Angular measurement with NEMO3/SuperNEMO

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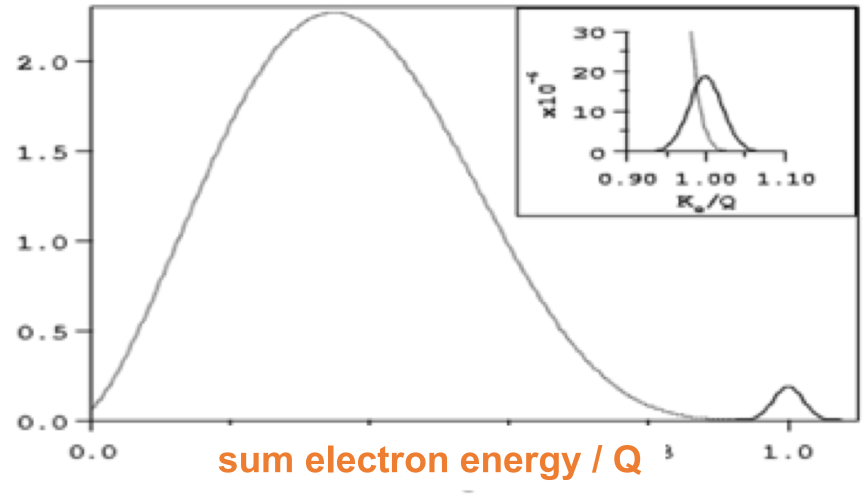
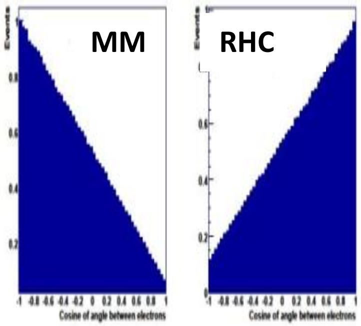
Double beta observables

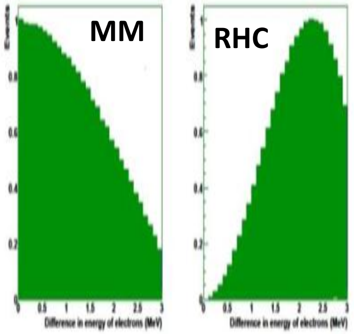


sum electron energy / Q

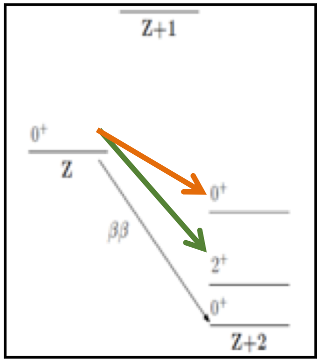
Angular distribution



$Ee_1 – Ee_2$ distribution



Mass vs Right-Handed Current mechanism



Decay to Excited States

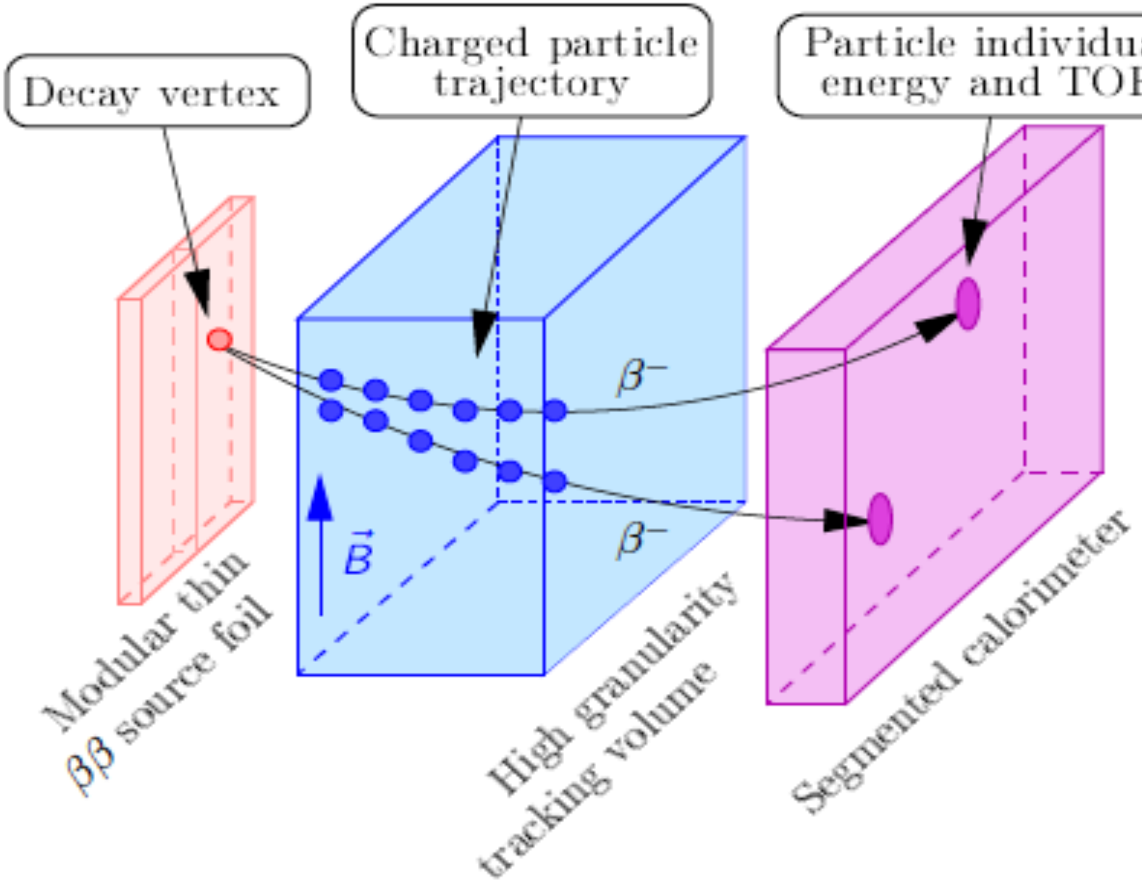
(A,Z) $\rightarrow$ (A, Z+2) + 2 e^- + 1,2 γ

