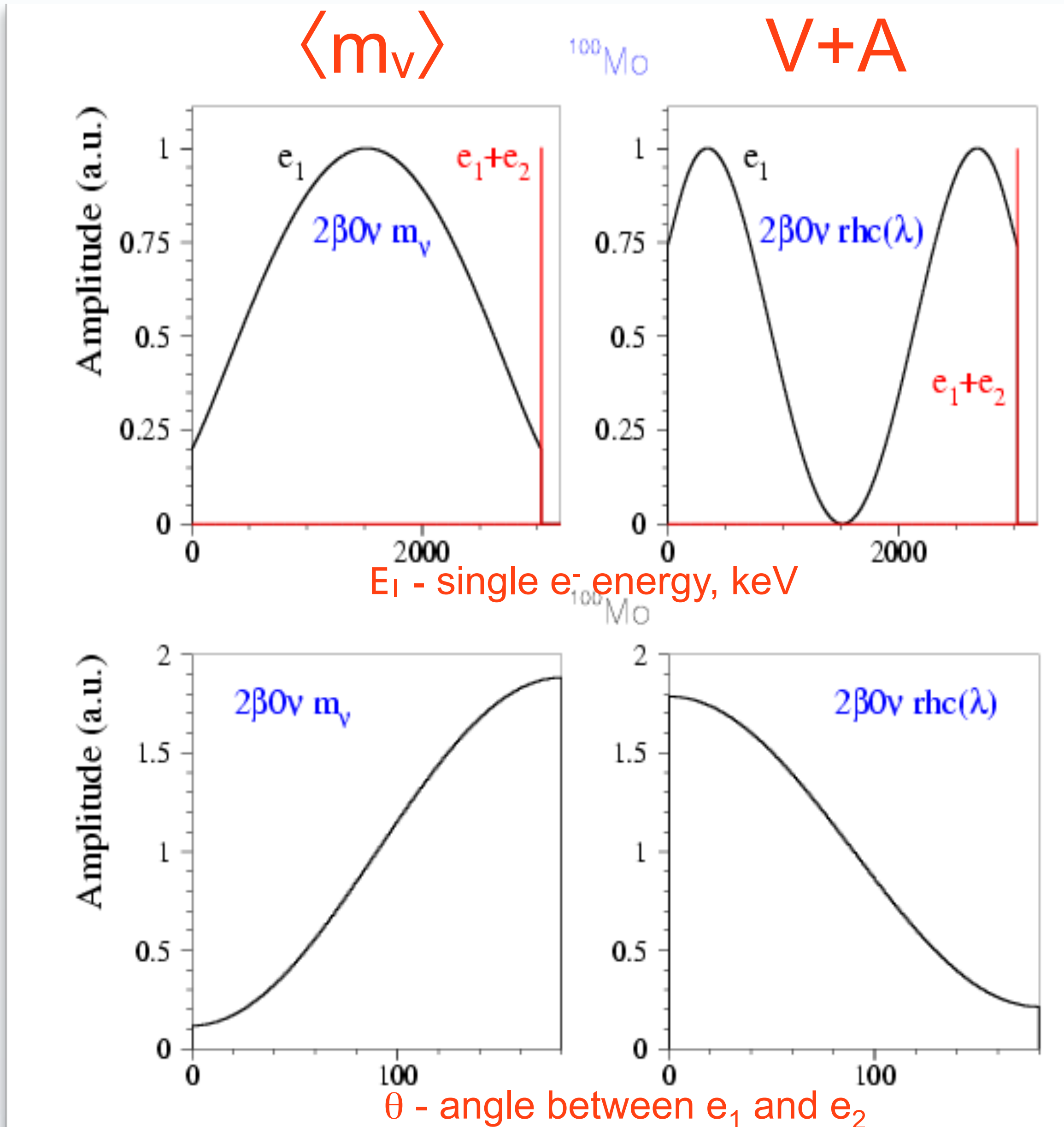
- $0\nu\beta\beta$ and $2\nu\beta\beta$
- Observation technique
- Nemo-3 Results
- SuperNEMO design and construction

Which processes cause the double beta decay?

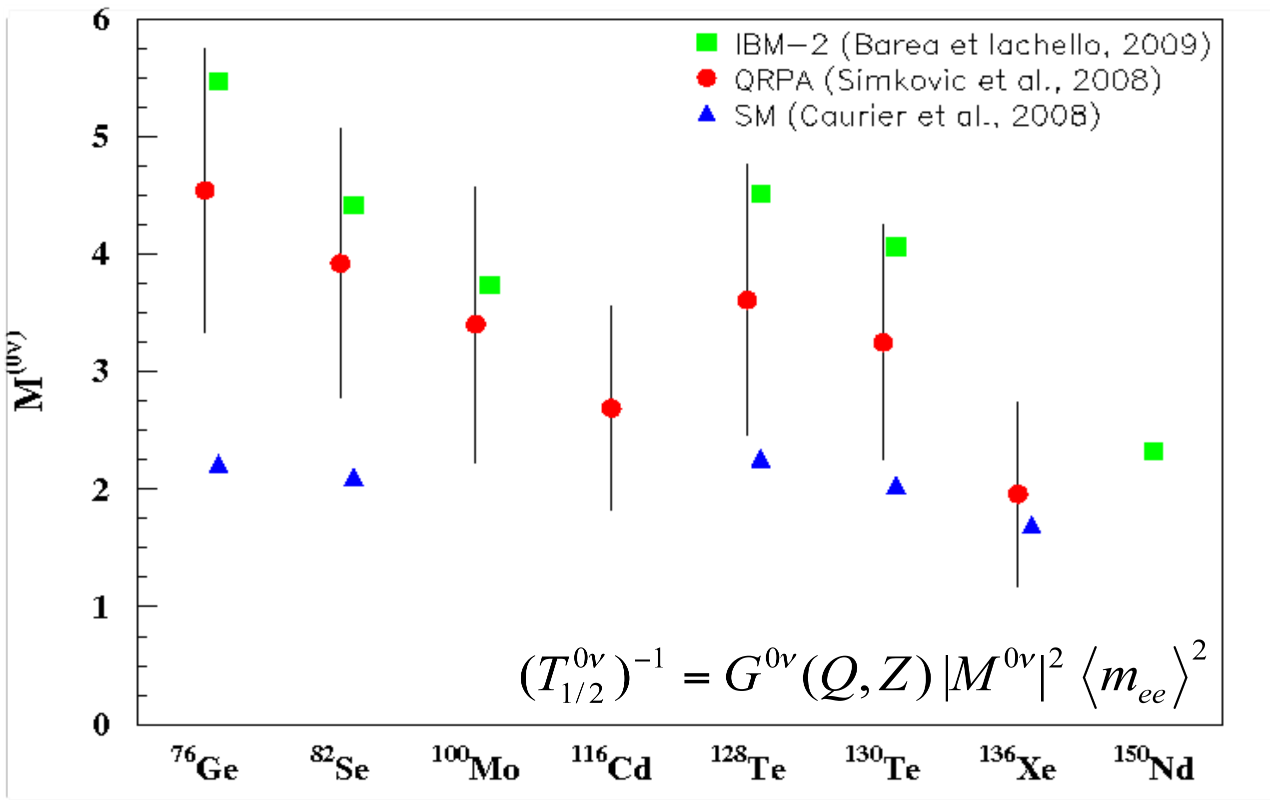
$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}\left(Q_{\beta\beta}, Z\right)\left|M^{0\nu}\right|^2 \eta^2$$

η can be due to mass mechanism, V+A, majoron, SUSY, ... with different topology in the final state





Measuring the Lepton Violating parameter



- phase space is known
- half life is measured
- need to know the Nuclear Matrix Element (NME)
- variation between models and Isotopes
- combine measurement from as many isotopes as possible

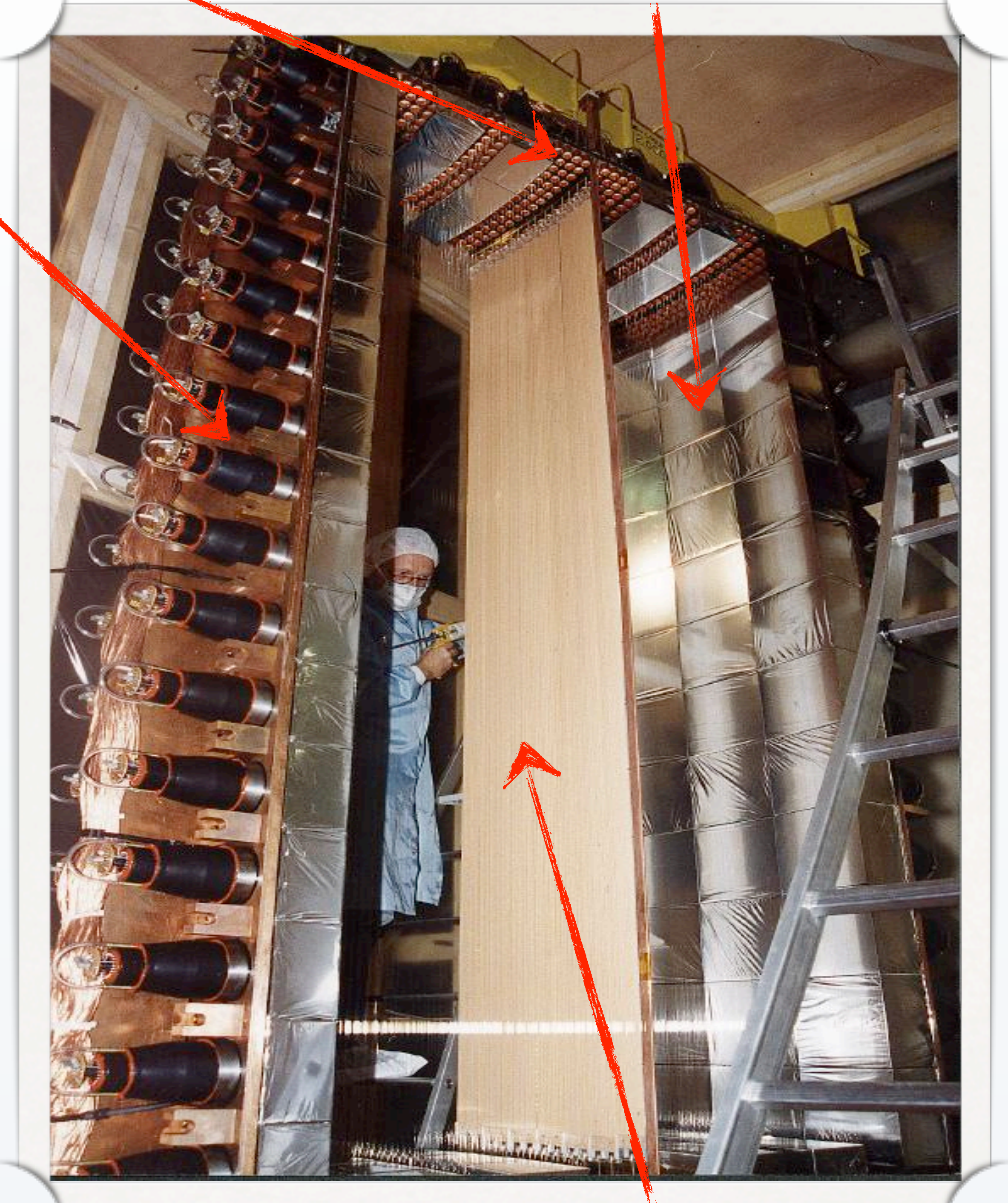
<u>Phase space factor</u>

J. Phys. G: Nucl. Part. Phys. 34 667 (2007)

Isotope $Q_{\beta\beta}$ (MeV)	^{48}Ca 4.27	^{76}Ge 2.04	^{82}Se 3.0	^{96}Zr 3.35	^{100}Mo 3.03	^{116}Cd 2.8	^{130}Te 2.53	^{136}Xe 2.48	^{150}Nd 3.37
$G^{0\nu}$ (10^{-15} yr^{-1})	75.8	7.6	33.5	69.7	54.5	58.9	52.8	56.3	249

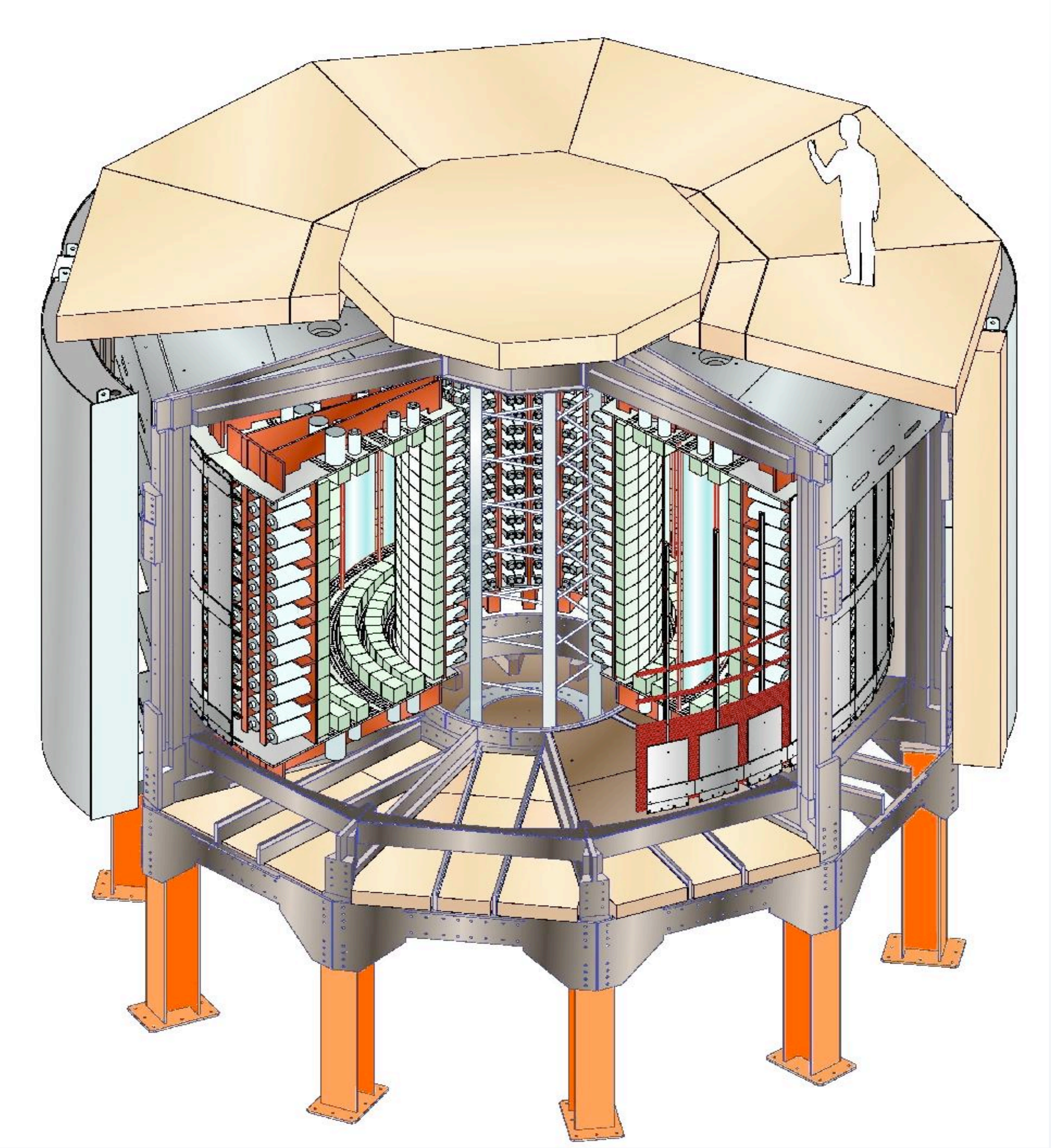
NEMO3

- use calorimeter for energy and time measurement
- use tracker for full event reconstruction
- identify e^-, e^+, ɣ, α
- 10 kg of ββ isotopes:
  - 7kg ^{100}Mo
  - 1kg ^{82}Se
  - smaller quantities of ^{116}Cd, ^{150}Nd, ^{48}Ca, ^{96}Zr, ^{130}Te