1 or 2 additonnal γ-rays

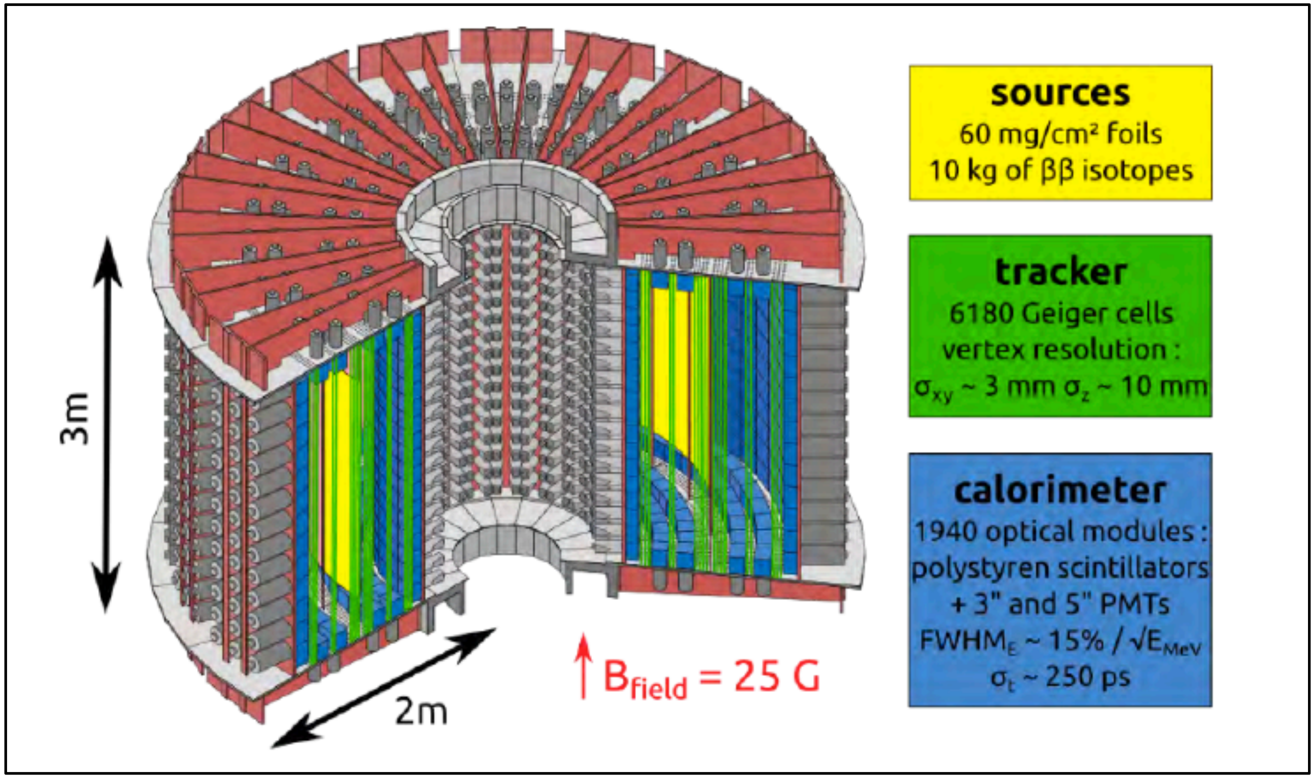
The NEMO technique aims to detect all particles and all kinematic parameters

NEMO detector principle

Particle physic approach: **to measure all kinematic parameters**



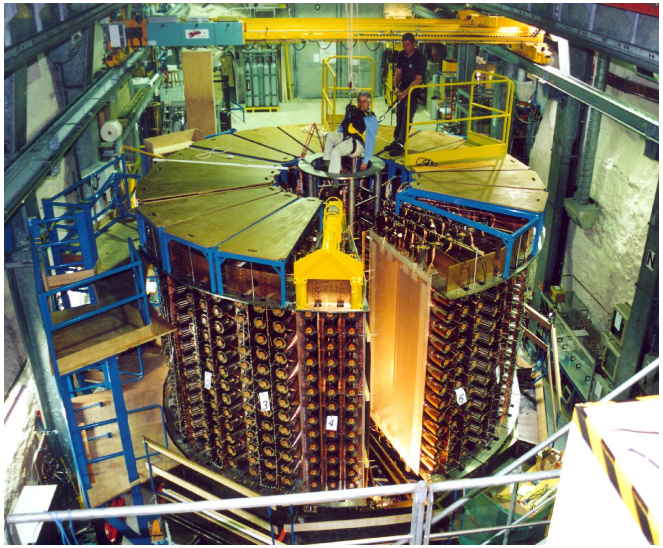
NEMO-3 detector



sources
60 mg/cm² foils
10 kg of ββ isotopes

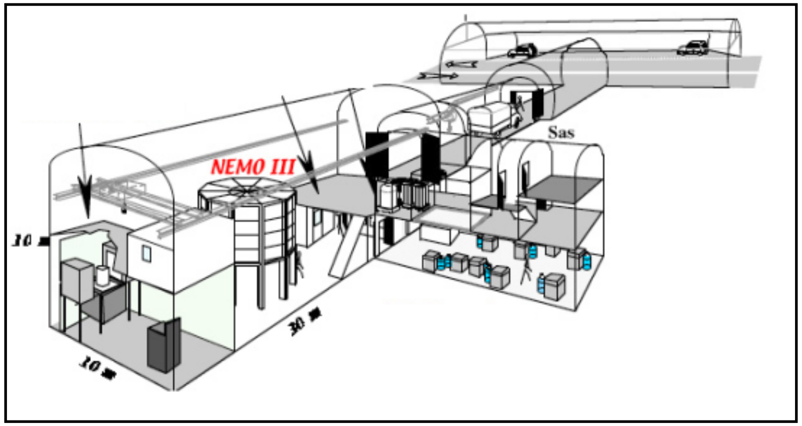
tracker
6180 Geiger cells
vertex resolution :
$\sigma_{xy} \sim 3$ mm $\sigma_z \sim 10$ mm

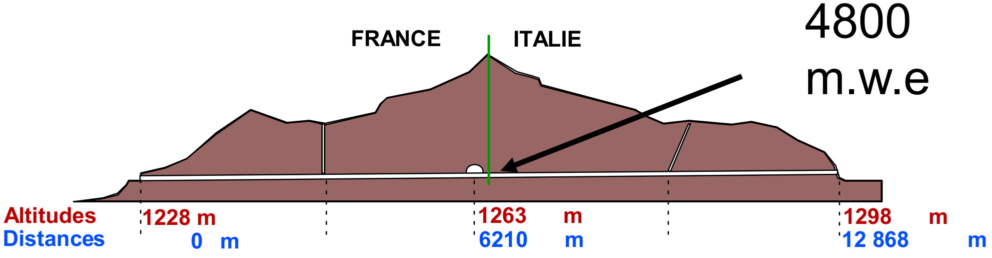
calorimeter
1940 optical modules :
polystyren scintillators
+ 3" and 5" PMTs
$\mathrm{FWHM}_E \sim 15\% / \sqrt{E_{MeV}}$
$\sigma_t \sim 250$ ps



NEMO-3 detector at LSM

Modane Underground Laboratory
(Laboratoire Souterrain de Modane, LSM, CNRS and Grenoble University)