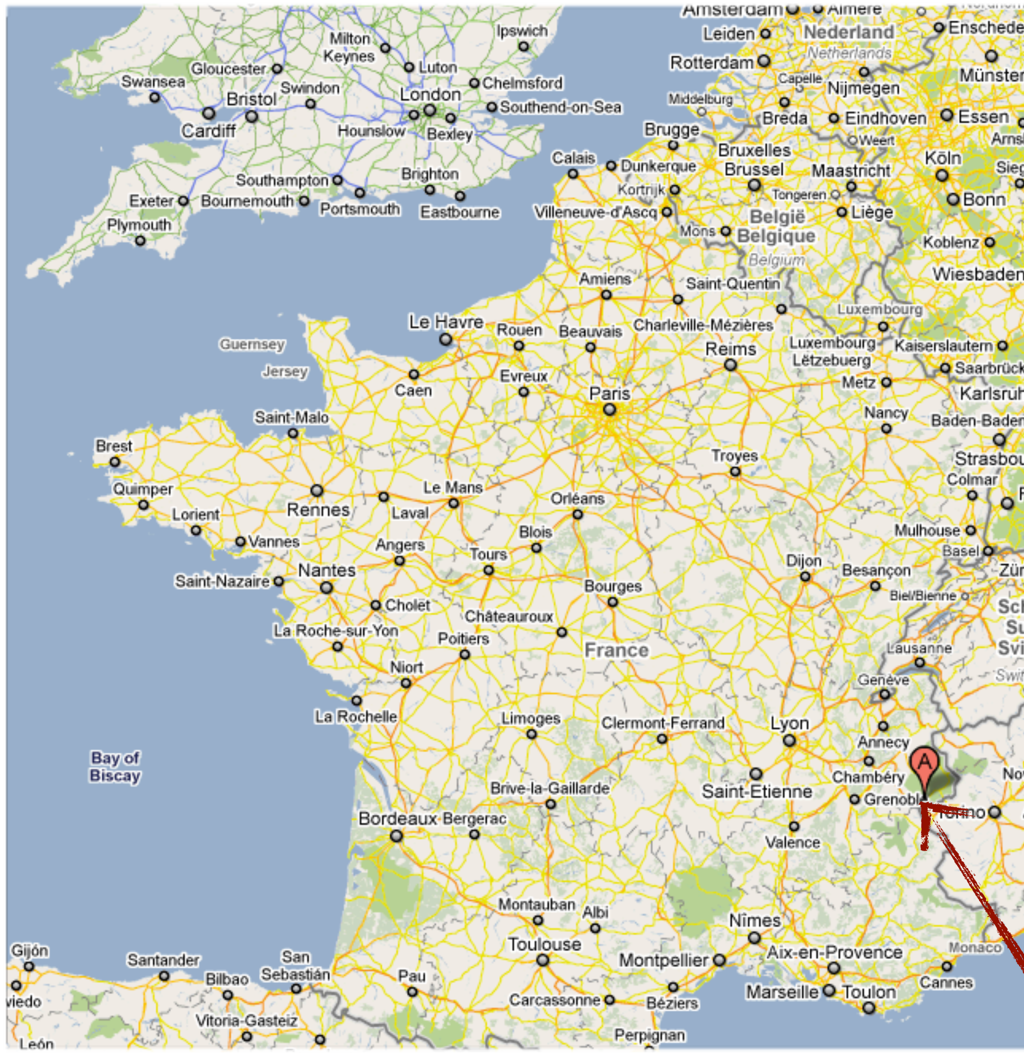


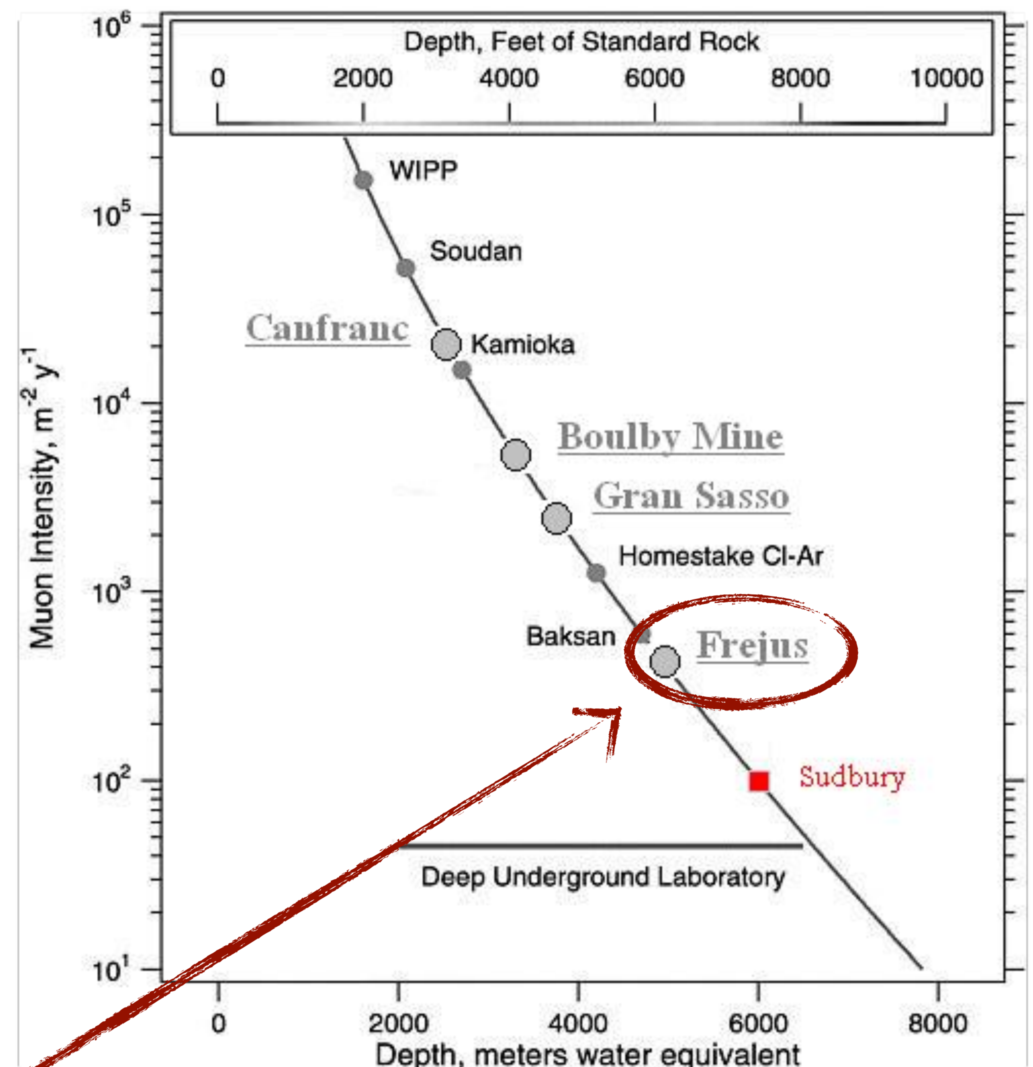
NEMO3

- source distributed on cylindrical surface
- drift wire chamber operated in geiger mode (6180 cells)
  - He + 4% ethyl alcohol + 1% Ar + 0.1%H_2O
- calorimeter made of 1940 plastic scintillators coupled to low radioactivity PMTs
- Magnetic field: 25 Gauss
- Gamma shield: iron
- Neutron shield:
  - 30cm borated water (external wall)
  - 40cm wood (top and bottom)



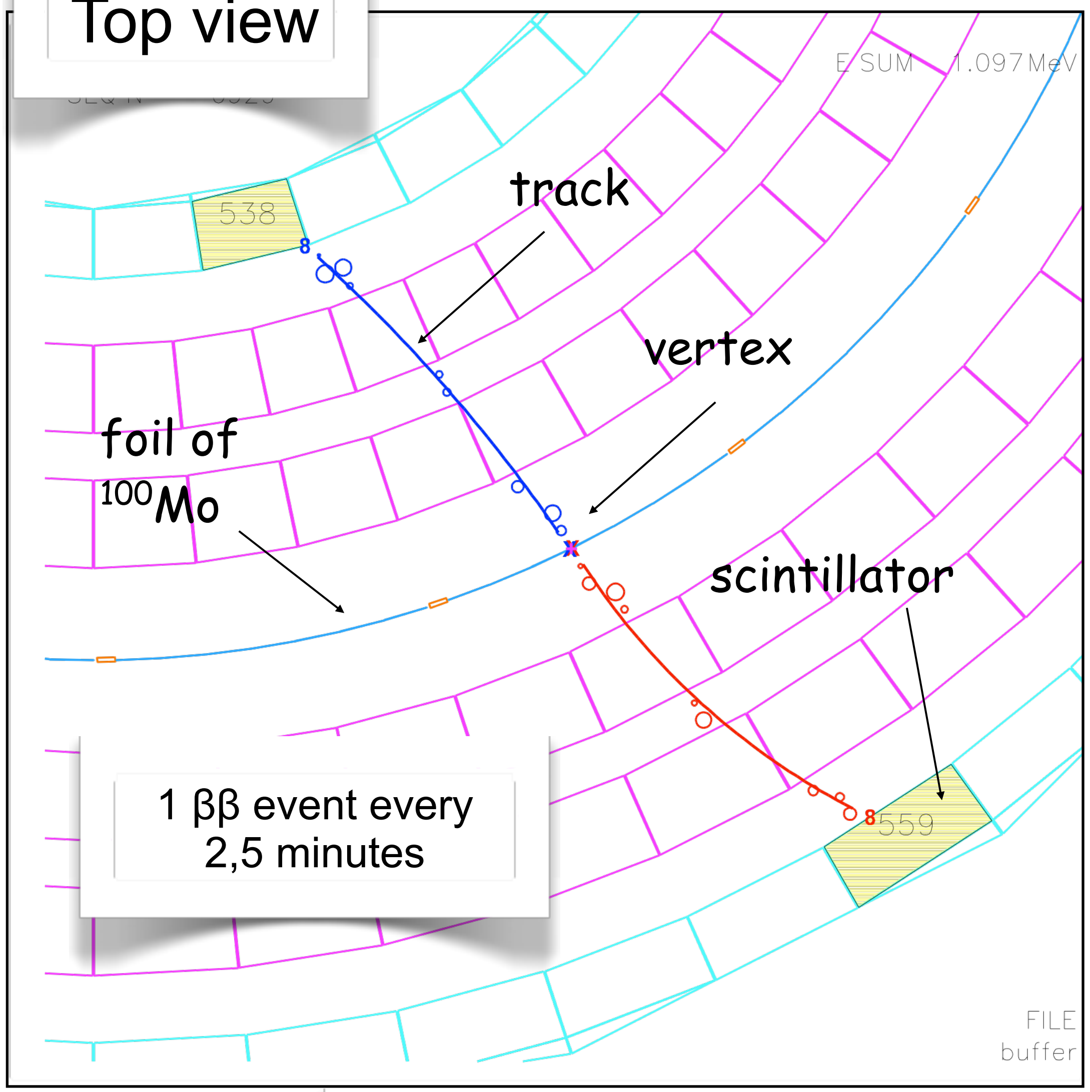
NEMO3



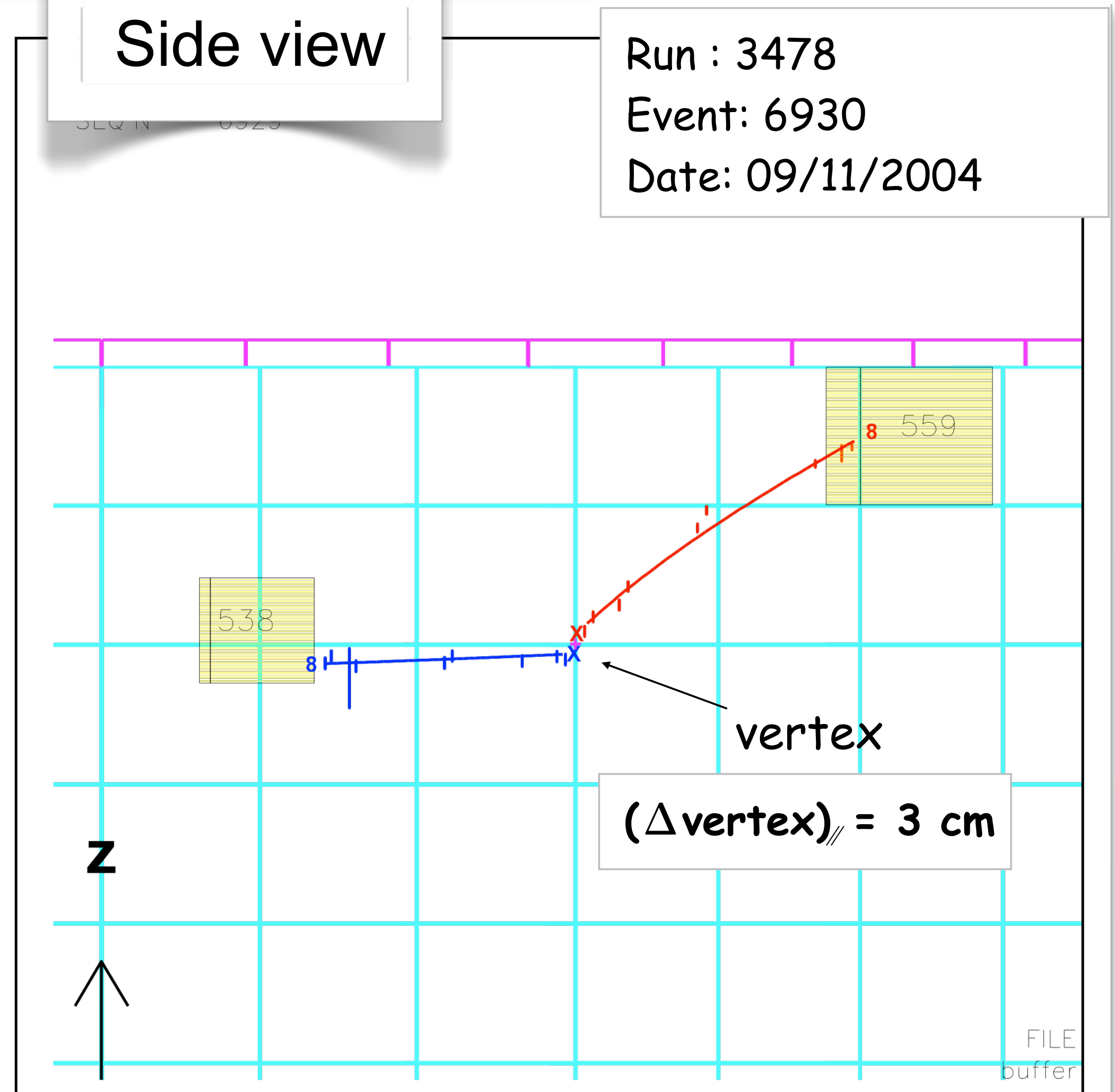


LSM Modane, France
(Tunnel Frejus, depth of ~4,800 mwe)

Selection of ββ events



1 ββ event every
2,5 minutes



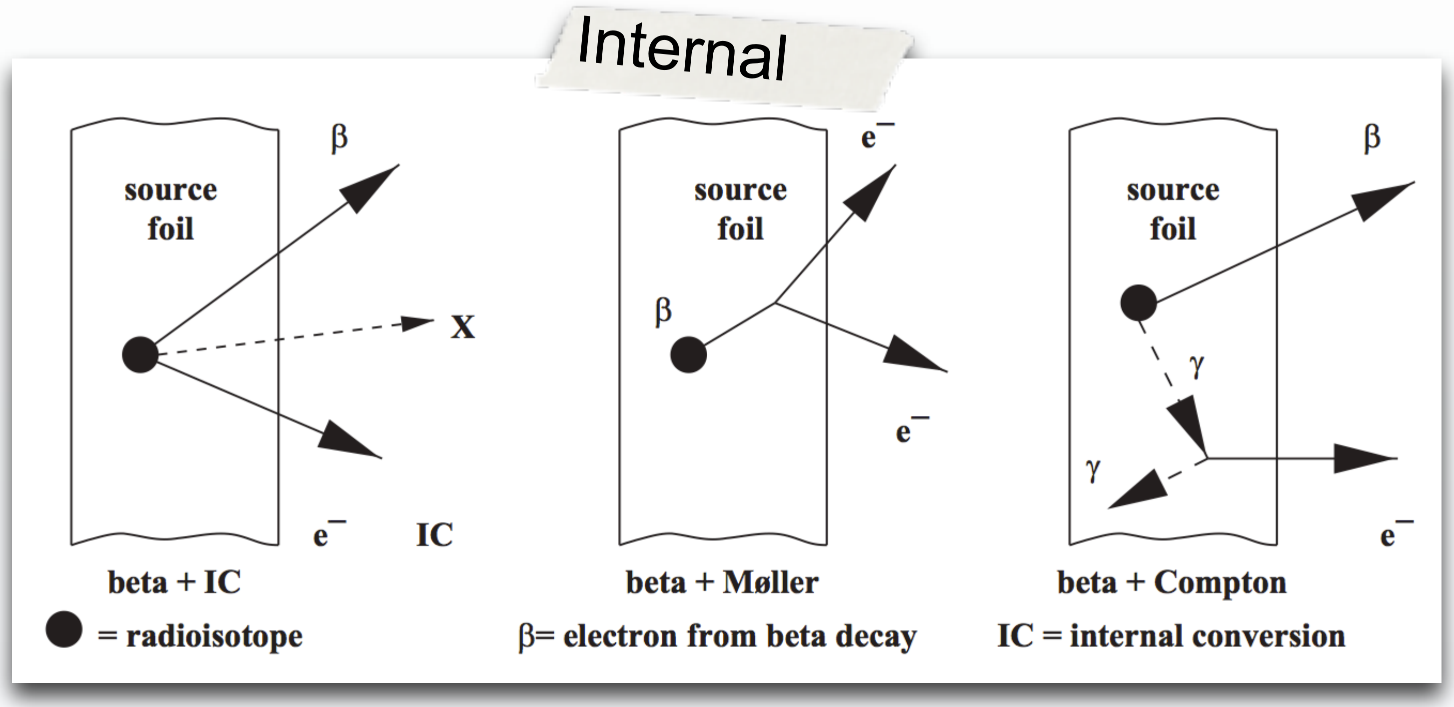
Criteria to select ββ events

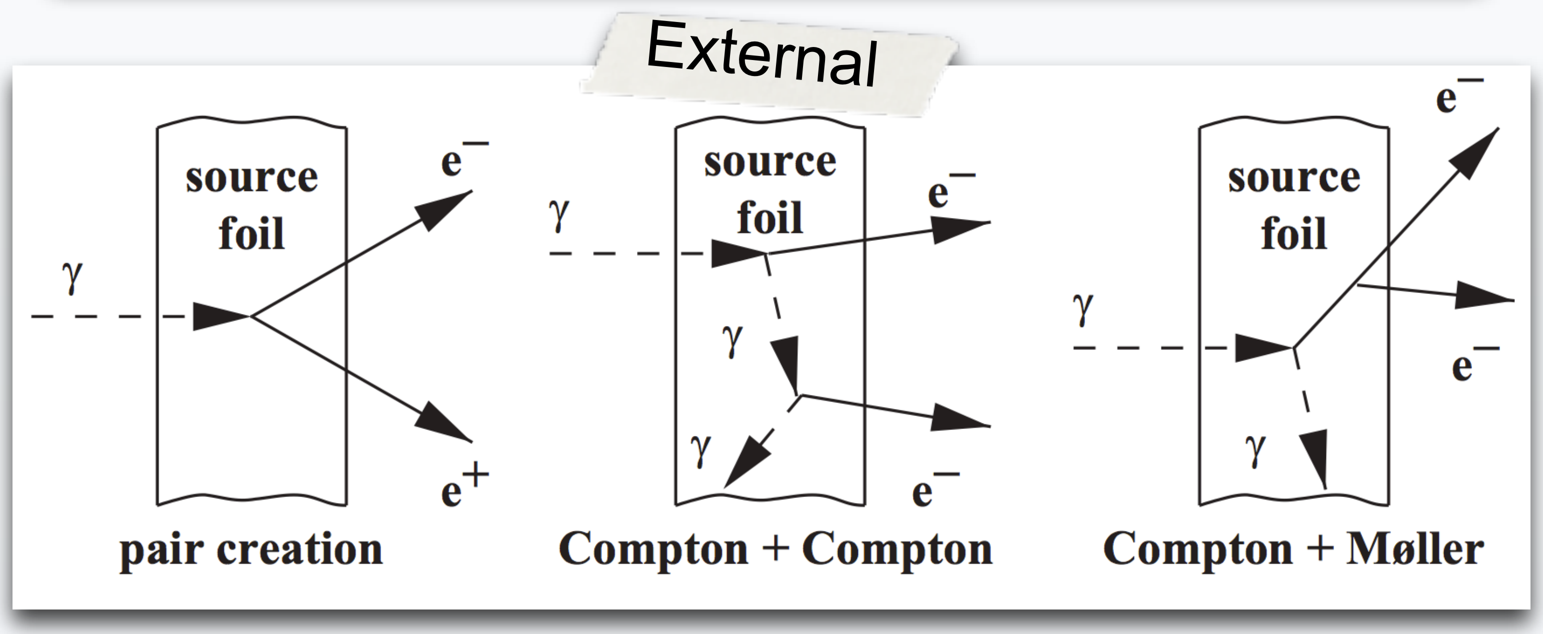
- 2 tracks with charge < 0
- 2 PMT, each > 200 keV
- PMT-Track association
- Common vertex

- Internal hypothesis (external event rejection)
- No other isolated PMT (γ rejection)
- No delayed track (^{214}Bi rejection)

Backgrounds

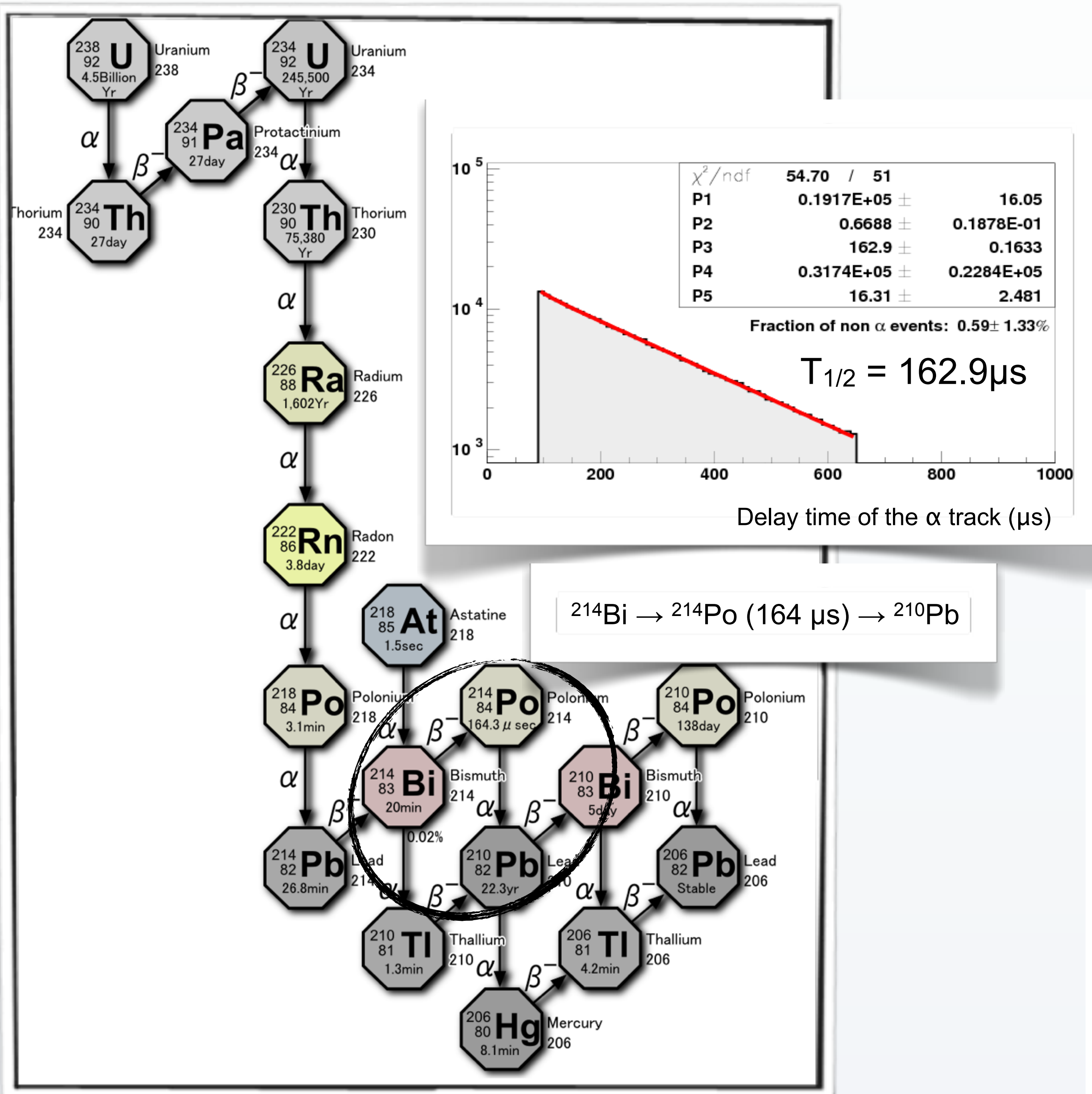
- Natural radioactivity
  - ^{238}U, ^{232}Th, ^{40}K, Rn
- Cosmics
- Neutrons





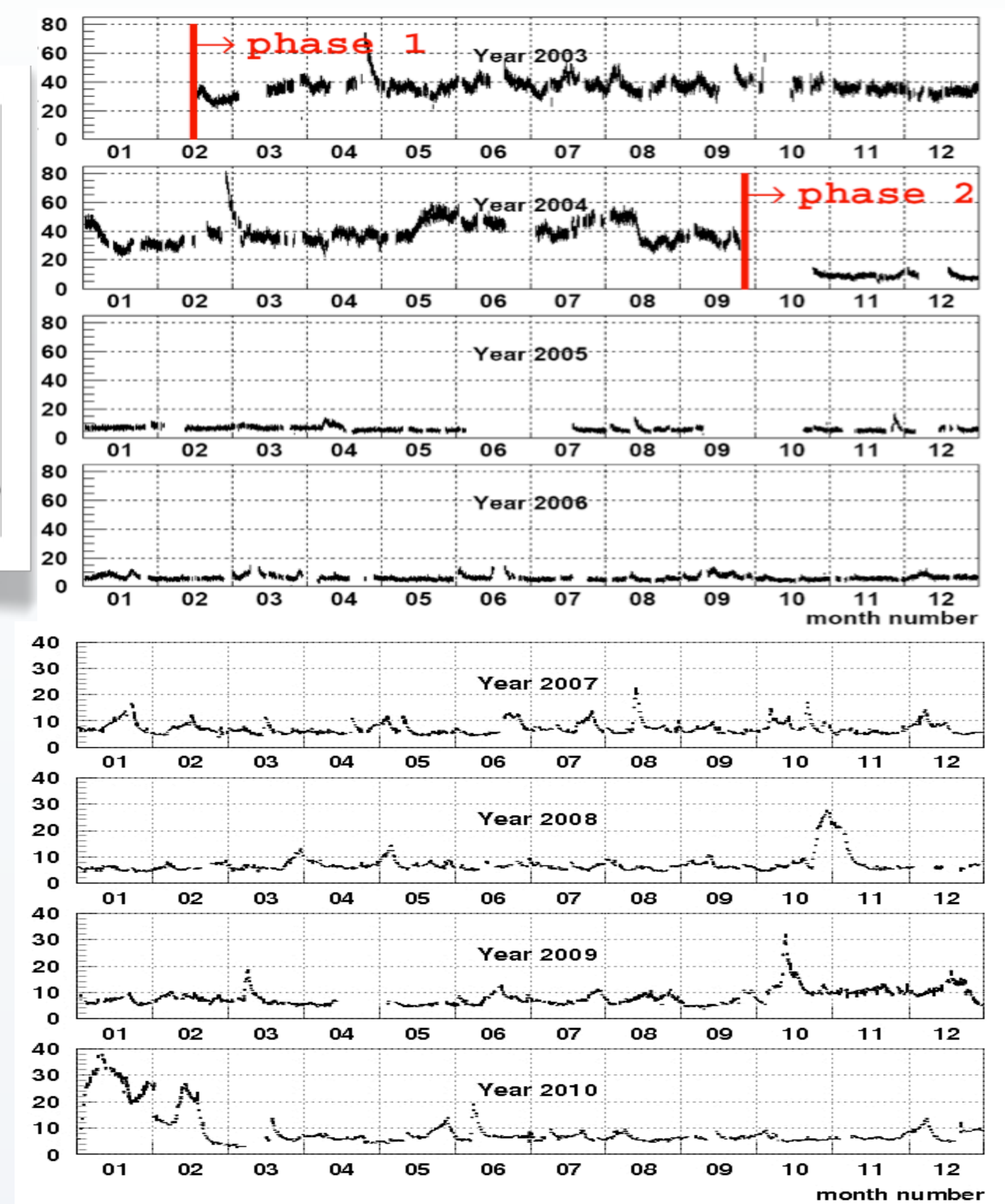
Background measurement in NEMO-3: NIM A606 (2009) 449

Background: Rn activity

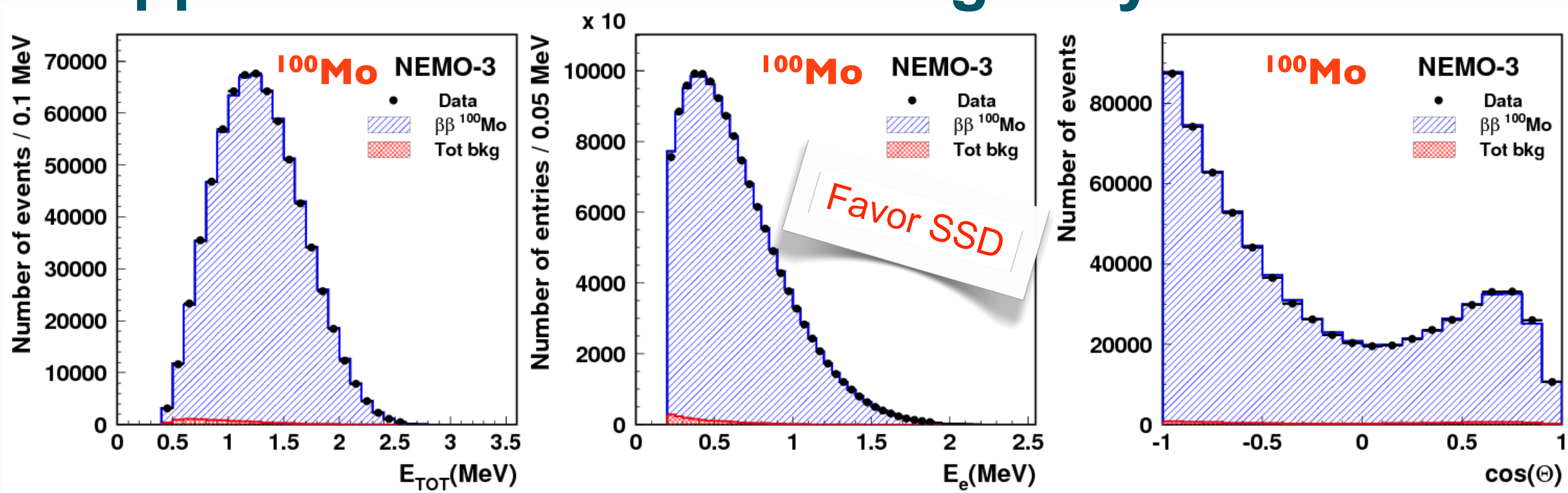


$^{214}Bi \rightarrow {}^{214}Po$ (164 μs) $\rightarrow {}^{210}Pb$

Measurements of ^{222}Rn activity in the gas of tracker (mBq/m^3)



2νββ ^{100}Mo Phase 2 data - 7kg x 4 years

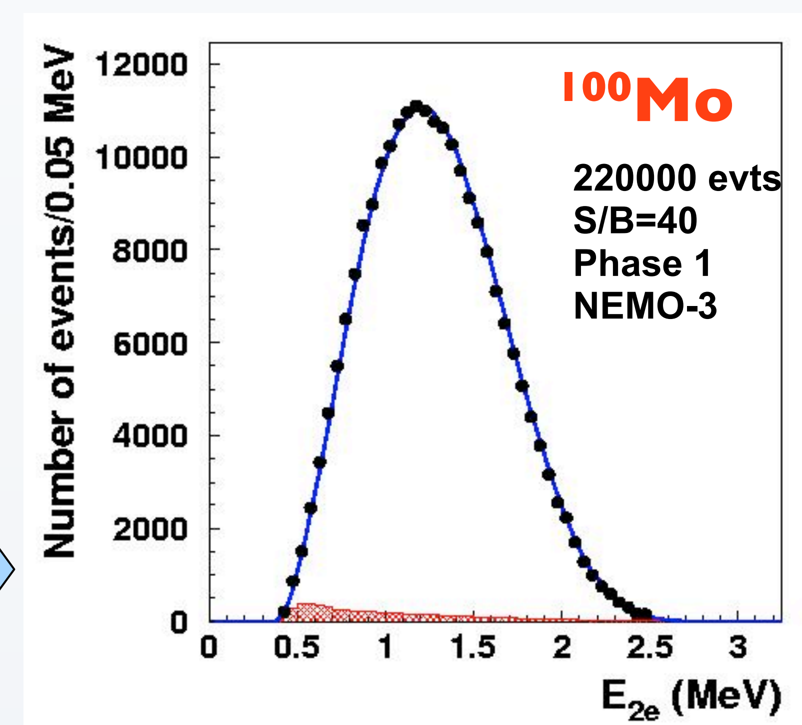


- 700000 two-electron events from ^{100}Mo foils
- S/B = 76
- ε(2ν2β) = 0.043

  $T_{1/2}$(2ν2β) = [7.16 ± 0.01 (stat)] 10^{18} y PRELIMINARY

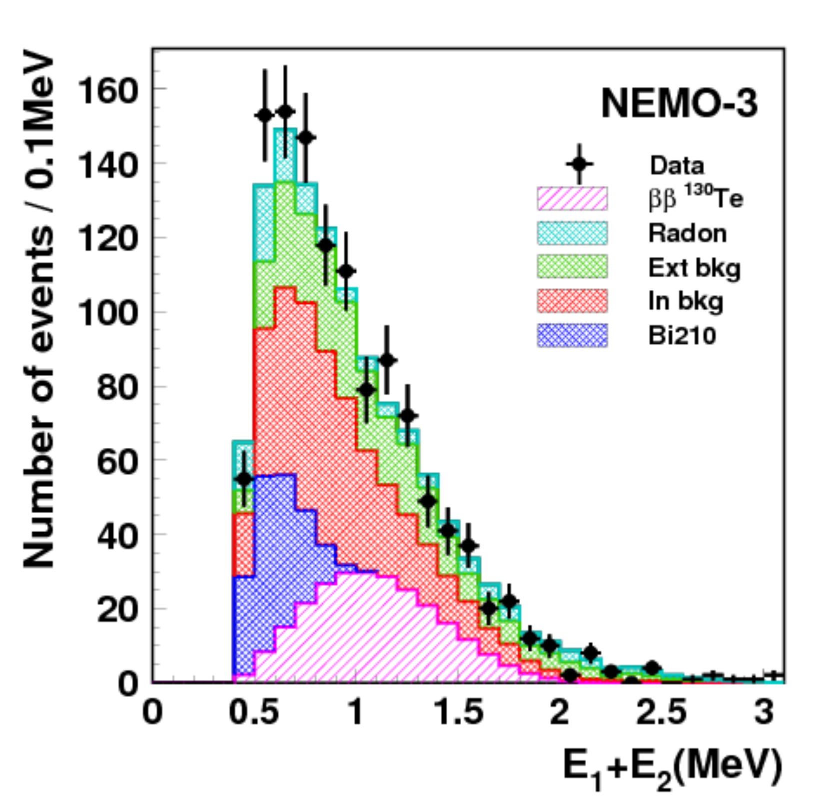
To be compared with the published NEMO-3 result
obtained with Phase 1 data
$T_{1/2}$ = [7.11 ± 0.02(stat) ± 0.54(syst)] 10^{18} y

Phys.Rev.Lett. 95(2005)483



2vββ Results

Isotope	Mass (g)	$Q_{\beta\beta}$(keV)	$T_{1/2}(2\nu)$ (10^{19}yrs)	S/B	Comment	Reference
^{82}Se	932	2996	9.6 ± 1.0	4	World's best!	Phys.Rev.Lett. 95(2005) 483
^{116}Cd	405	2809	2.8 ± 0.3	10	World's best!	
^{150}Nd	37	3367	0.9 ± 0.07	2.7	World's best!	Phys. Rev. C 80, 032501 (2009)
^{96}Zr	9.4	3350	2.35 ± 0.21	1	World's best!	Nucl.Phys.A 847(2010) 168
^{48}Ca	7	4271	4.4 ± 0.6	6.8 (h.e.)	World's best!	
^{100}Mo	6914	3034	0.71 ± 0.05	80	World's best!	Phys.Rev.Lett. 95(2005) 483
^{130}Te	454	2533	70 ± 14	0.5	First direct detection!!!	Phys. Rev. Lett. 107, 062504 (2011)

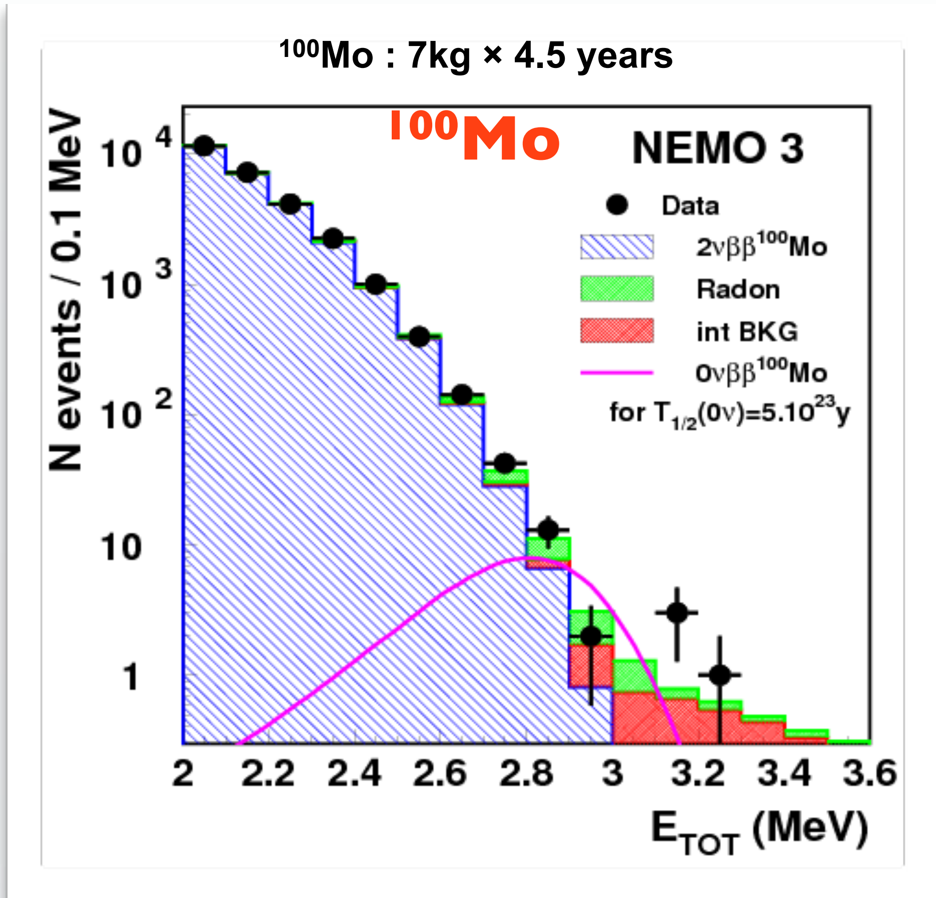


First direct observation: 7.7σ significance

Indirect observations:
- ~2.7 x 10^{21} yrs in 10^9 yr old rocks
- ~8 x10^{20} yrs in 10^7-10^8 yr old rocks

Indication from MIBETA Coll in isotopically enriched crystals: 6.1 ± 1.4(st) $^{+2.9}_{-3.5}$(sy) x10^{20} yrs

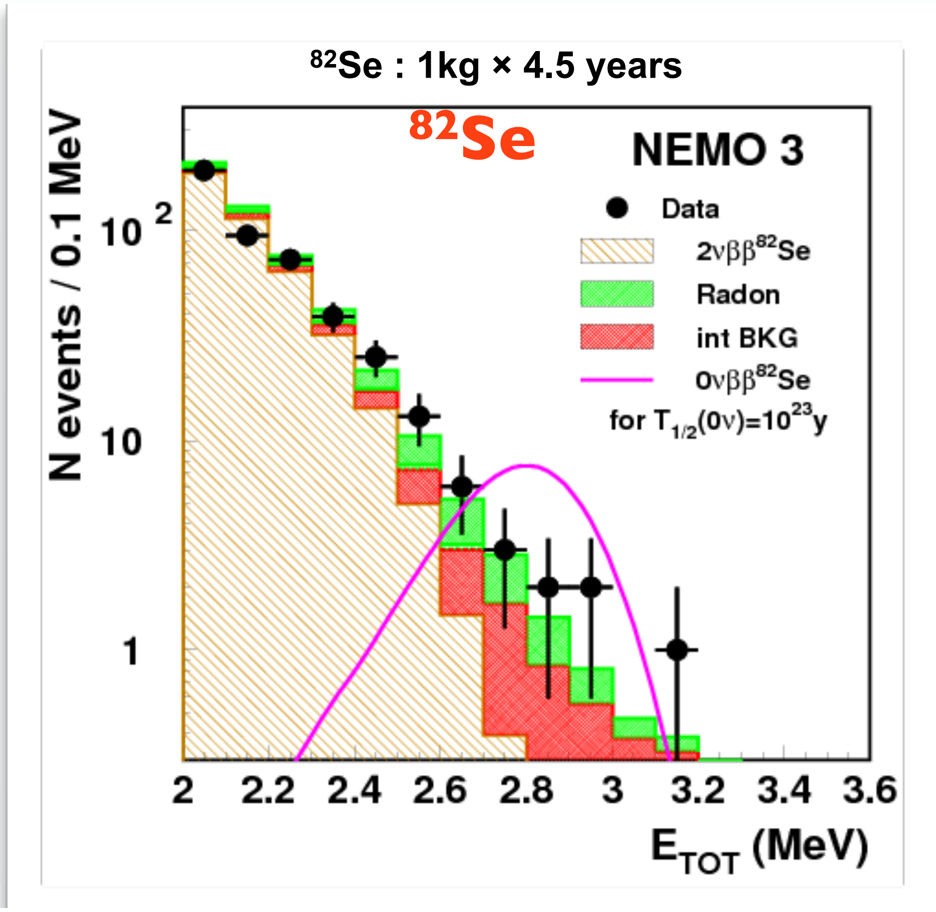
Search for 0νββ



Total mean 0ν efficiency ε = 0.13

^{100}Mo $T_{1/2}(0\nu) > 1.0 \cdot 10^{24}$ y @90% C.L.