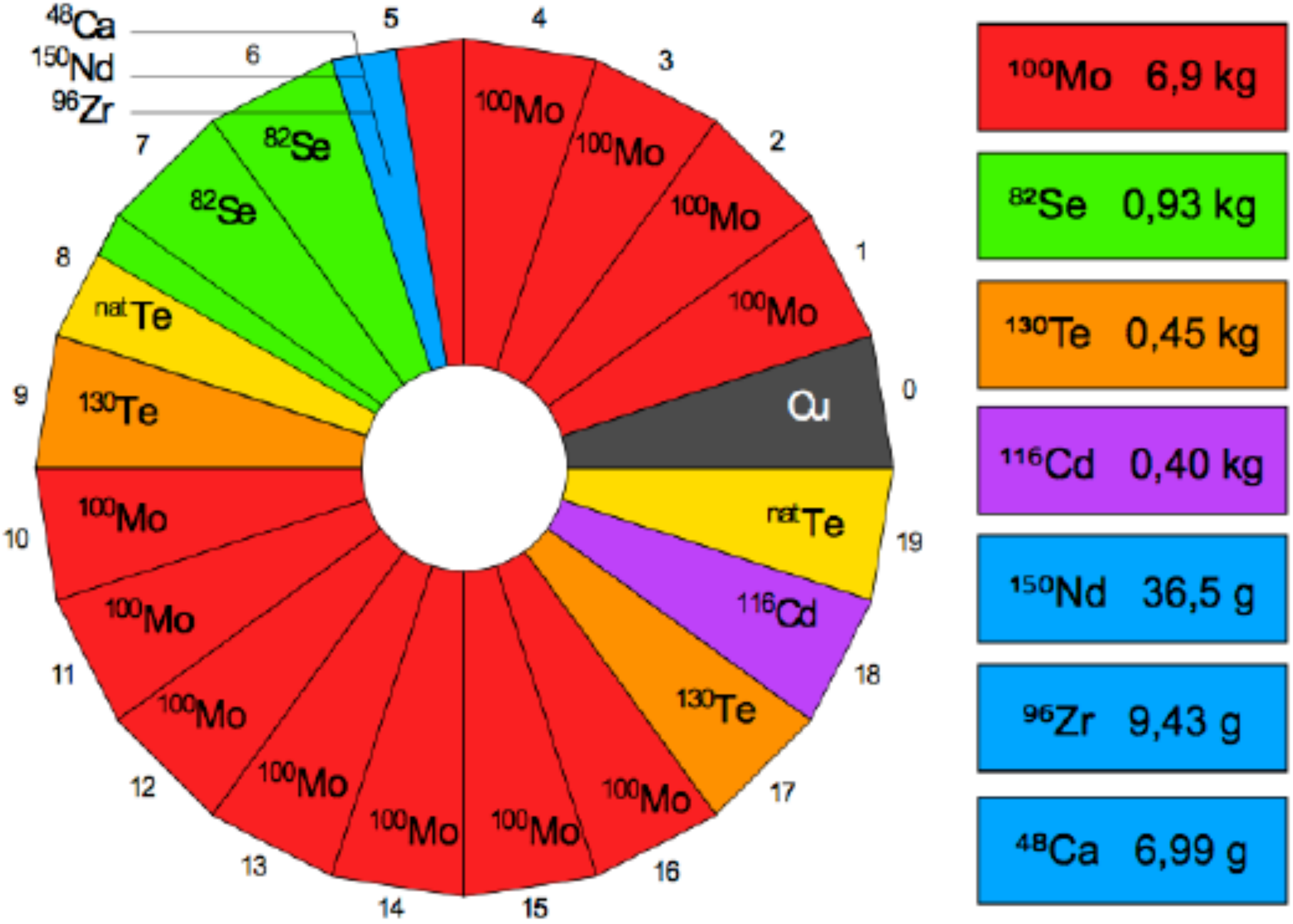




1700 m (4800 m.w.e. under Fréjus mountain)

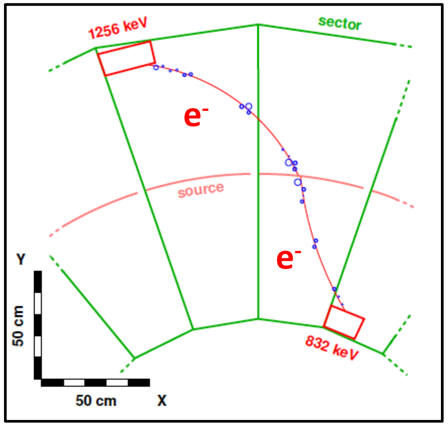
NEMO-3 camembert

NEMO-3 "camembert" (source top view)



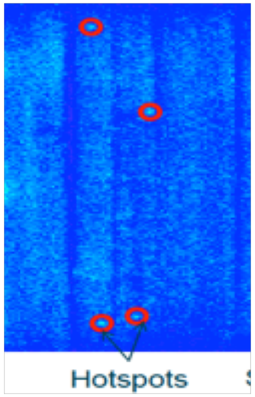
Tracko-calo avantages

Identification of electrons



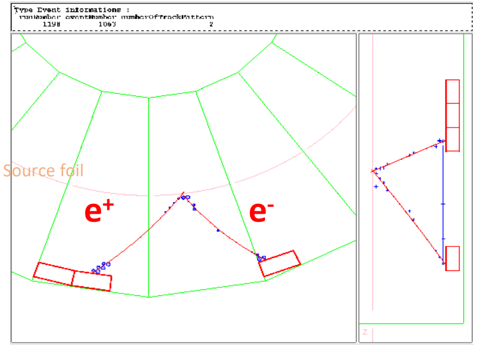
Vertex reconstruction:

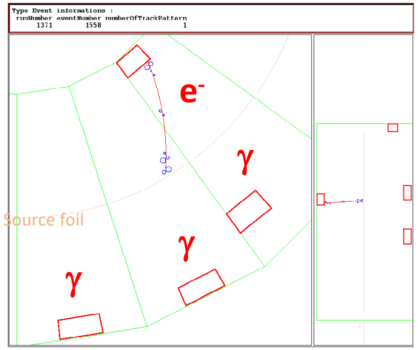
possible identification of « hot spots » on the source foil



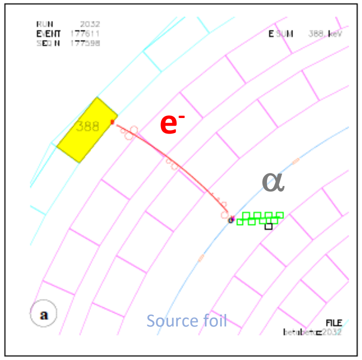
Identification of e^+, γ, α particles

e^+e^- pair





e-nγ (Ex: ^{214}Bi and ^{208}Tl)



e-α-nγ (Ex: ^{214}Bi)

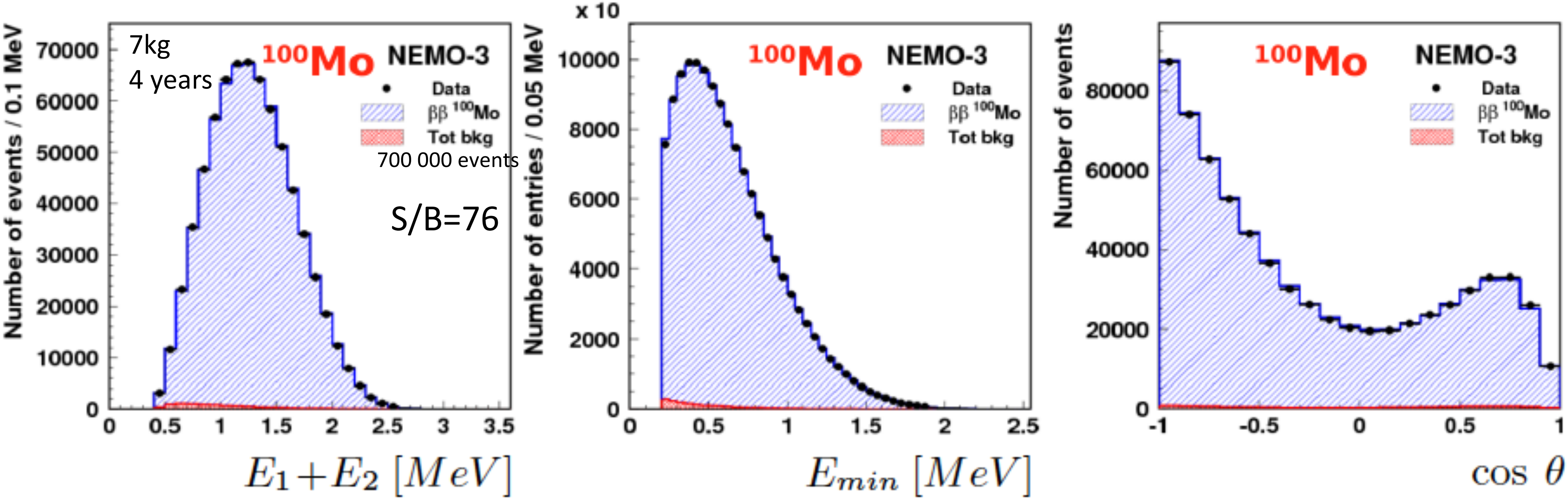
- Powerful background rejection by topology
- Identification and cross-check of backgrounds with several topologies

Precision measurements with ββ(2ν)

Accurate measurement of ββ(2ν) observables

$$T_{1/2}^{2\nu} = 7.16 \pm 0.01\ (\text{stat}) \pm 0.54\ (\text{syst})\ 10^{18}\ \text{y}$$

[Phys. Rev. Lett. 95, 182302 (2005)]



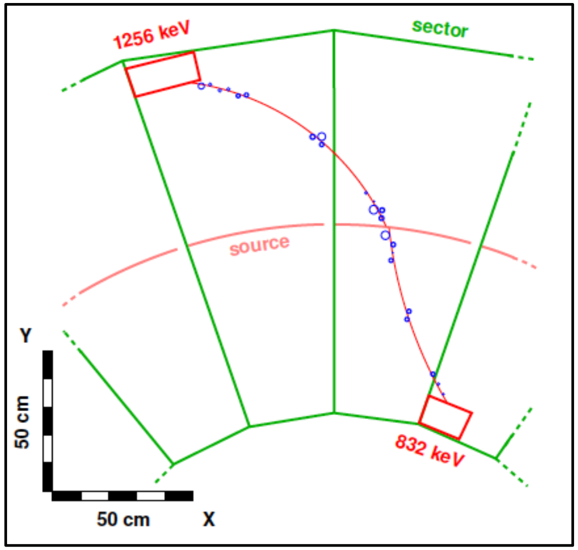
7kg
4 years

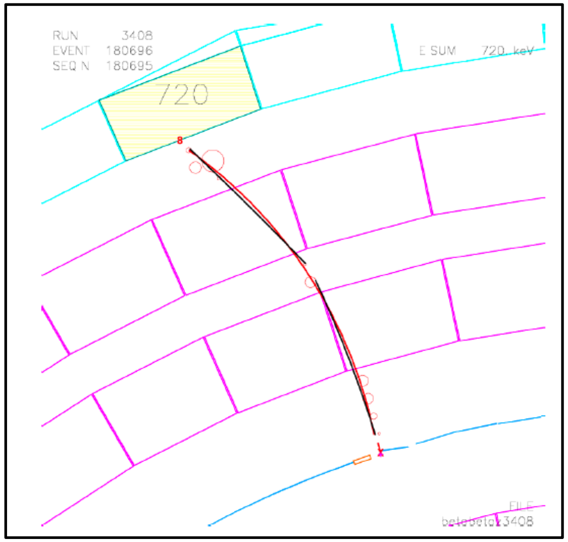
700 000 events

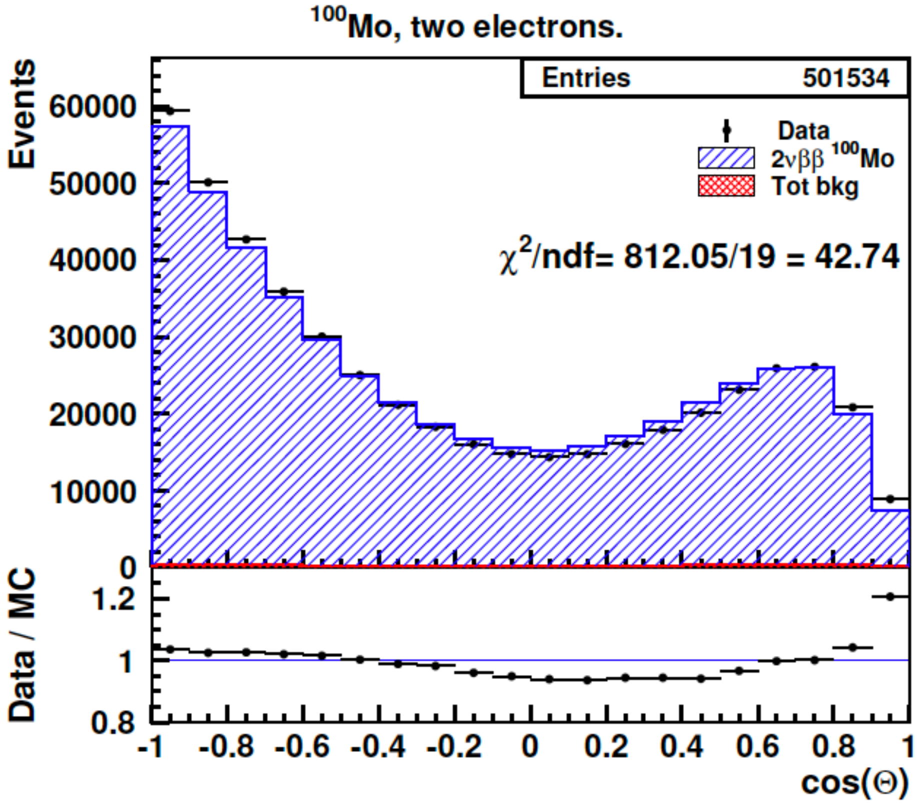
S/B=76

- ➢ Nuclear physics (ββ(2ν) half-life to extract N.M.E., HSD vs SSD)
- ➢ To look for deviation from standard physics and search for exotic physics

Angular distribution between the 2 electrons







Slight discrepency between data and MC (MC modelisation of ;)tracking chamber, Left-right ambiguity, hot cells,…)