<mν> < 0.31 – 0.96 eV NME [1-5]



Total mean 0ν efficiency ε = 0.14

^{82}Se $T_{1/2}(0\nu) > 3.2 \cdot 10^{23}$ y @90% C.L.

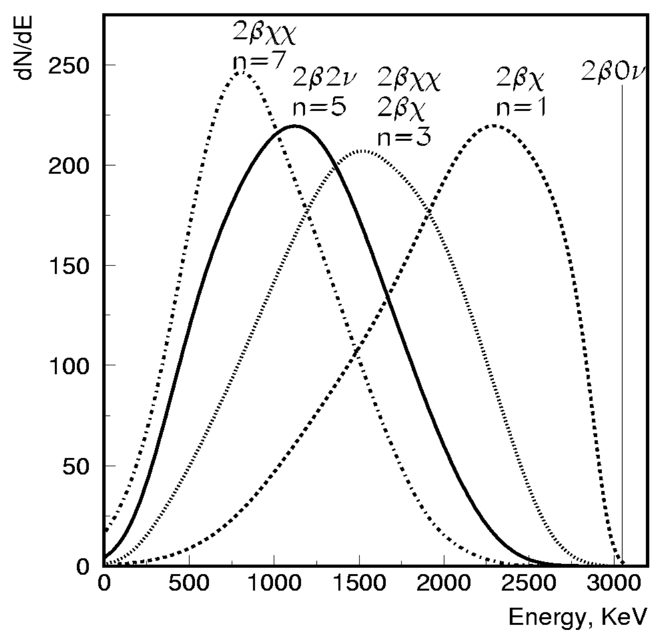
<mν> < 0.94 – 1.71 eV NME [1-4]

<mν> < 2.6 eV NME [6]

NME

[1] QRPA M.Kortelainen and J.Suhonen, Phys.Rev. C 75 (2007) 051303(R)
[2] QRPA M.Kortelainen and J.Suhonen, Phys.Rev. C 76 (2007) 024315
[3] QRPA F.Simkovic, et al. Phys.Rev. C 77 (2008) 045503
[4] IBM2 J.Barrea and F.Iachello Phys.Rev.C 79(2009)044301
PHFB [5] P.K. Rath et al., Phys. Rev. C 82 (2010) 064310
SM [6] E.Caurrier et al. Phys.Rev.Lett 100 (2008) 052503

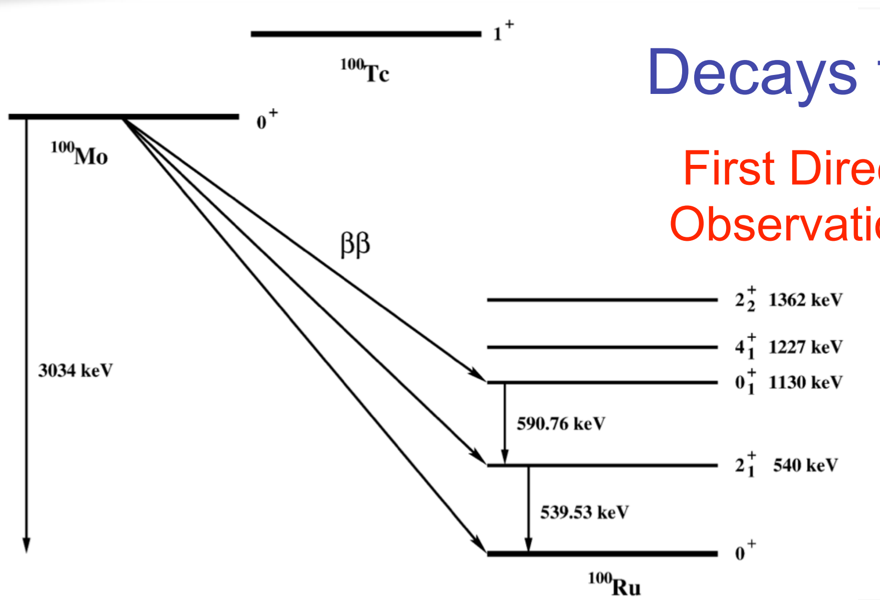
Majorons, V+A currents and excited states



Majoron emission would distort the shape of the energy sum spectrum

	V+A*	n=1**	n=2**	n=3**	n=7**
Mo	$>5.7\cdot10^{23}$ $\lambda<1.4\cdot10^{-6}$	$>2.7\cdot10^{22}$ $G_{ee}<(0.4-1.8)\cdot10^{-4}$	$>1.7\cdot10^{22}$	$>1.0\cdot10^{22}$	$>7\cdot10^{19}$
Se	$>2.4\cdot10^{23}$ $\lambda<2.0\cdot10^{-6}$	$>1.5\cdot10^{22}$ $G_{ee}<(0.7-1.9)\cdot10^{-4}$	$>6\cdot10^{21}$	$>3.1\cdot10^{21}$	$>5\cdot10^{20}$

n: spectral index, limits on half-life in years
* Phase I+Phase II data (including 2008)
** Phase I data, ***R.Arnold et al. Nucl. Phys. A765 (2006) 483***



Decays to excited states have several photons in final state

First Direct Observation

$T_{1/2}^{2\nu}(0^+ \rightarrow 0^+_1) = 5.7^{+1.3}_{-0.9}$ (stat) ± 0.8 (syst) × 10^{20} y

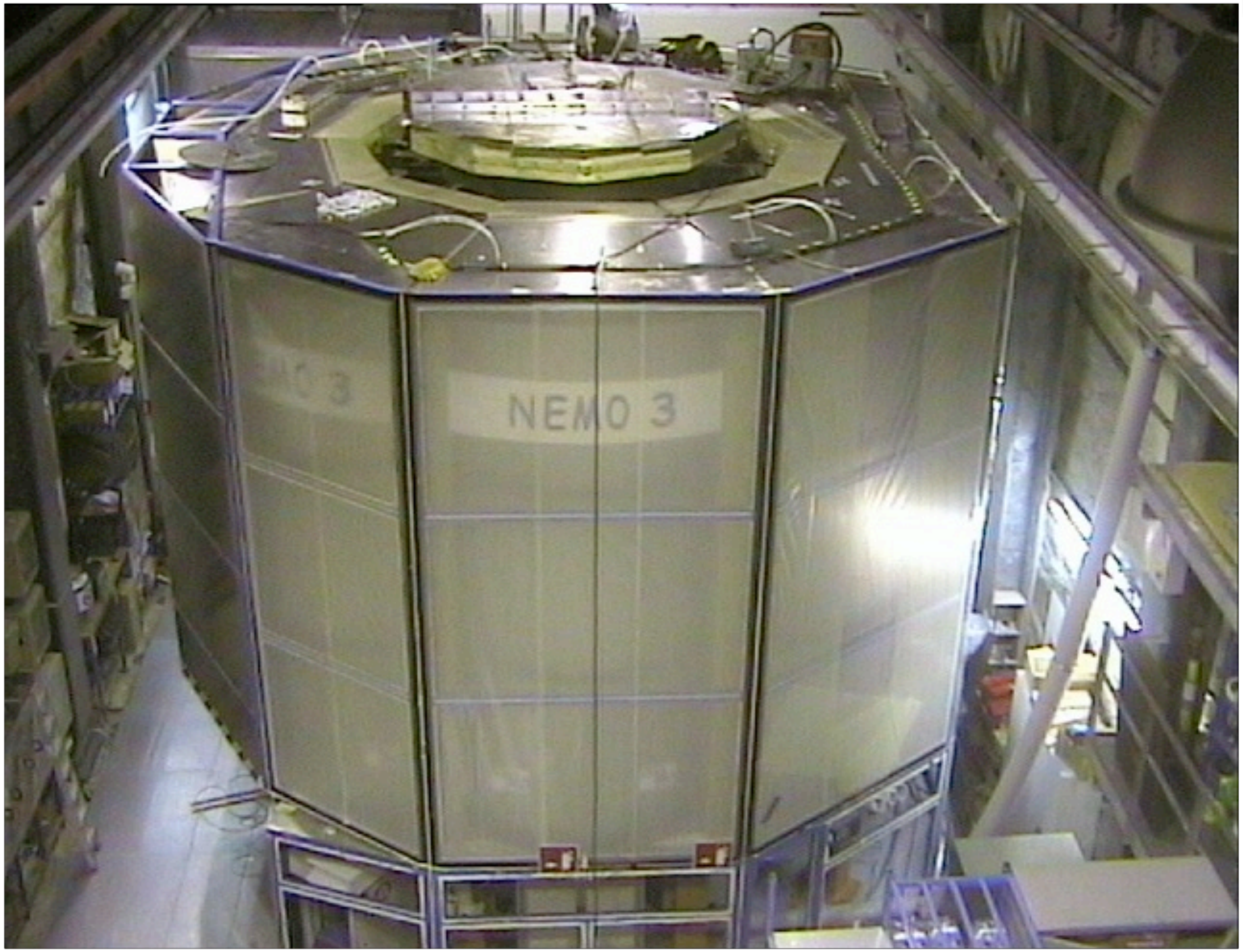
$T_{1/2}^{0\nu}(0^+ \rightarrow 0^+_1) > 8.9 \times 10^{22}$ y @ 90% C.L.

$T_{1/2}^{2\nu}(0^+ \rightarrow 2^+_1) > 1.1 \times 10^{21}$ y @90% C.L.

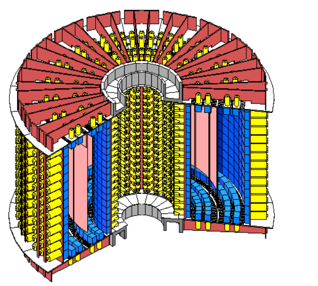
$T_{1/2}^{0\nu}(0^+ \rightarrow 2^+_1) > 1.6 \times 10^{23}$ y @ 90% C.L.

Nuclear Physics A781 (2006) 209-226.

12th January 2011: So long NEMO3



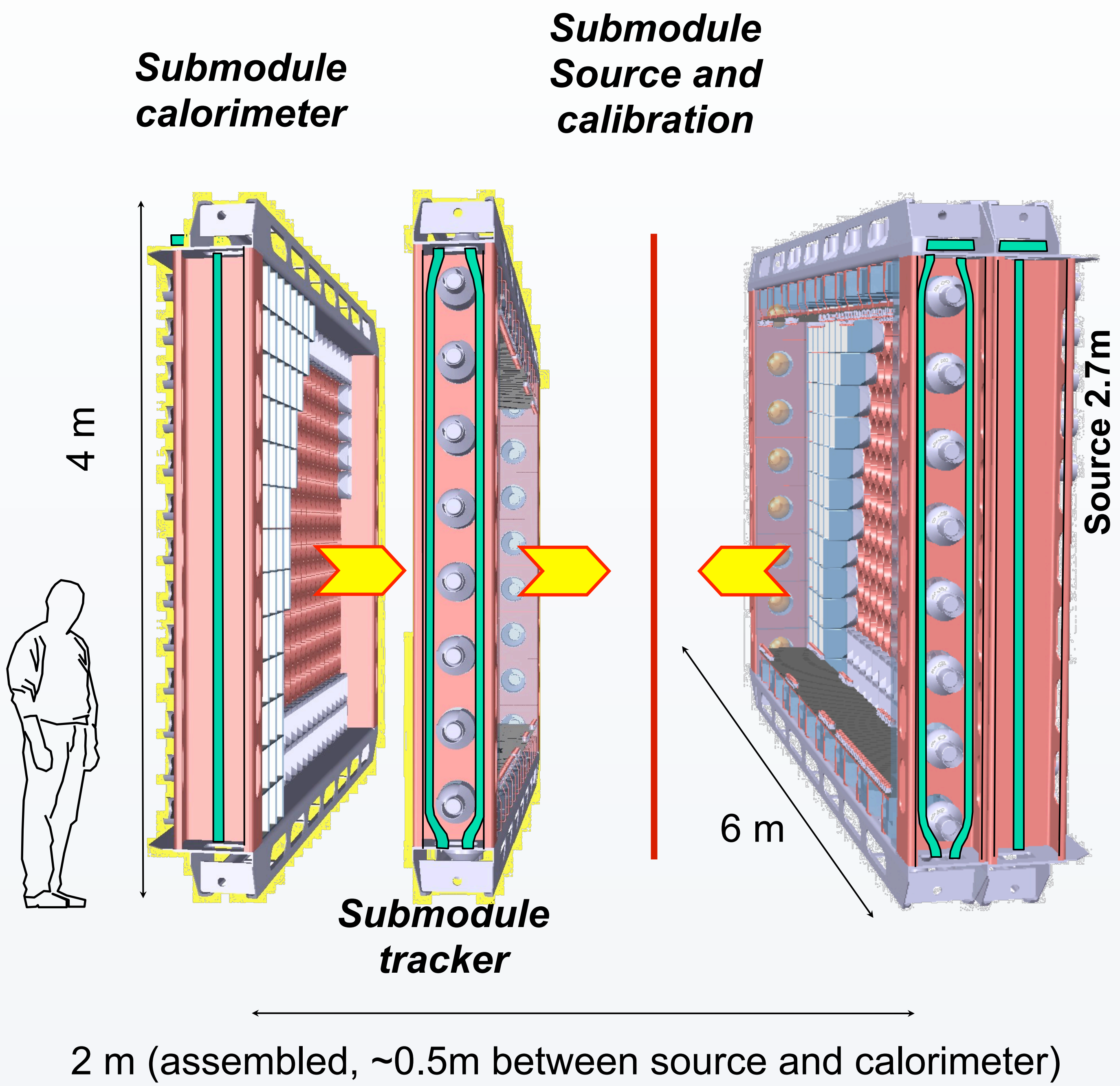
From NEMO to SuperNEMO



NEMO-3	R&D since 2006 →	SuperNEMO
^{100}Mo	Isotope	^{82}Se (or ^{150}Nd or ^{48}Ca)
7 kg	Isotope mass M	100+ kg
^{208}Tl: ~ 100 μBq/kg ^{214}Bi: < 300 μBq/kg	Contaminations in the ββ foil	^{208}Tl ≤ 2 μBq/kg ^{214}Bi ≤ 10 μBq/kg
Rn: 5 mBq/m^3	Rn in the tracker	Rn ≤ 0.15 mBq/m^3
8% @ 3MeV	Calorimeter energy resolution (FWHM)	4% @ 3 MeV
$T_{1/2}(\beta\beta0\nu) > 1÷2 \times 10^{24}$ y $<m_\nu> < 0.3 – 0.9$ eV	Sensitivity	$T_{1/2}(\beta\beta0\nu) > 1 \times 10^{26}$ y $<m_\nu> < 0.04 - 0.1$ eV

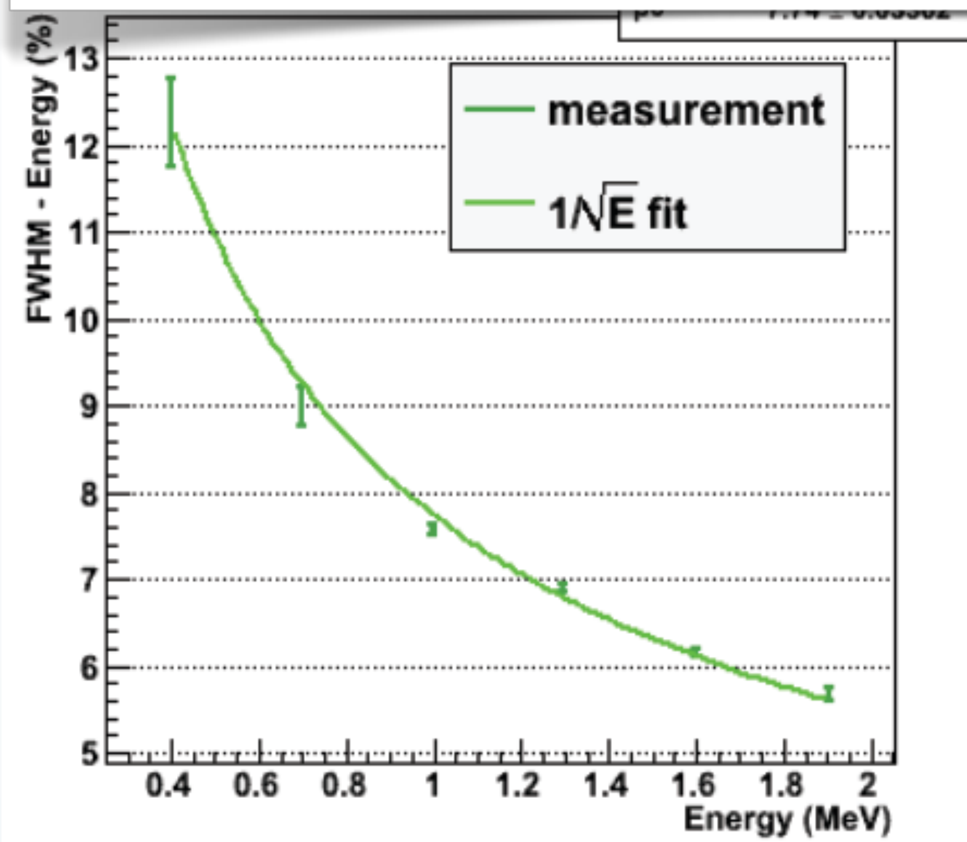
SuperNEMO

- Modular design
  - 20 modules, each with 5kg of isotope
- Each Module:
  - Source: (40mg/cm^2) 4x2.7m^2
    - ^{82}Se (High $Q_{\beta\beta}$, long $T_{1/2}(2\nu)$, proven enrichment technology)
    - ^{150}Nd, ^{48}Ca being looked at
  - Tracking
    - drift chamber ~2000 cells in Geiger mode
  - Calorimeter:
    - 550 PMTs + scintillators
  - Module surrounded by water and passive shielding