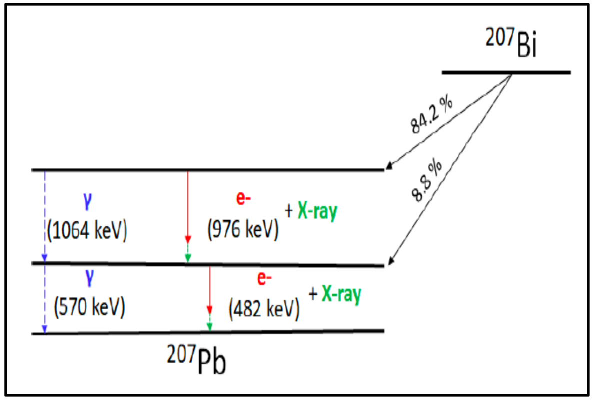
Calibration with ^{207}Bi source

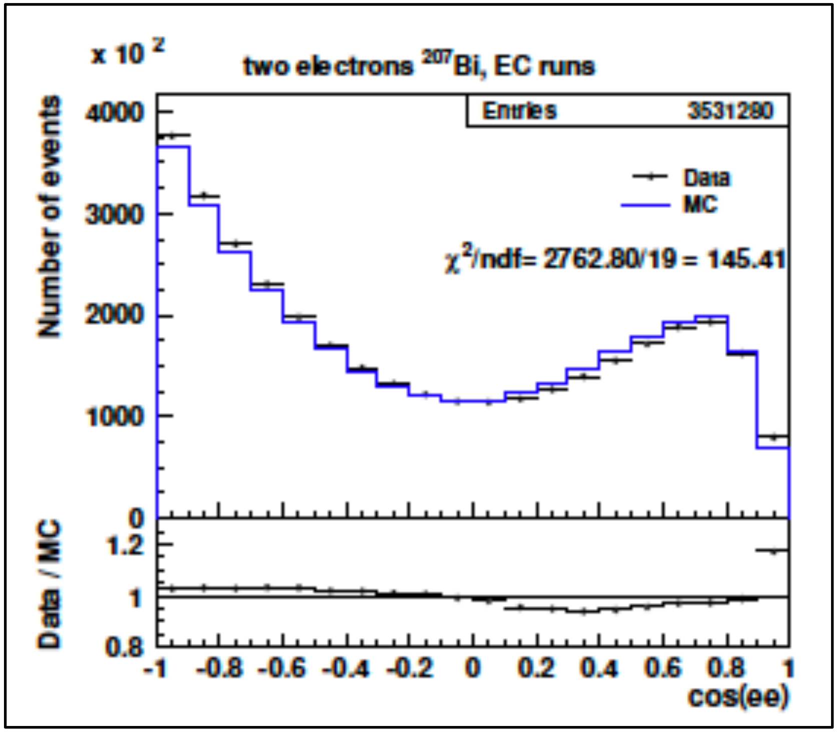
Calibration of angular distribution with ^{207}Bi sources

For energy calibration, we used 60 ^{207}Bi sources (3 per sector)

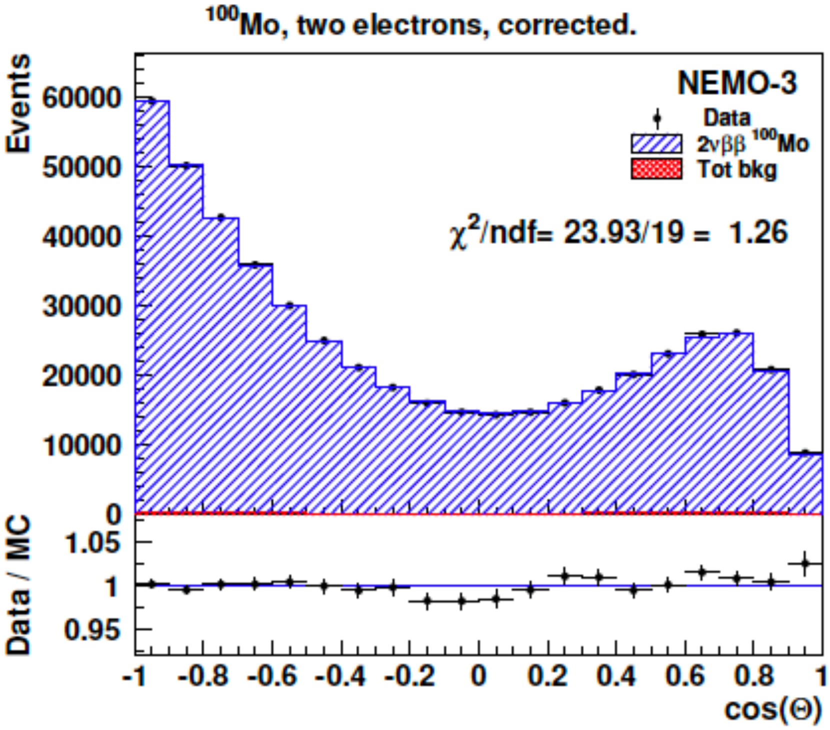
Possibility of emission of 2 EC → calibration of the detector

Distribution checked sector by sector

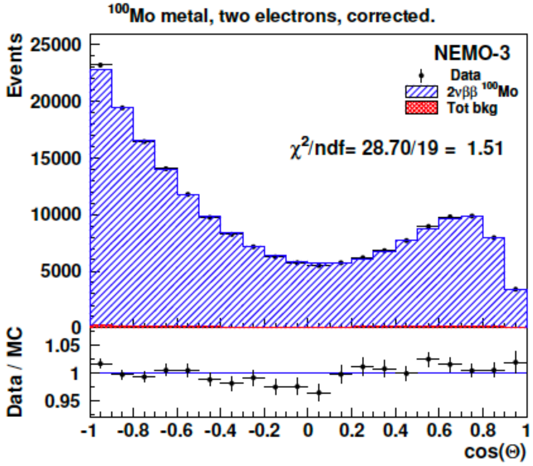


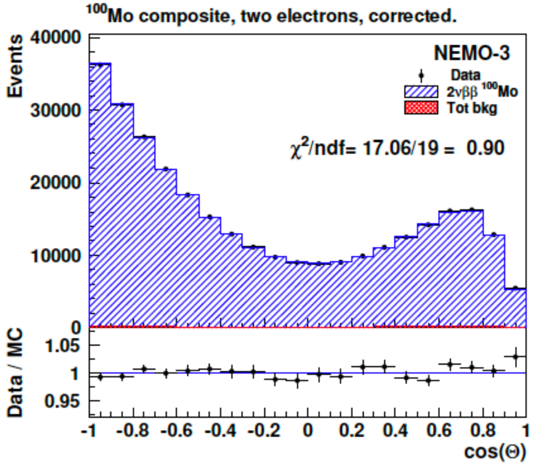


Angular distribution after correction


^{100}Mo, two electrons, corrected.

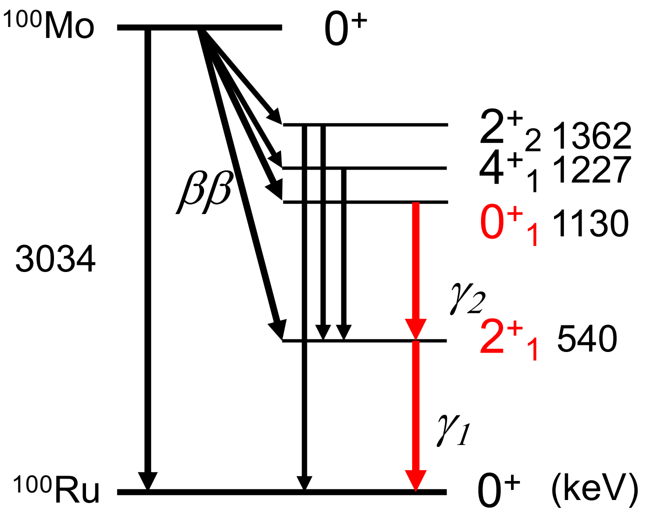
Cross-check with the 2 types of ^{100}Mo sources : Metallic and composite

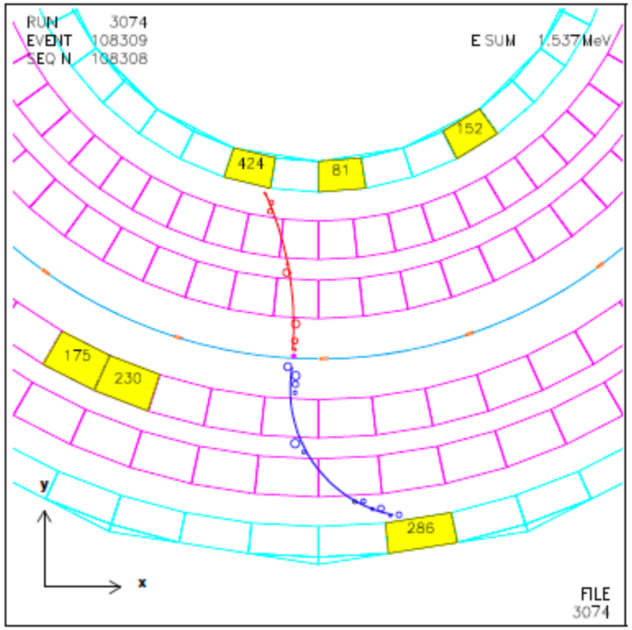

^{100}Mo metal, two electrons, corrected.


^{100}Mo composite, two electrons, corrected.

Angular distribution for ^{100}Mo decay to excited states

Scheme of DBD of ^{100}Mo





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

$$T_{1/2}^{(2\nu)}(0^+ \rightarrow 2_1^+) > 1.1 \cdot 10^{21}\ \mathrm{y}$$

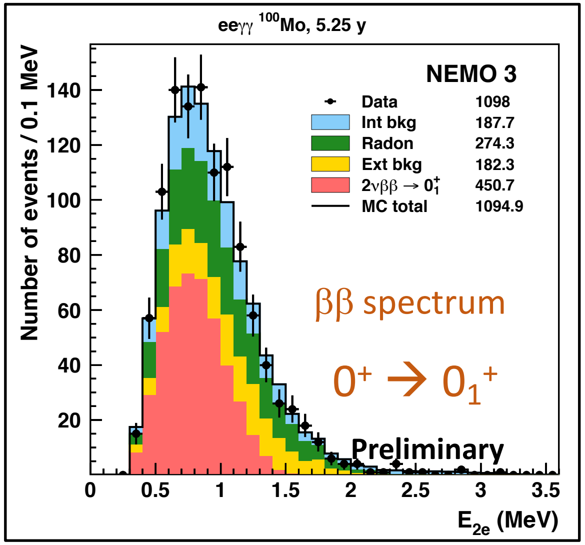
$$T_{1/2}^{(0\nu)}(0^+ \rightarrow 0_1^+) > 8.9 \cdot 10^{22}\mathrm{y}$$

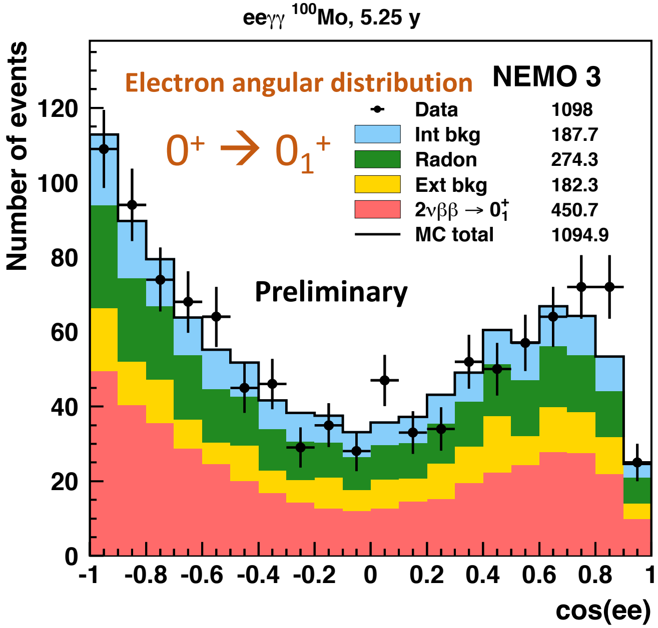
All limits at 90% CL

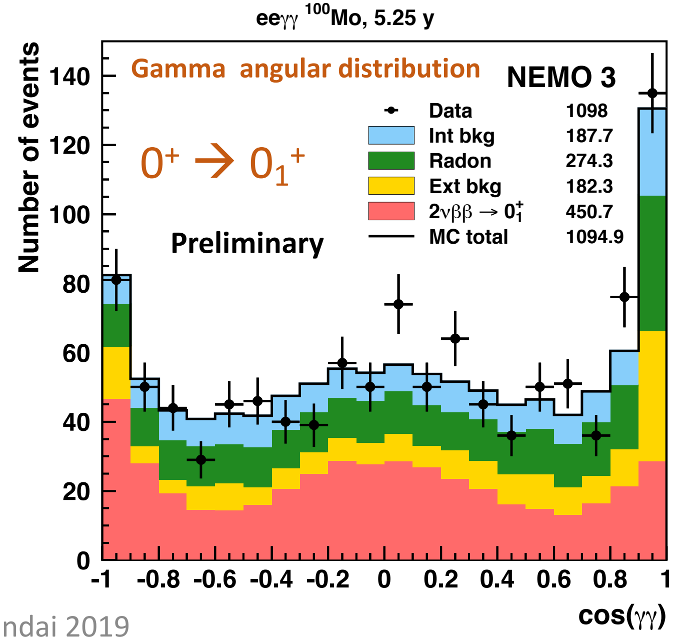
$$T_{1/2}^{(0\nu)}(0^+ \rightarrow 2_1^+) > 1.6 \cdot 10^{23}\ \mathrm{y}$$

Nucl.Phys. A781 (2007) 209-226

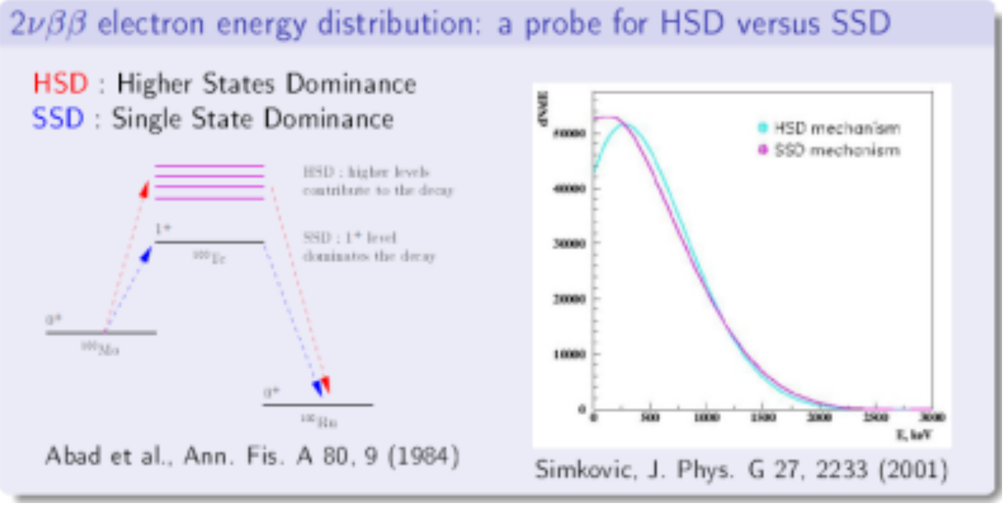
Angular distribution for ^{100}Mo decay to excited states