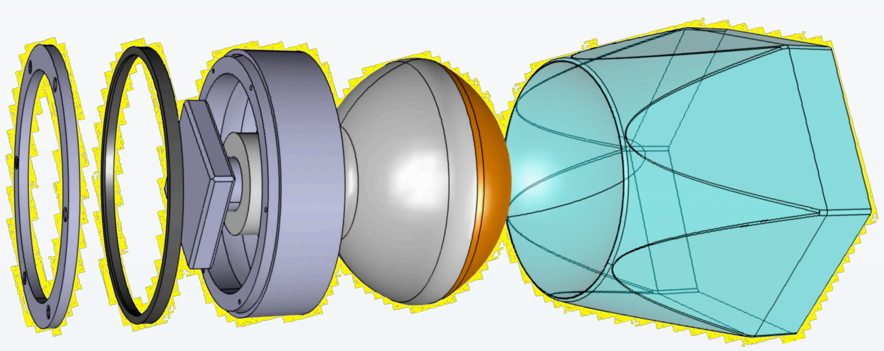


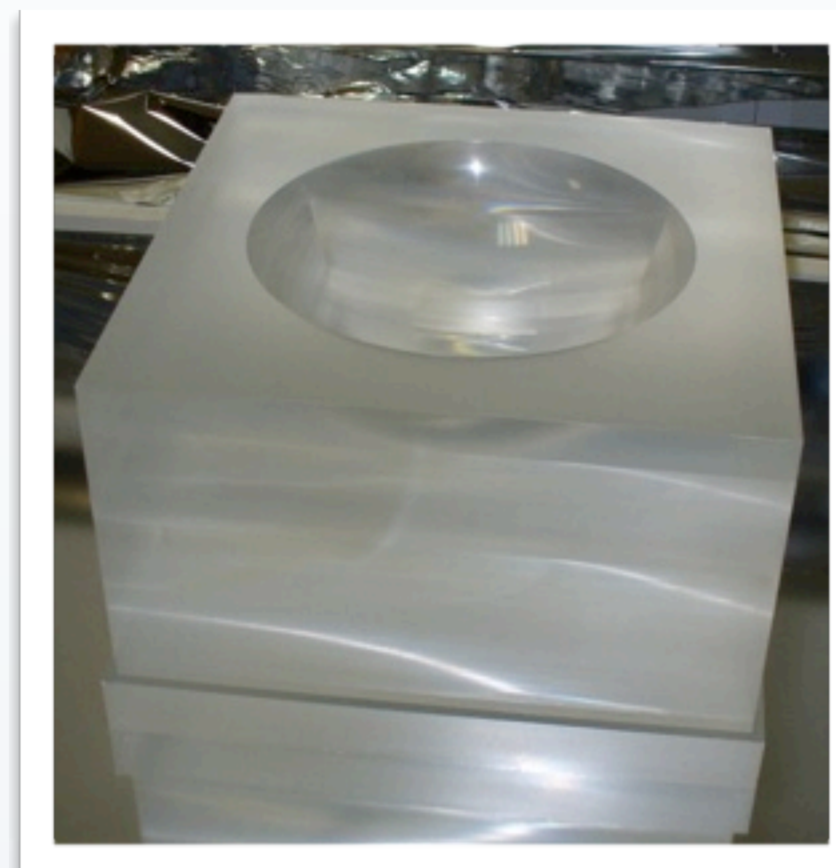
Main calorimeter walls design

$\Delta E/E$ ~ 7.2% (FWHM) at 1 MeV equiv. to 4% @ $Q_{\beta\beta}$ = 3 MeV



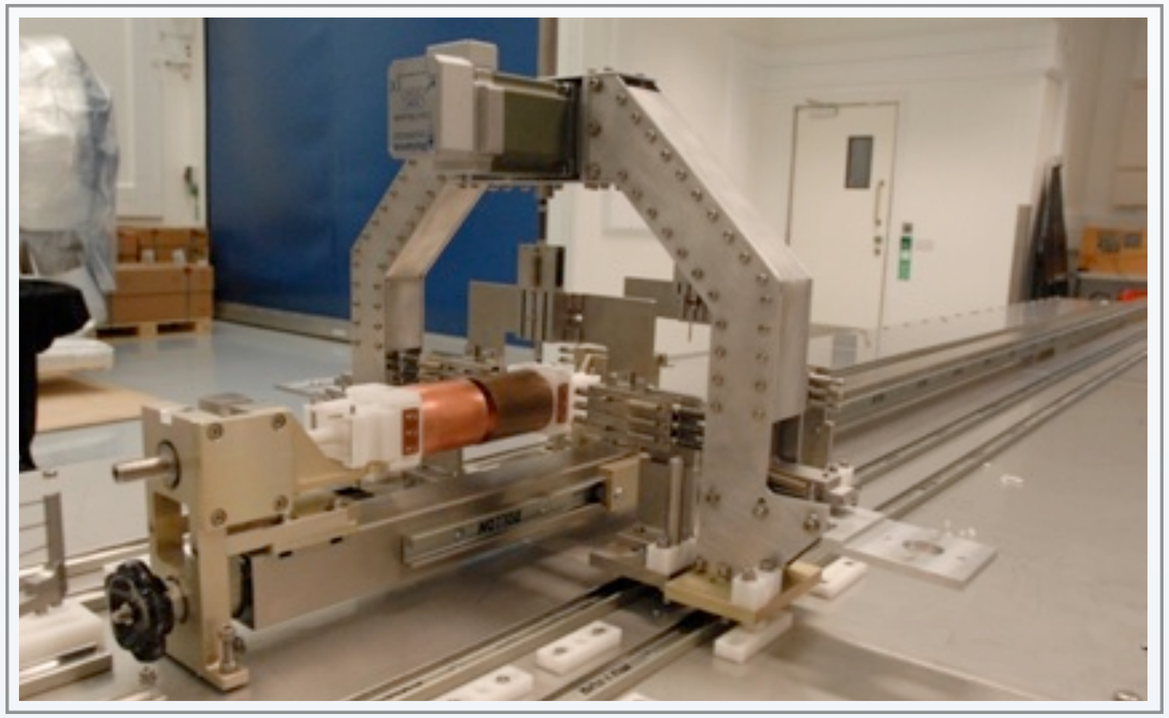
Required resolution has now been reached on hexagonal as well as cubic blocks

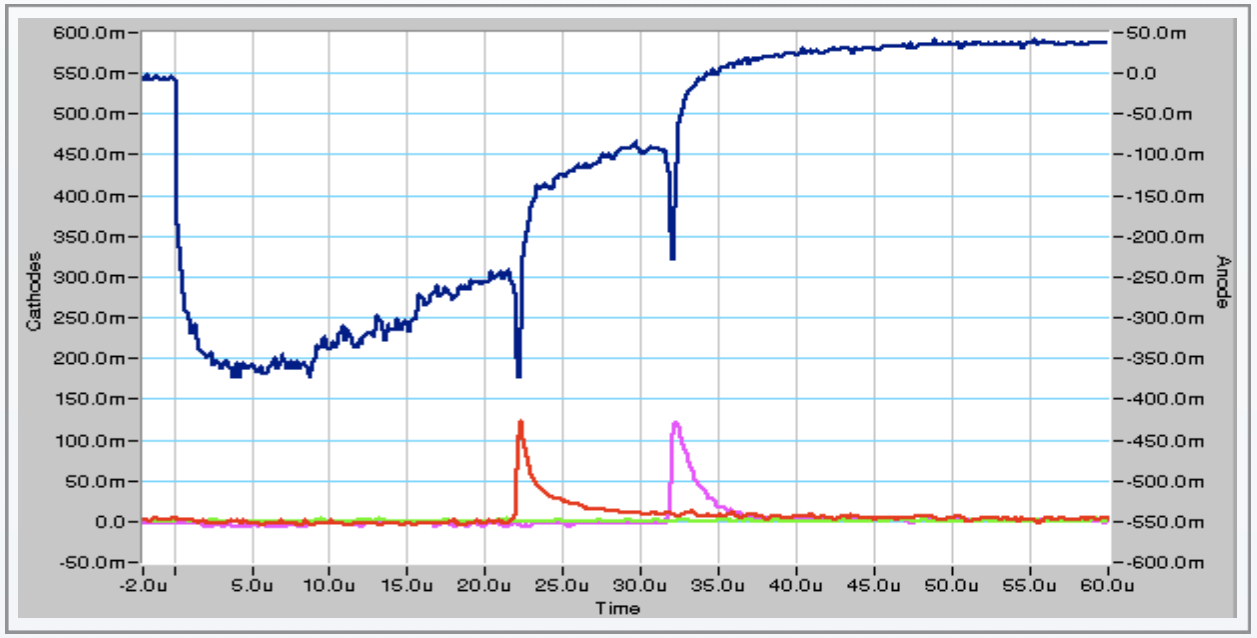




Tracker R&D

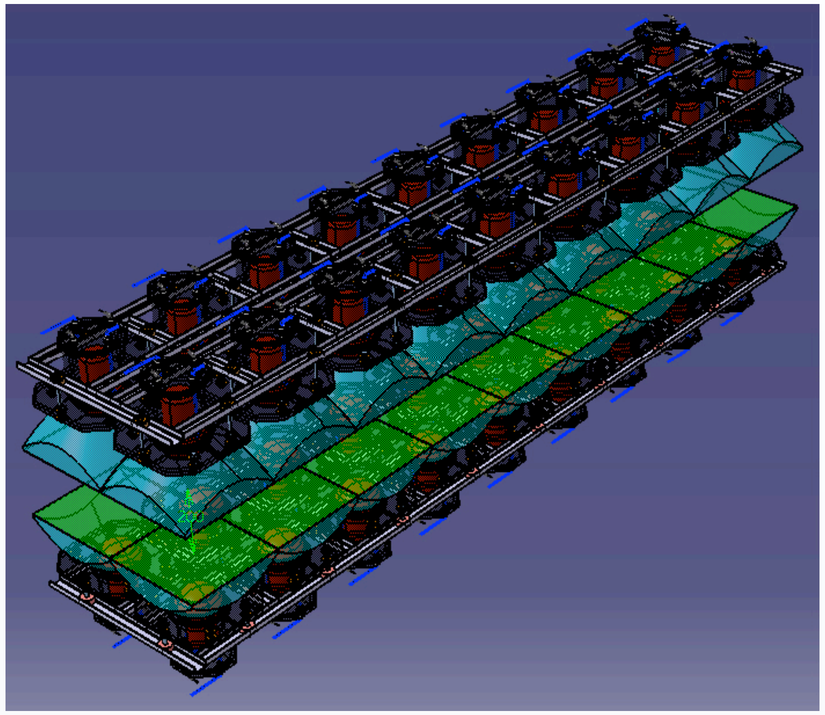
- Basic design developed and verified with several prototypes
  - Resolution: 0.7mm transverse, 1cm longitudinal
  - Cell efficiency > 98%
- Automated wiring robot design to mass produce at ultra low background condition
- Readout electronic being developed right now:
  - Allow for single and double cathodes readout
  - Differentiate anode signal

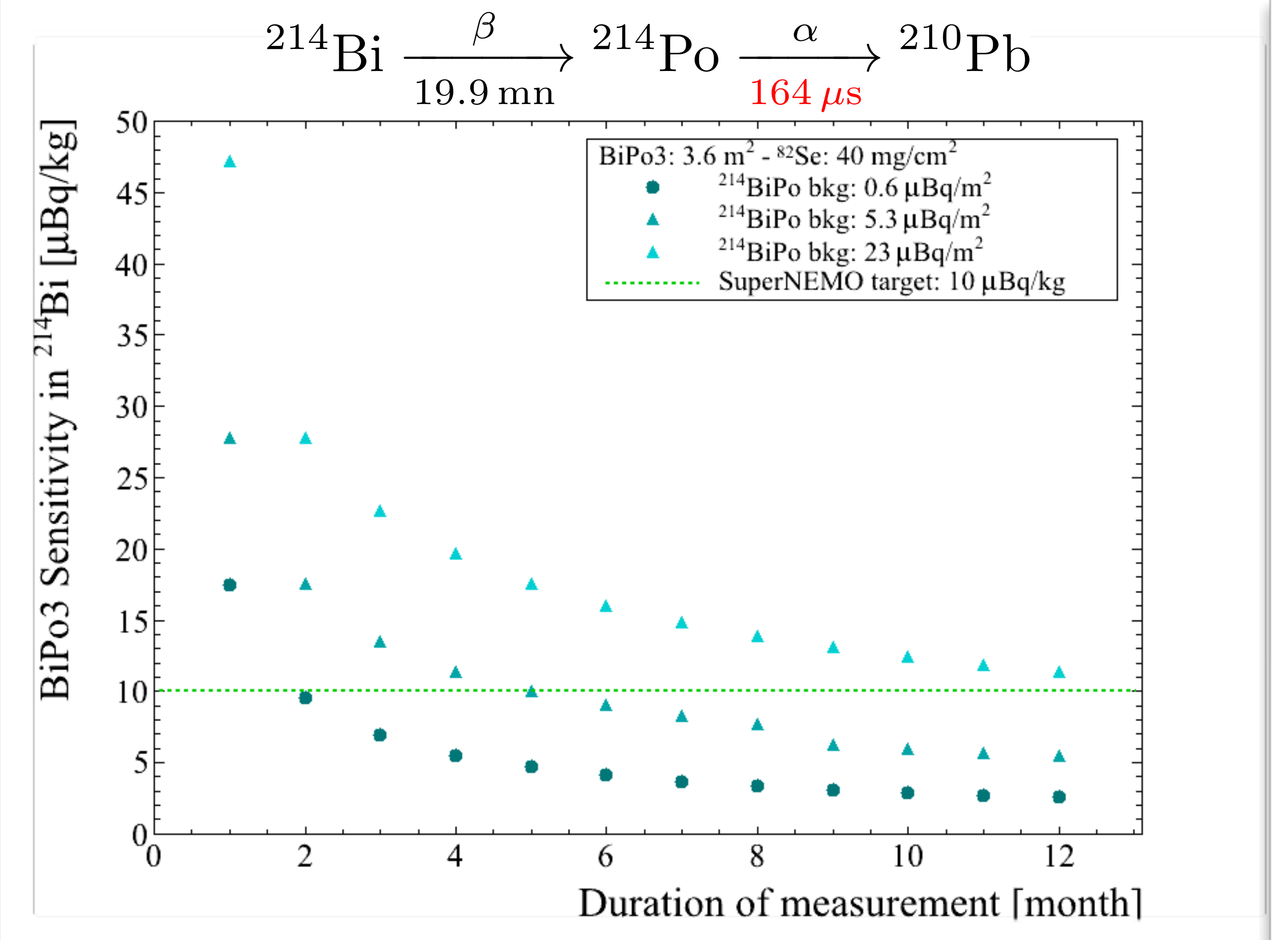


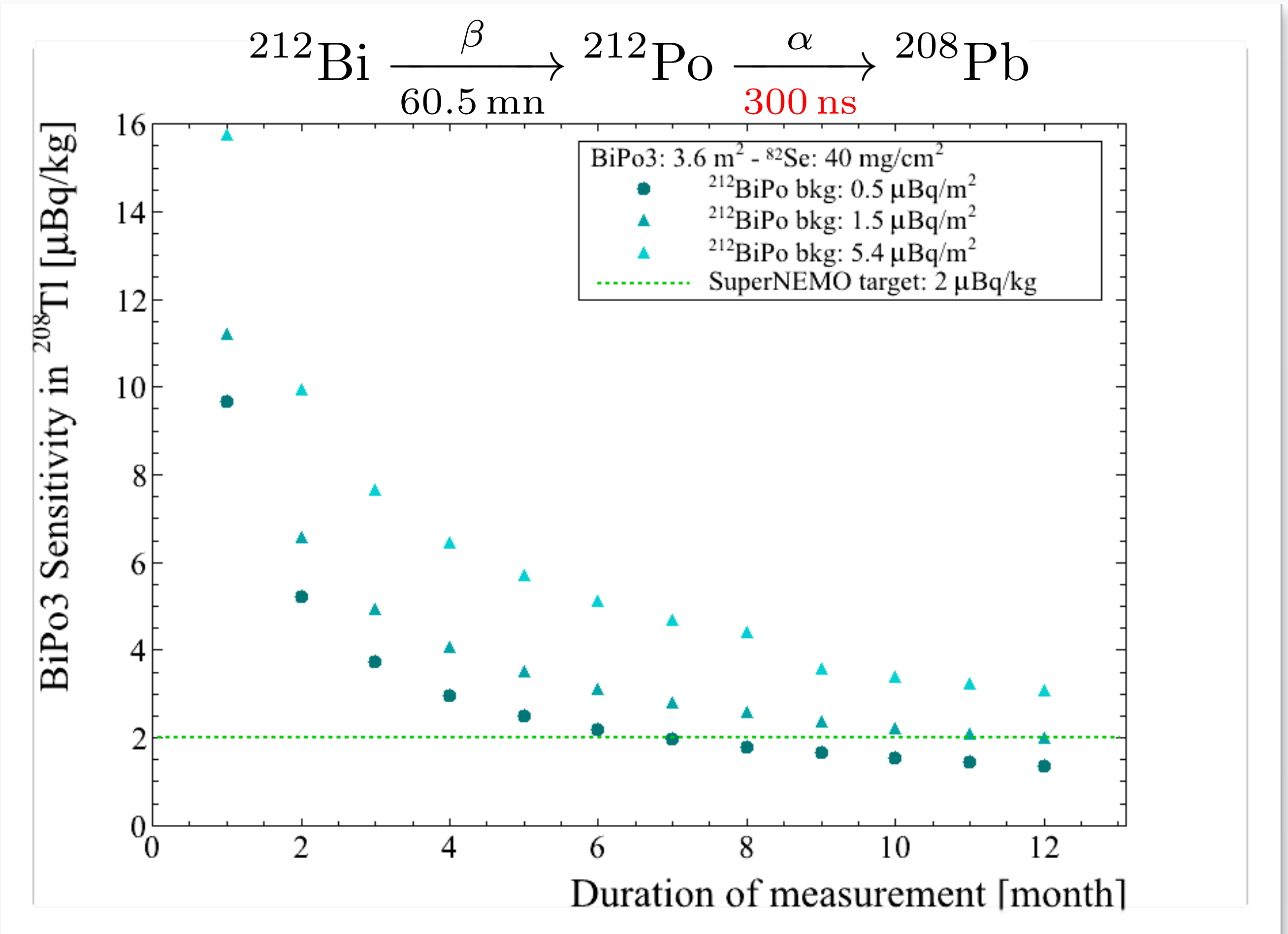


^{82}Se source radiopurity

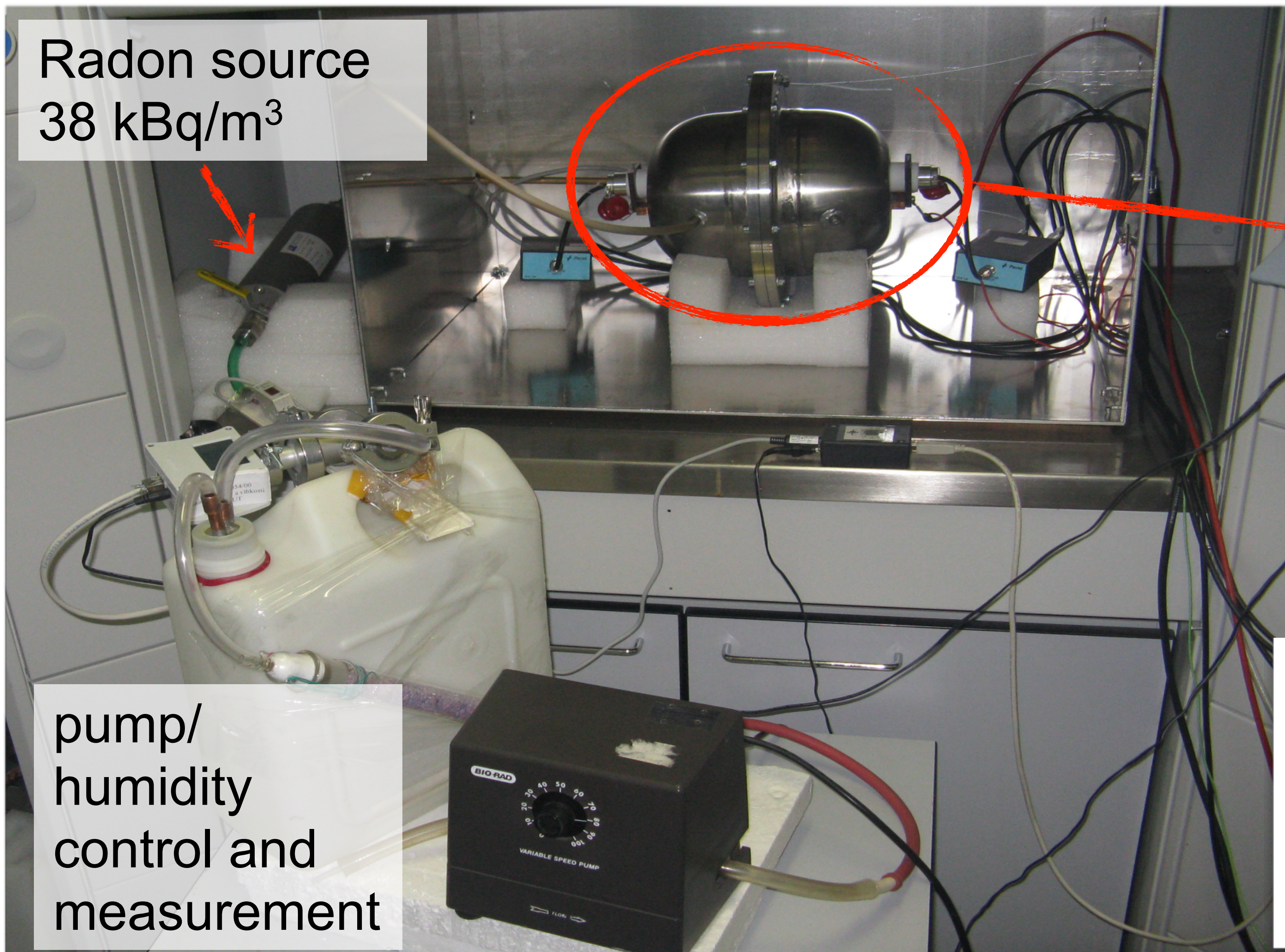
- Shaped in foils of 40-50 mg/cm^2
- Radiopurity
  - ^{208}Tl < 2 μBq/kg
  - ^{214}Bi < 10 μBq/kg
- Dedicated BiPo detector developed and installed in Canfranc (in March 2012)