^{100}Mo HSD vs SSD

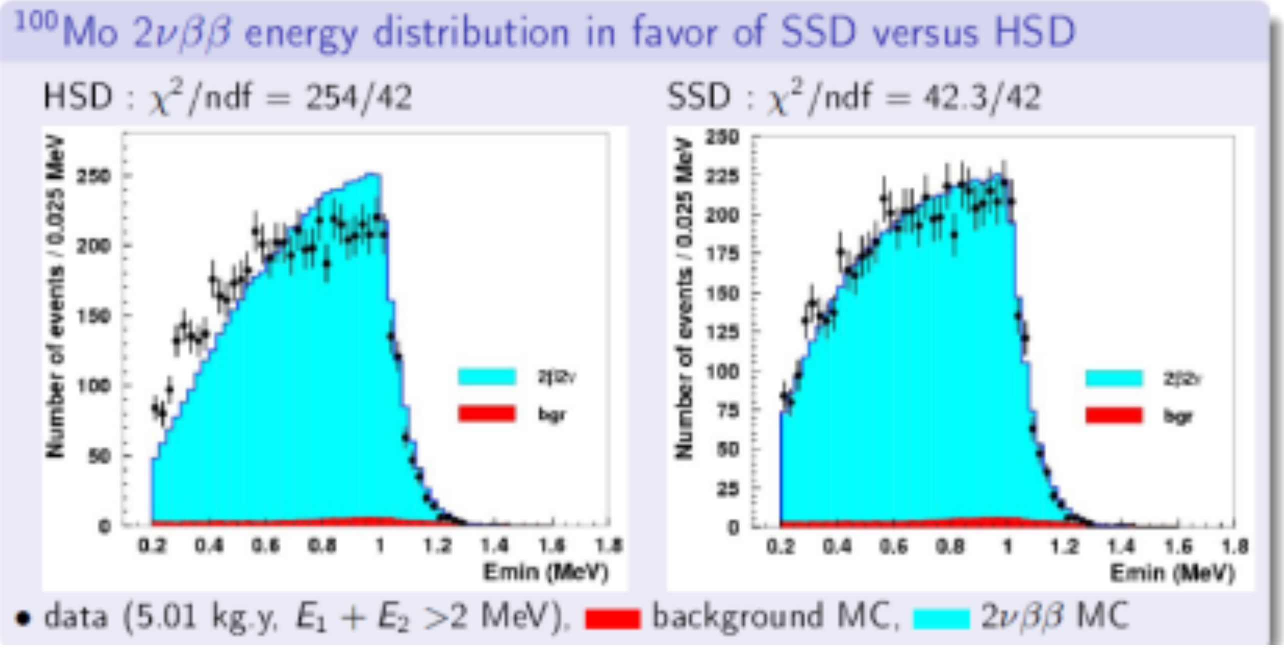


$2\nu\beta\beta$ electron energy distribution: a probe for HSD versus SSD

HSD : Higher States Dominance
SSD : Single State Dominance

Abad et al., Ann. Fis. A 80, 9 (1984)

Simkovic, J. Phys. G 27, 2233 (2001)



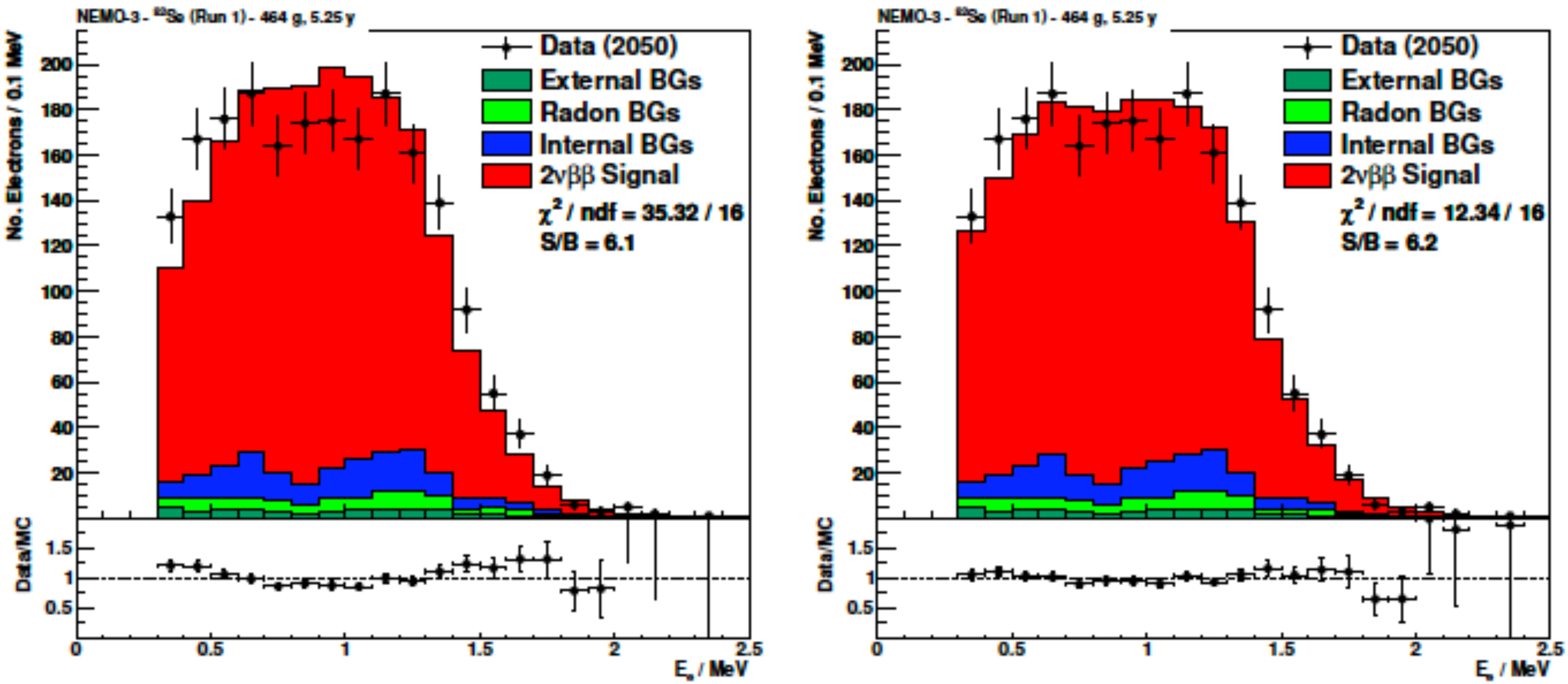
^{100}Mo $2\nu\beta\beta$ energy distribution in favor of SSD versus HSD

HSD : χ^2/ndf = 254/42

SSD : χ^2/ndf = 42.3/42

● data (5.01 kg.y, $E_1 + E_2$ >2 MeV), 🟥 background MC, 🟦 $2\nu\beta\beta$ MC

^{82}Se HSD vs SSD

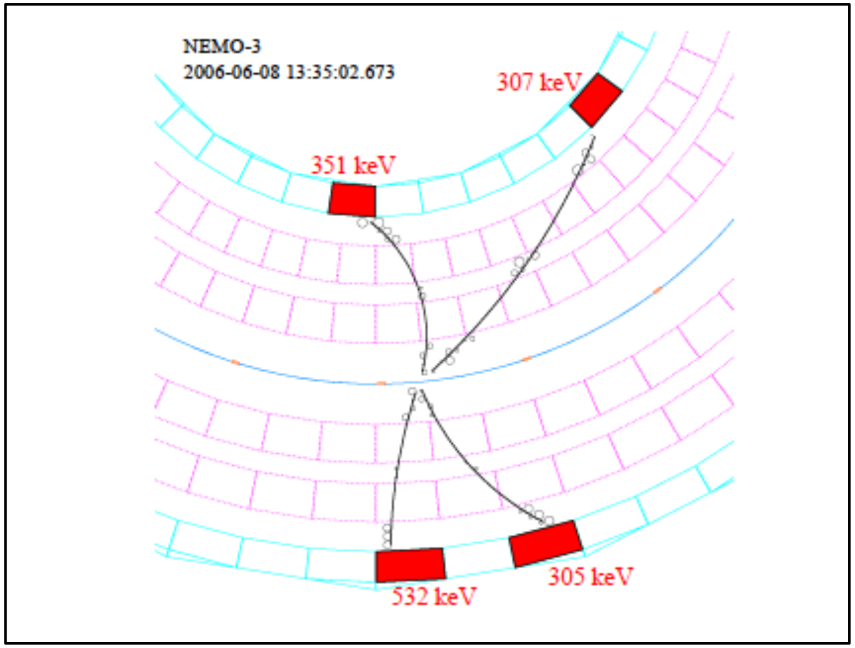


(a) Higher-state Dominated (HSD) (b) Single-state Dominated (SSD)