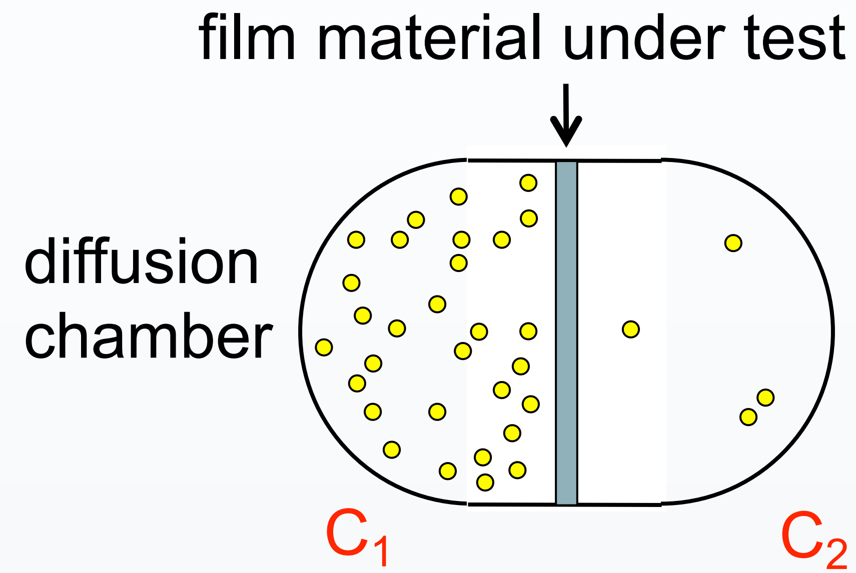






Radon Diffusion Measurements





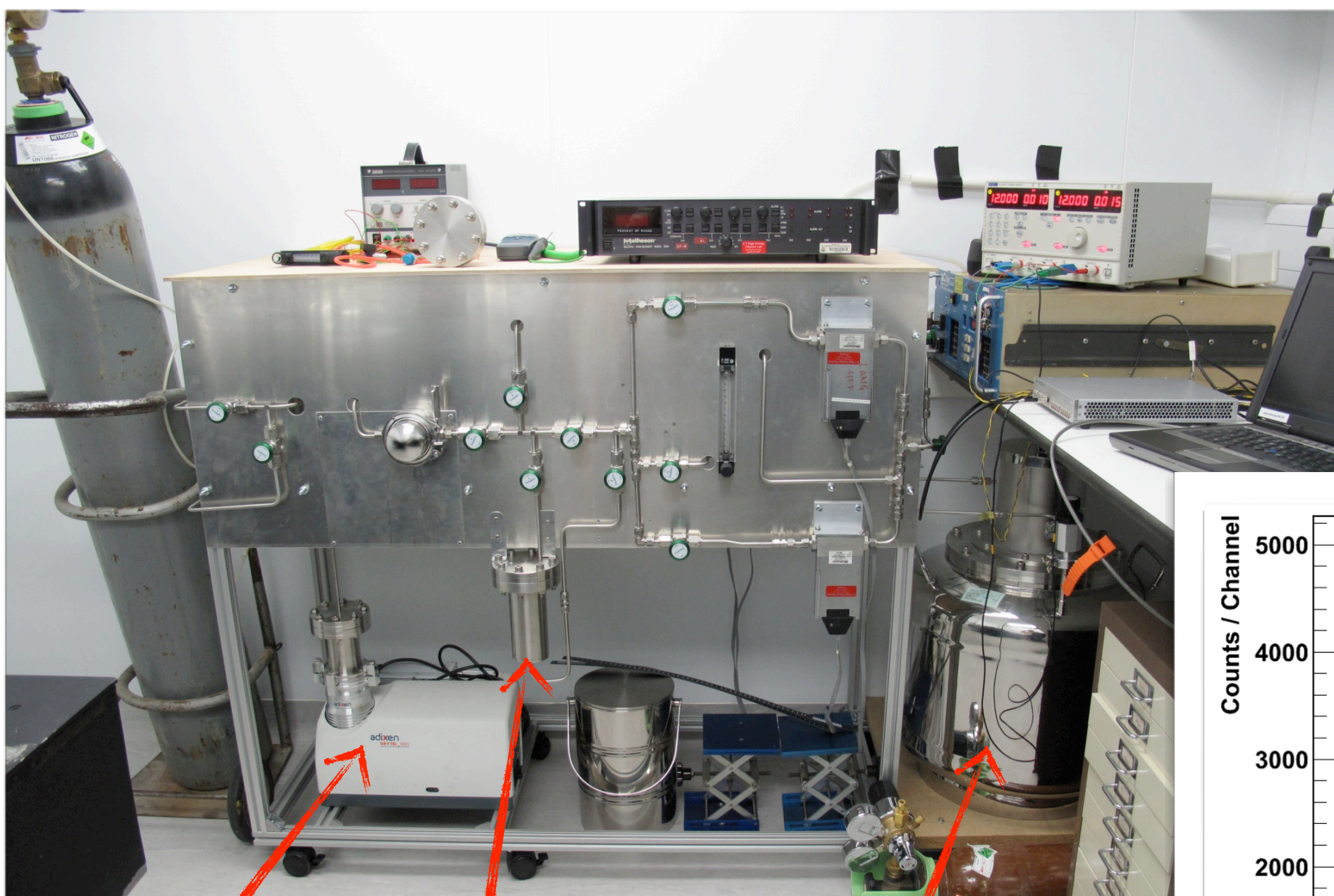
$C_1/C_2 \rightarrow$ diffusion coefficient

Possible radon seals:

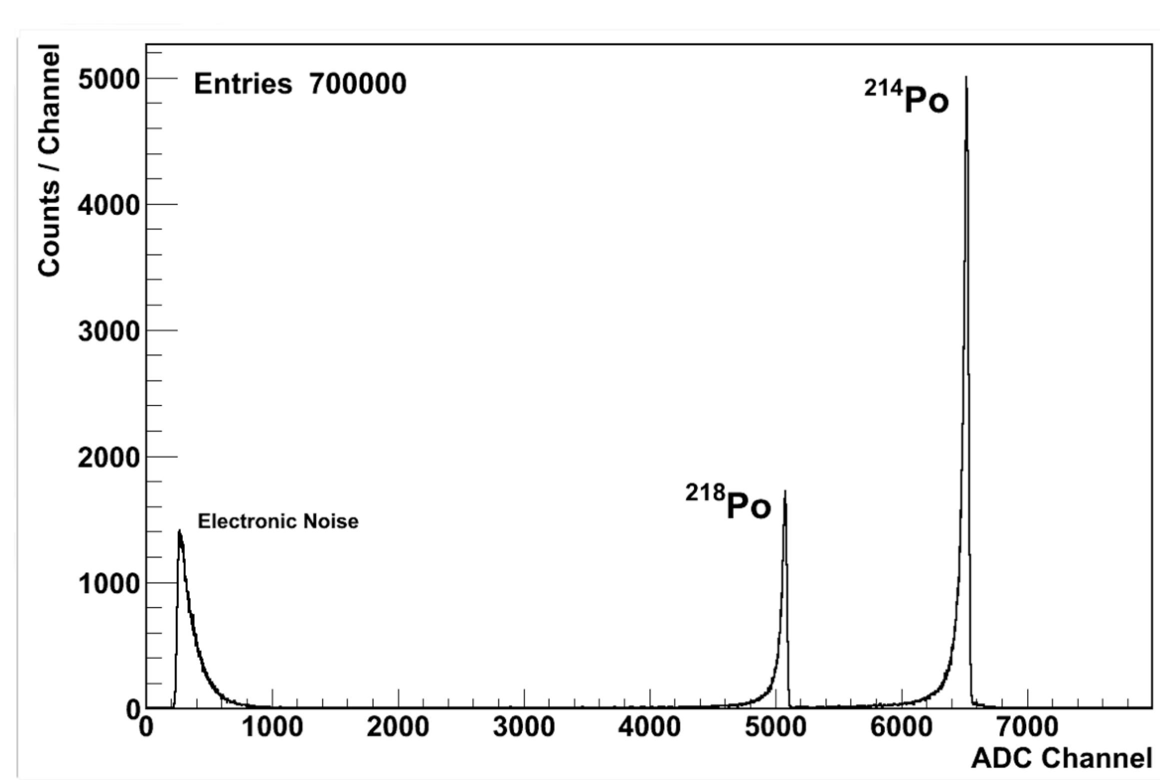
RTV, silicone : $C_1 \sim C_2 \rightarrow$ transparent!

Mylar/Tropac/PVA : $C_1/C_2 \geq\sim 10{,}000$

Rn activity measurement

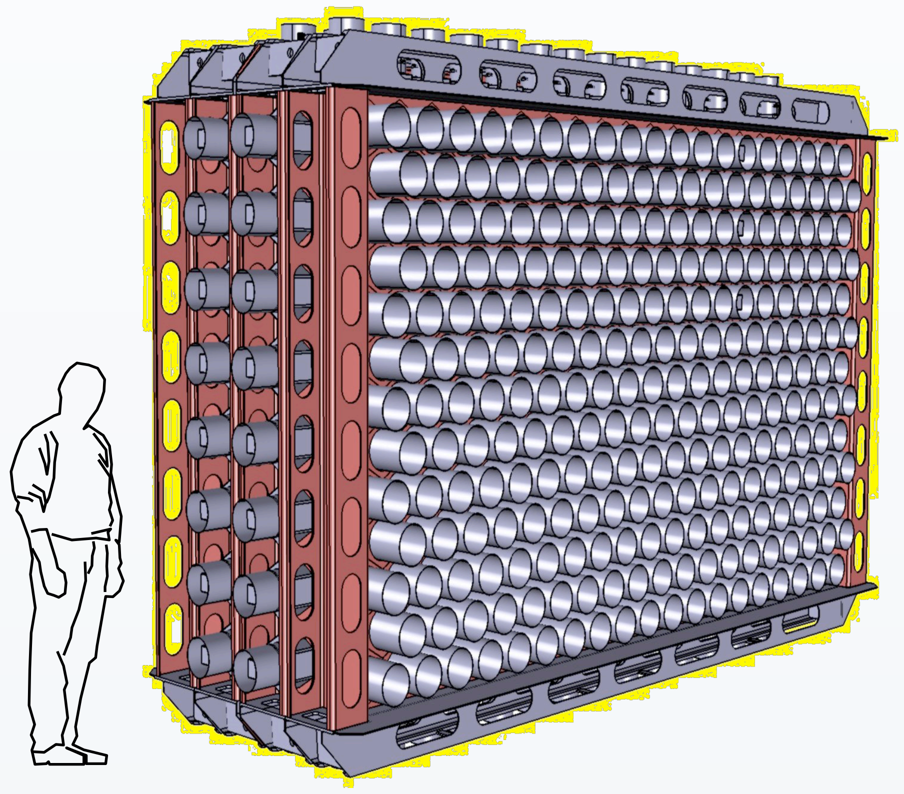


Radon Concentration Line
sensitivity < 0.1 mBq/m^3



The Demonstrator

1. A zero background experiment
   - match SuperNEMO's radiopurity requirements
   - less than 0.2 background events in search region with 21 kg yr (7kg×3yrs)
2. Achieve competitive sensitivity:
   - NEMO3 (^{100}Mo) in 4.5 months
   - By 2015: $T_{1/2}^{0\nu} > 6.5 \cdot 10^{24}$ yr (equivalent to $3 \cdot 10^{25}$ yr for ^{76}Ge)
3. first SuperNEMO module

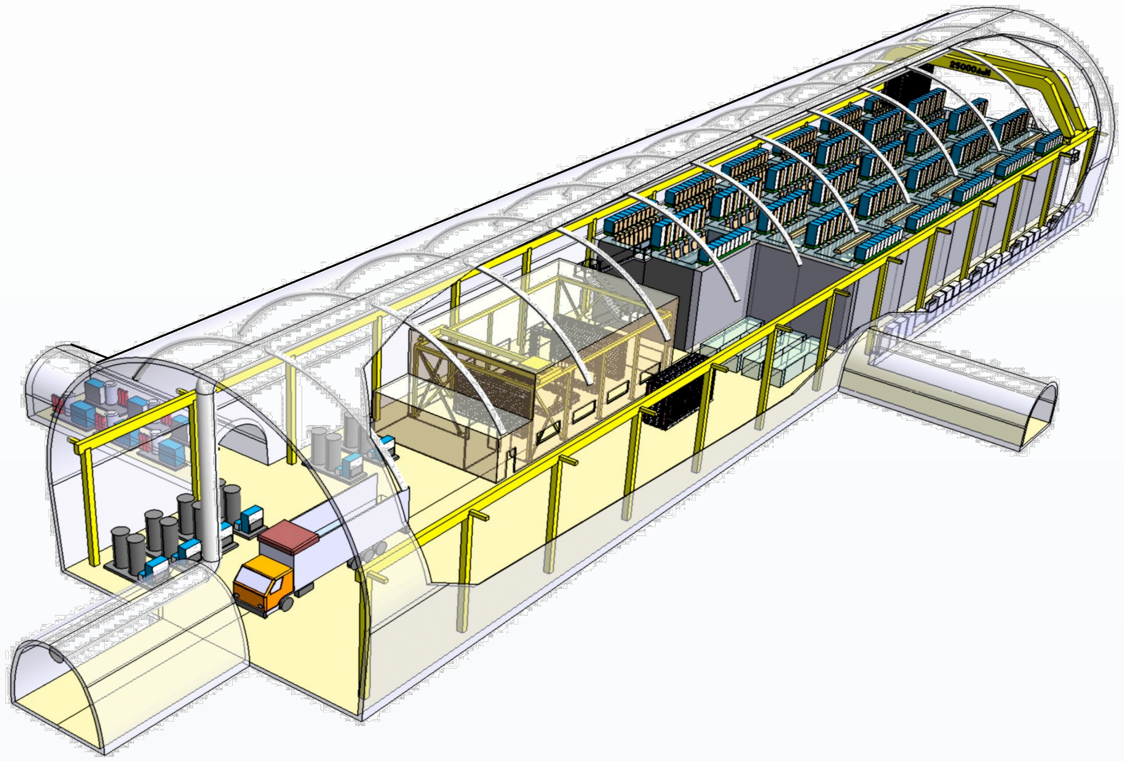


SuperNEMO Construction has started

- Construction of optical modules to be mounted on tracker frame has begun
- Assembly hall being prepared for tracker construction and commissioning



Schedule



Demonstrator Module construction and commissioning

Demonstrator Module running. “Klapdor” sensitivity end of 2015

2011	2012	2013	2014	2015	2016	2017	2018	2019	2020

Installation in LSM

Construction and deployment of successive SuperNEMO modules

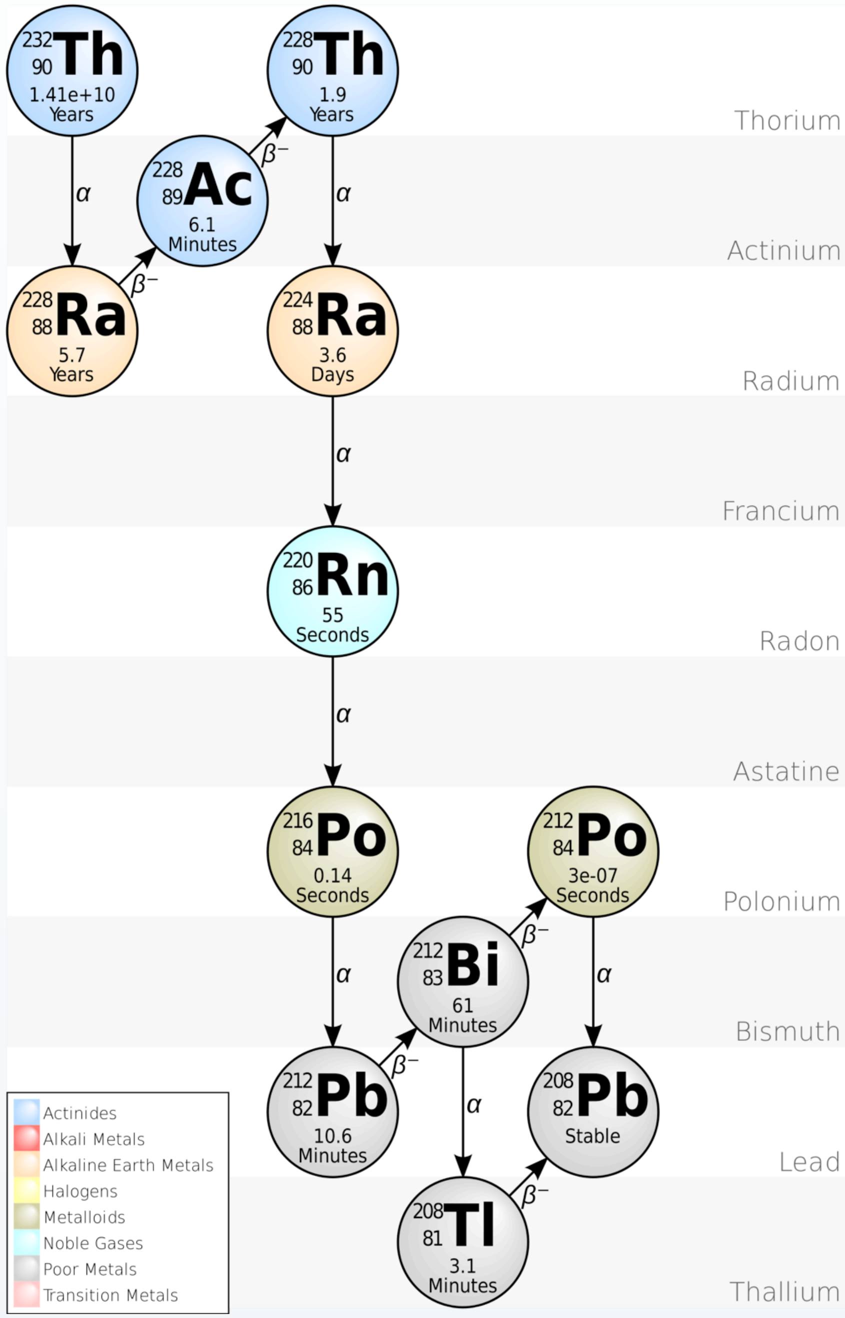
Continuous operation of ≥1 SuperNEMO module

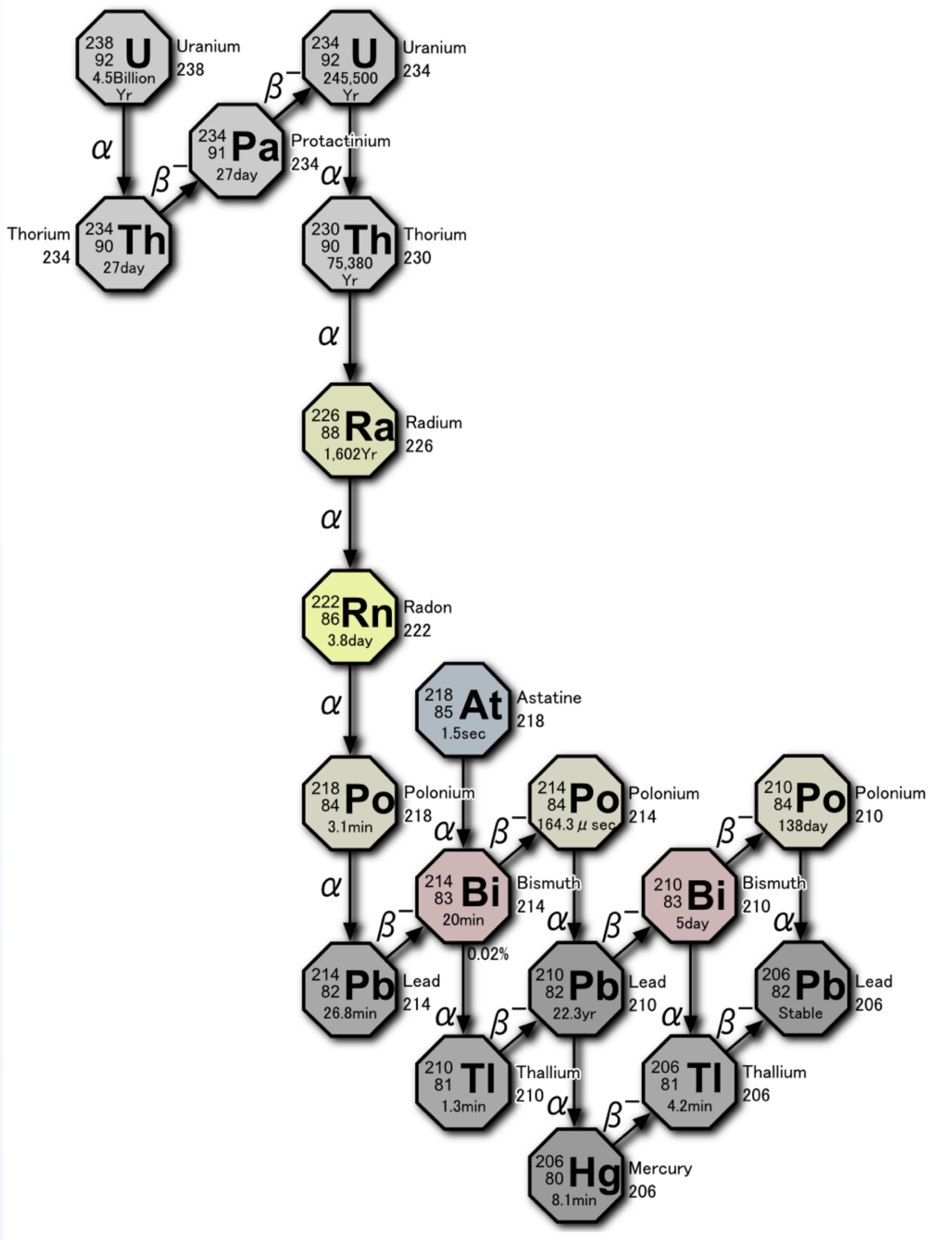
Conclusions

- NEMO3 has finished data taking
  - no evidence of lepton violating decays has been found
  - the double beta decay of seven isotopes including decays into excited states has been measured
  - analysis of final samples is currently ongoing
- SuperNEMO design is now being finalized
- The Demonstrator has now entered the construction phase

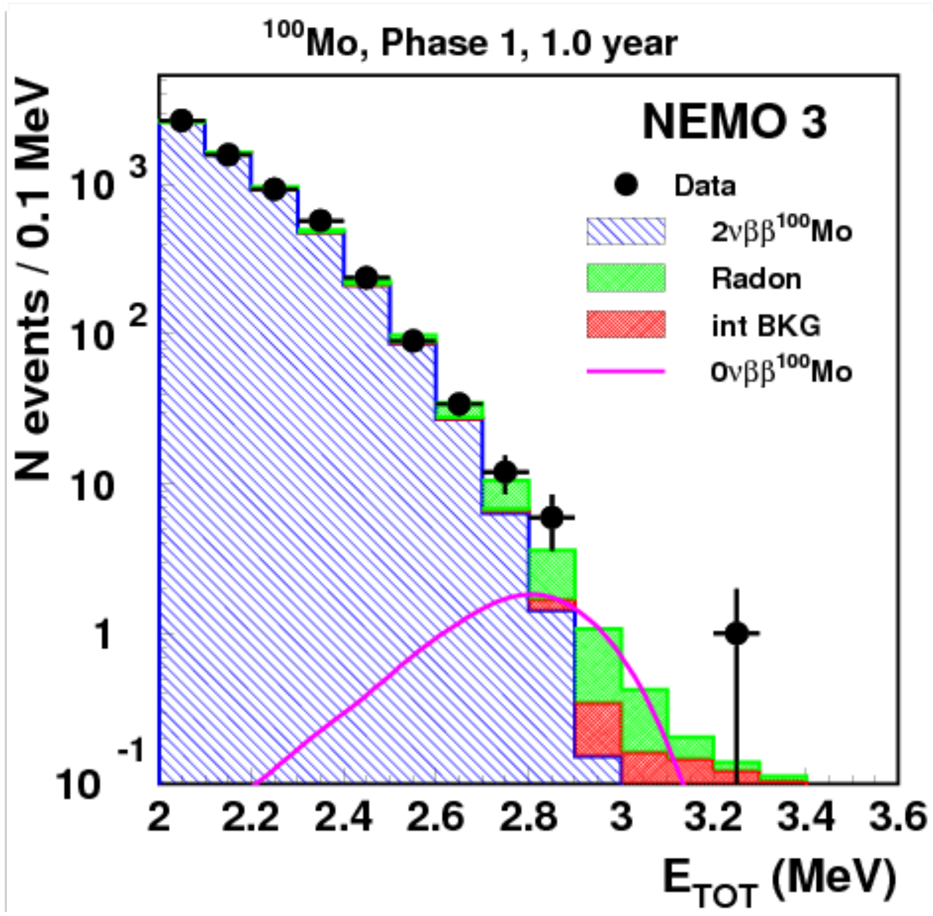
Backup

Th and U chains





Search for 0νββ with ^{100}Mo



[2.8 , 3.2] MeV:

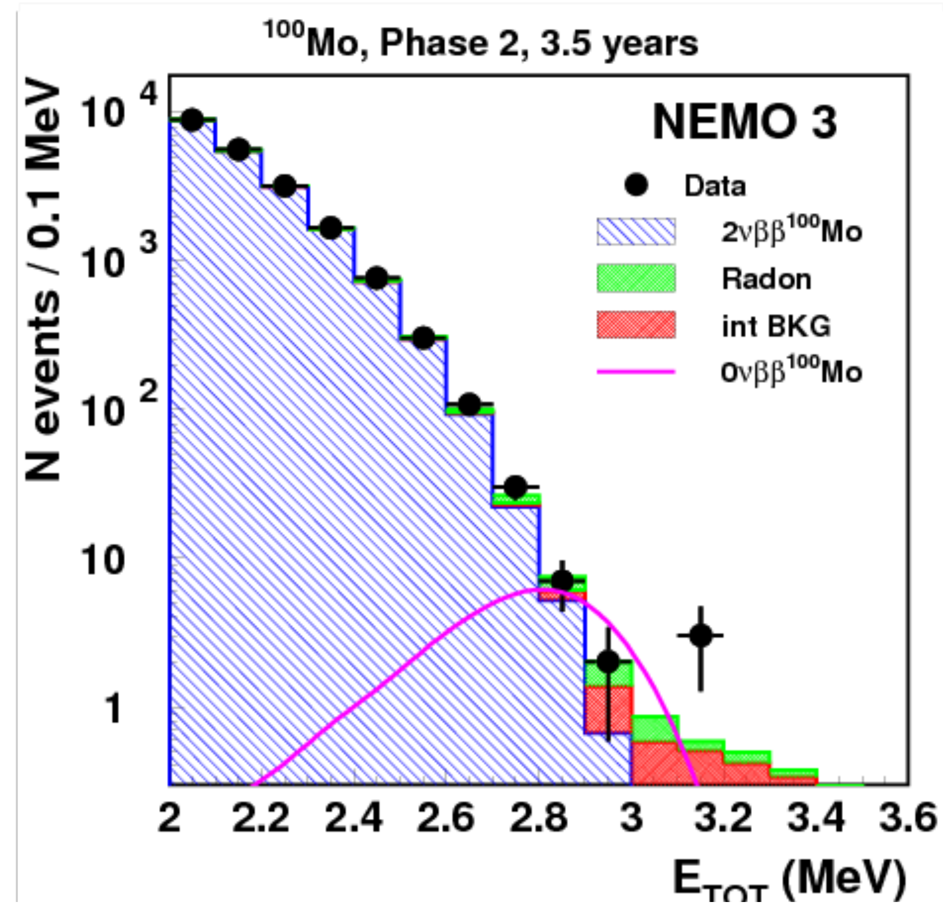
ε(0ν) = 0.056

Tot MC= 5.4±0.5 , Data: 6 events

MC 2vbb = 1.6±0.1

MC radon = 3.0±0.4

MC int bkg=0.8±0.1 (^{214}Bi=0.1,^{208}Tl=0.7)



[2.8 , 3.2] MeV:

ε(0ν) = 0.055

Tot MC= 11.0±0.8 , Data: 12 events

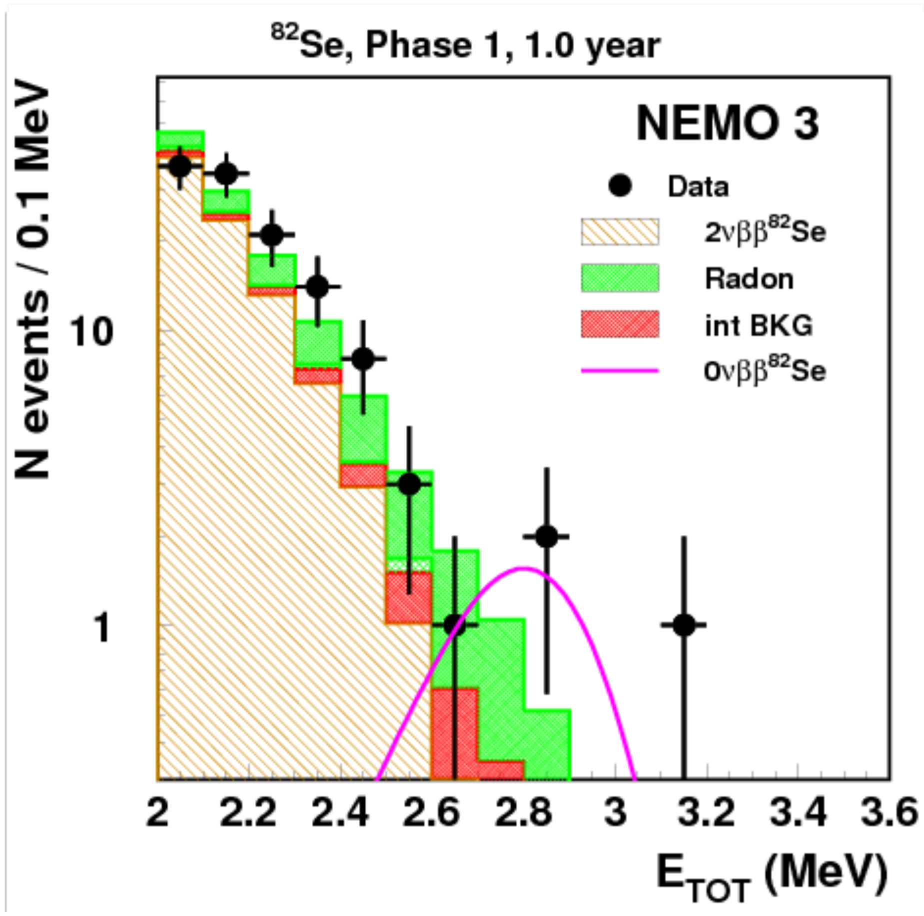
MC 2vbb = 5.8±0.4

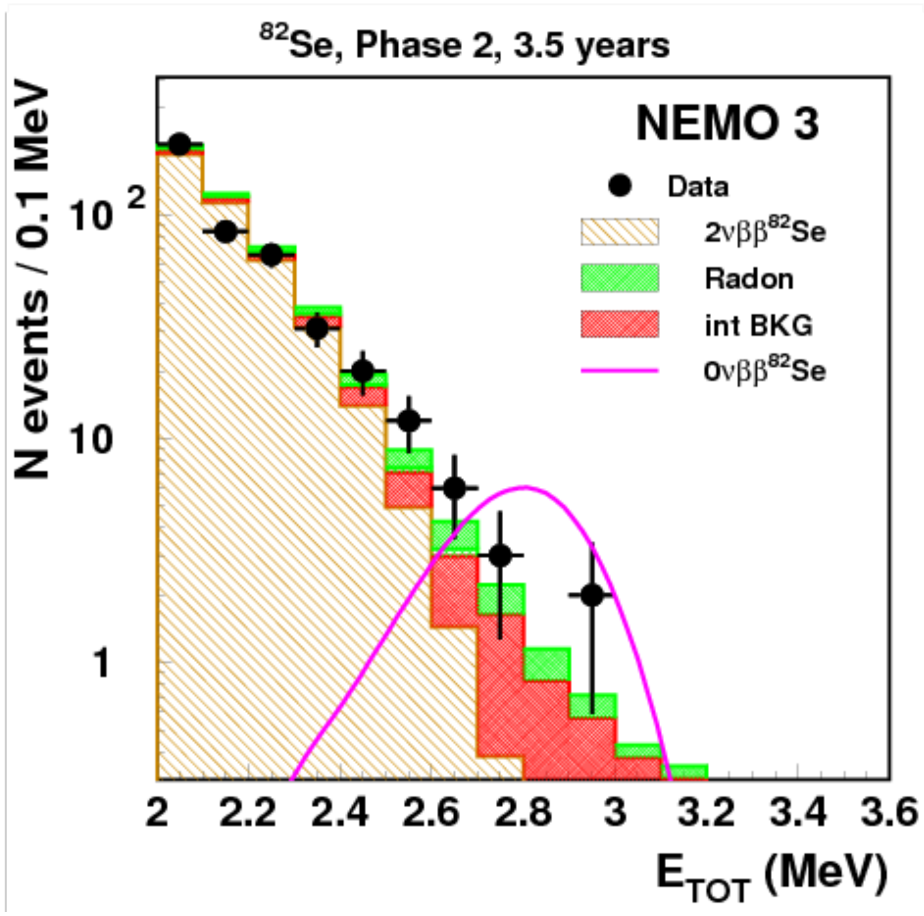
MC radon = 2.5±0.4

MC int bkg=2.7±0.4 (^{214}Bi=0.4,^{208}Tl=2.3)

[2.8,3.2]MeV in 4.5 years 18 events observed, 16.4±1.3 expected

Search for 0νββ with ^{82}Se





[2.6 , 3.2] MeV:

ε(0ν) = 0.105
Tot MC= 3.8±0.5 , Data: 4 events
MC 2vbb = 0.4±0.1
MC radon = 2.4±0.4
MC int bkg=1.0±0.2 (^{214}Bi=0.55,^{208}Tl=0.42)

[2.6 , 3.2] MeV:

ε(0ν) = 0.118
Tot MC= 7.3±0.8 , Data: 10 events
MC 2vbb = 1.5±0.4
MC radon = 2.0±0.3
MC int bkg=3.8±0.6 (^{214}Bi=2.2,^{208}Tl=1.6)

[2.6,3.2]MeV in 4.5 years 14 events observed, 11.1+1.3 expected

^{100}Mo 2β2ν decay to excited states

$T_{1/2}^{2\nu}(0^+ \rightarrow 0^+_1) = 5.7^{+1.3}_{-0.9}$ (stat) ± 0.8 (syst) × 10^{20} y

$T_{1/2}^{0\nu}(0^+ \rightarrow 0^+_1) > 8.9 \times 10^{22}$ y @ 90% C.L.

$T_{1/2}^{2\nu}(0^+ \rightarrow 2^+_1) > 1.1 \times 10^{21}$ y @90% C.L.

$T_{1/2}^{0\nu}(0^+ \rightarrow 2^+_1) > 1.6 \times 10^{23}$ y @ 90% C.L.

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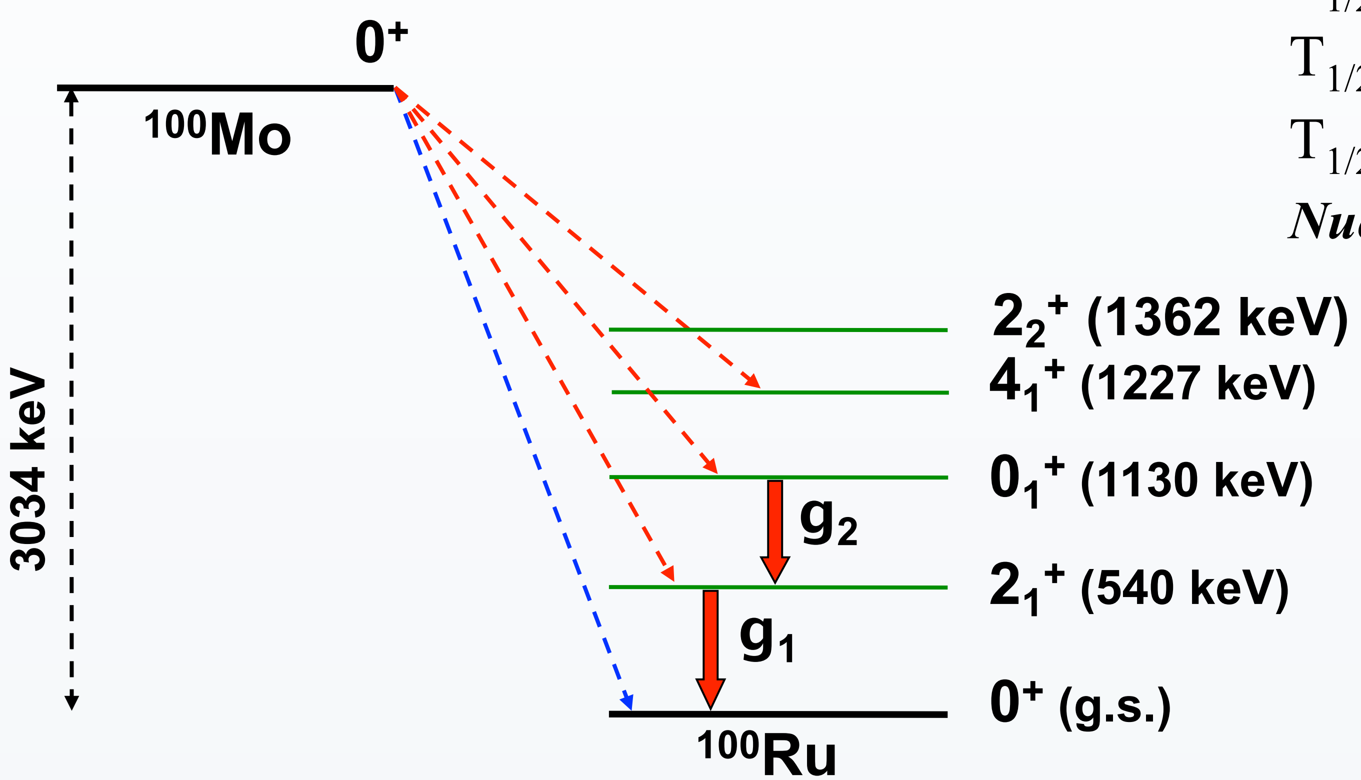
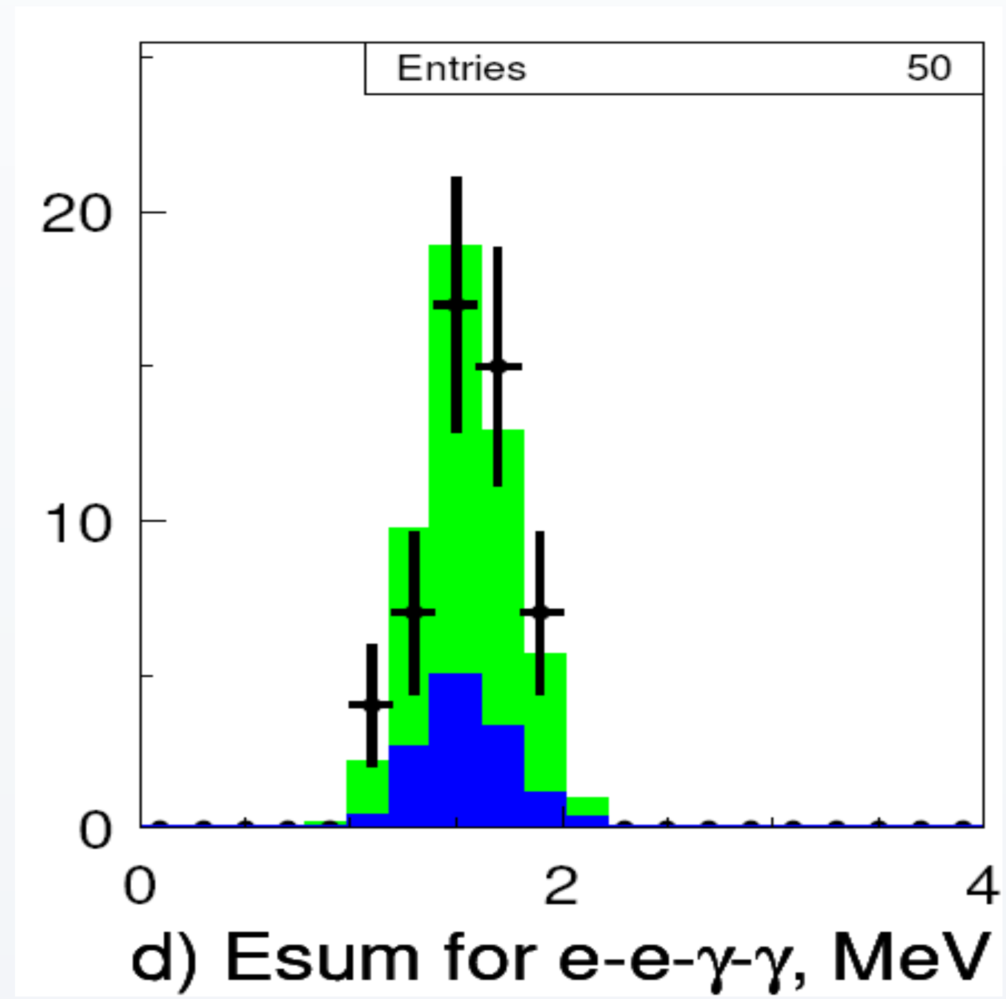


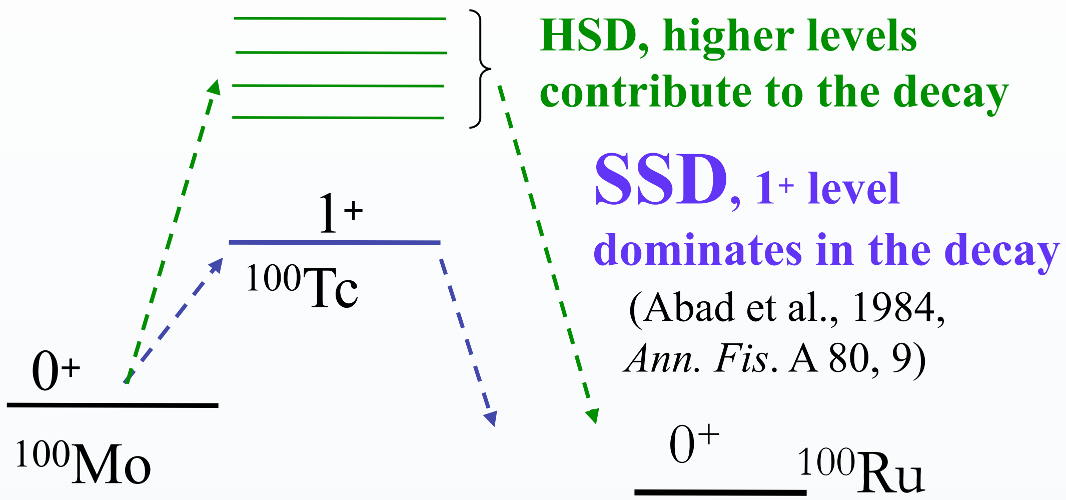


Event topology:

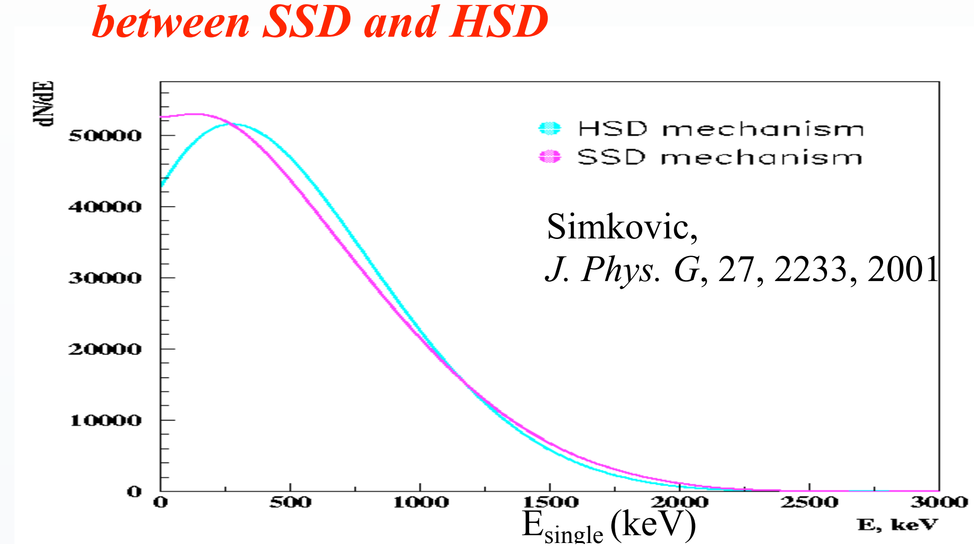
0_1^+: 2e$^-$ + 2g in time & energy and TOF cuts

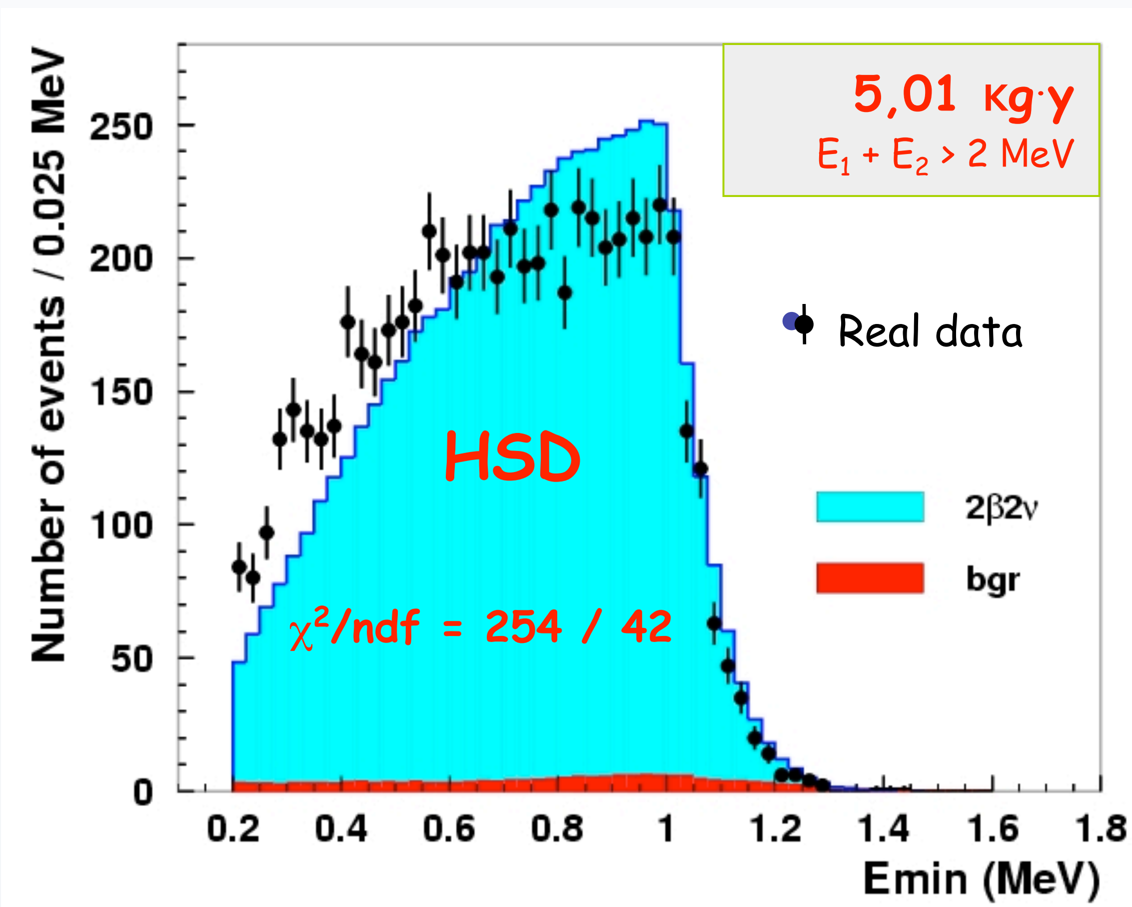
2_1^+: 2e$^-$ + 1g in time & energy and TOF cuts

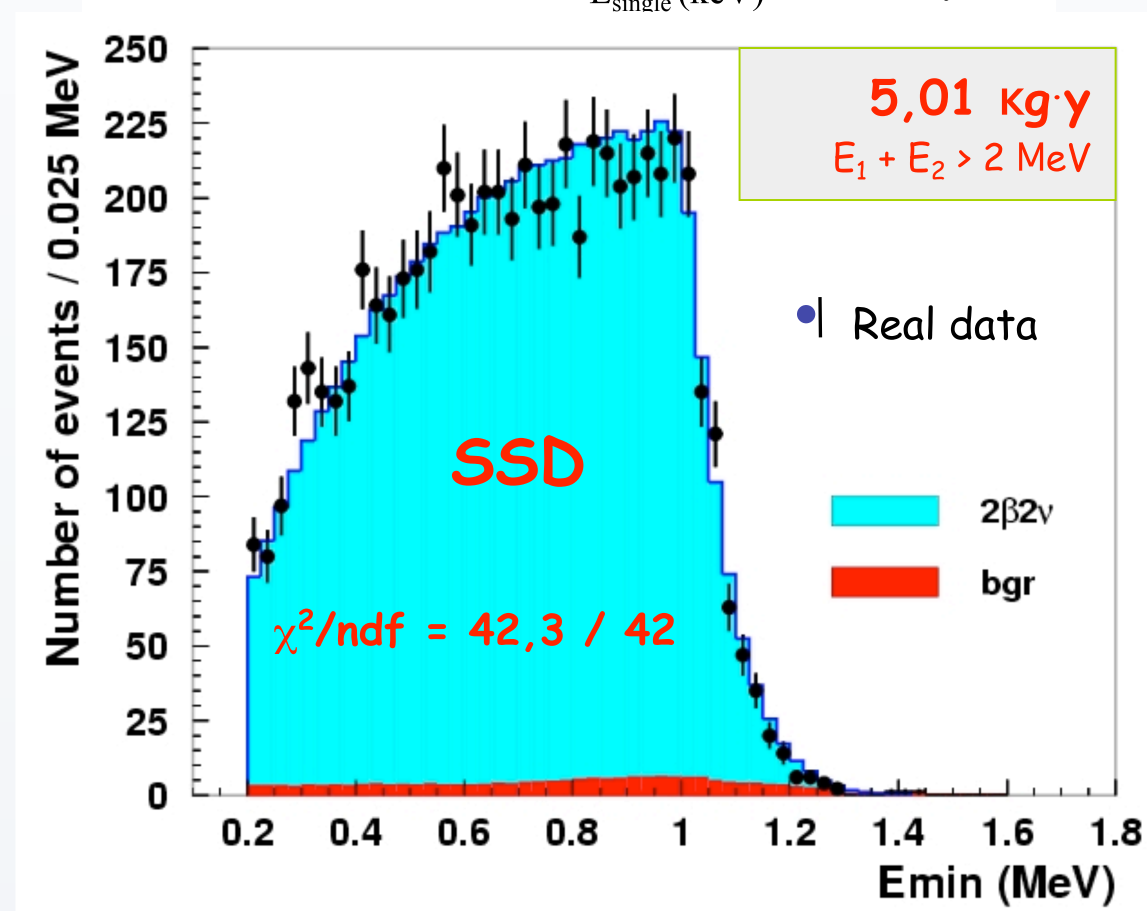
SSD/HSD 2νββ (^{100}Mo)



Single electron spectrum different between SSD and HSD





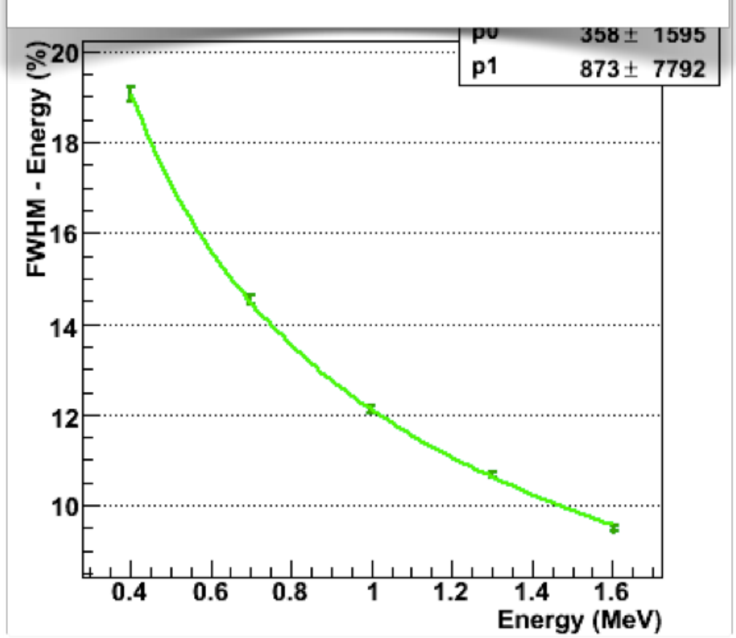


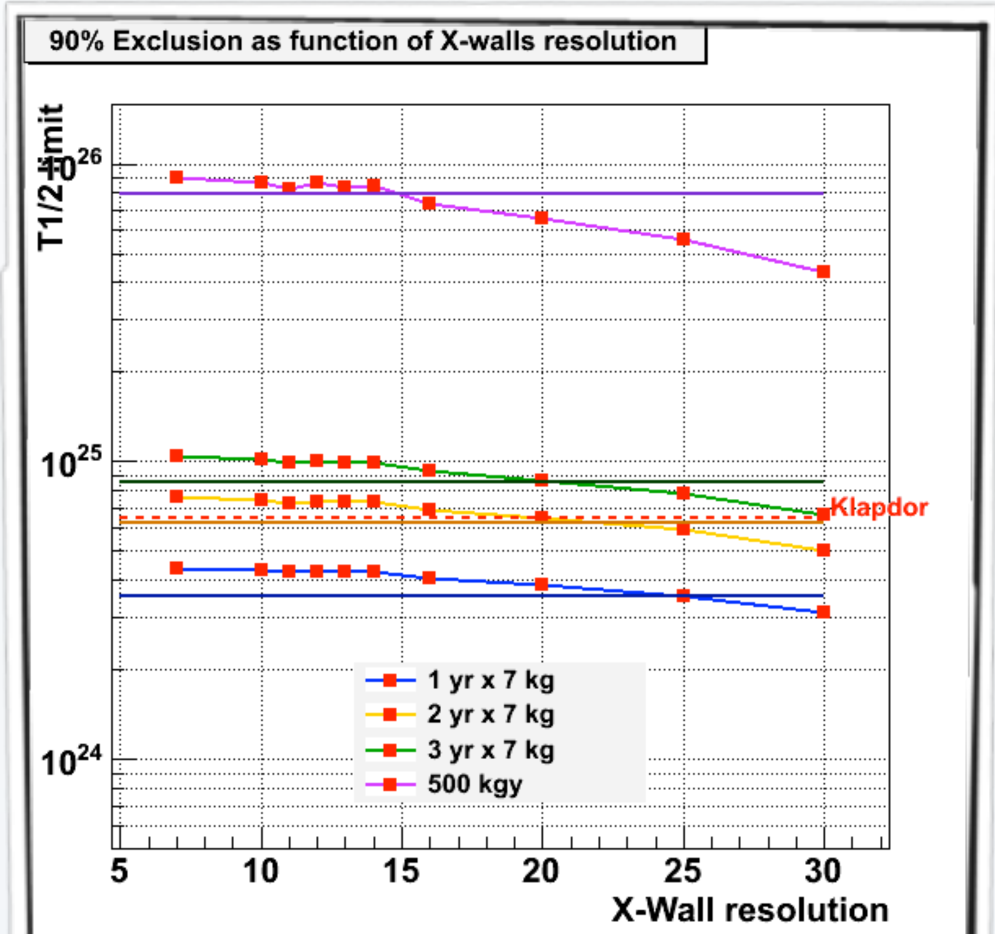
Electron energy distribution in 2β2ν decay of ^{100}Mo is in favour of Single State Dominance (SSD)

X-walls R&D and construction

- Use scintillators on the side of tracker (X-wall) for event reconstruction
- increase acceptance on signal and SuperNEMO sensitivity if resolution <16% @1MeV

Resolution: ~ 12% @ 1Mev





$3 \cdot 10^{25}$ yr for ^{76}Ge ~ $6.5 \cdot 10^{24}$ yr for ^{82}Se