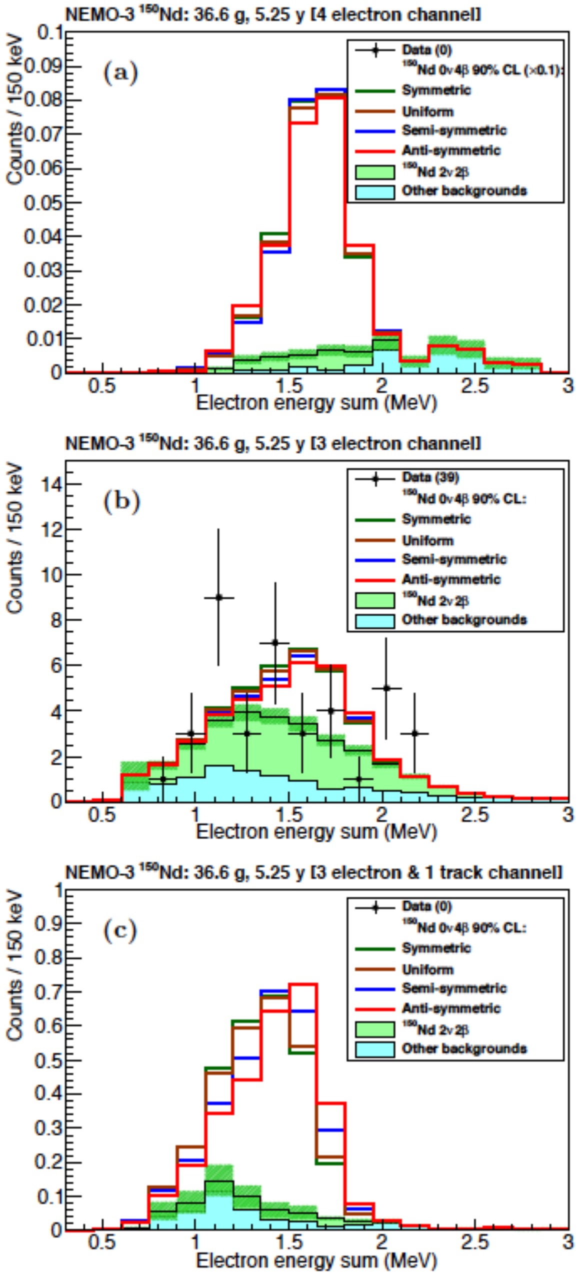
HSD is disfavoured for ^{82}Se

Eur.Phys.J. C78 (2018) no.10, 821

NEMO3 Results : first limit on 0ν4β

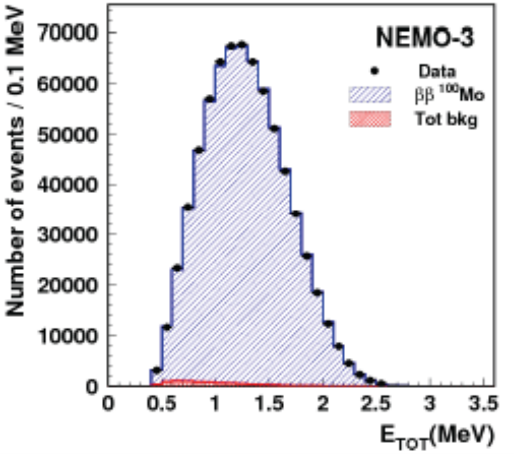


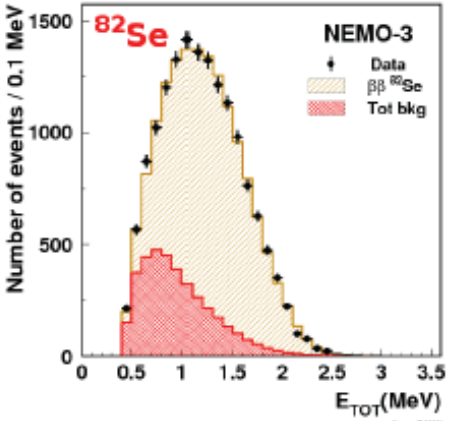
$$T_{1/2}^{0\nu4\beta} > 1.1 \times 10^{21} \text{ years,}$$

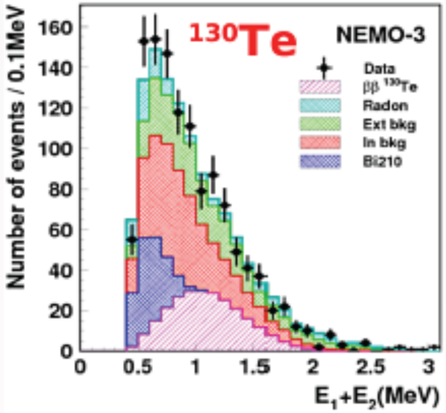


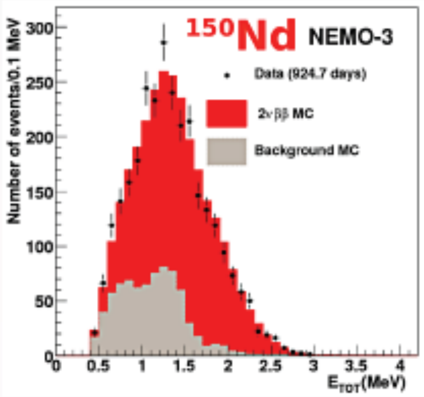
NEMO-3 results

Isotope	Mass (g)	Qββ(keV)	T(2ν) (1E19yrs)	S/B	Comment	Reference
Se82	932	2996	9.6 ± 1.0	4	World's best	Phys.Rev.Lett. 95(2005) 483
Cd116	405	2809	2.8 ± 0.3	10	World's best	*Preliminary*
Nd150	37	3367	0.9 ± 0.07	2.7	World's best	Phys. Rev. C 80, 032501 (2009)
Zr96	9.4	3350	2.35 ± 0.21	1	World's best	Nucl.Phys.A 847(2010) 168
Ca48	7	4271	4.4 ± 0.6	6.8 (h.e.)	World's best	*Preliminary*
Mo100	6914	3034	0.71 ± 0.05	80	World's best	Phys.Rev.Lett. 95(2005) 483
Te130	454	2533	70 ± 14	0.5	First direct detection	Phys. Rev. Lett. 107, 062504 (2011)

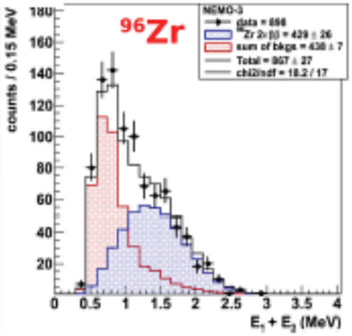


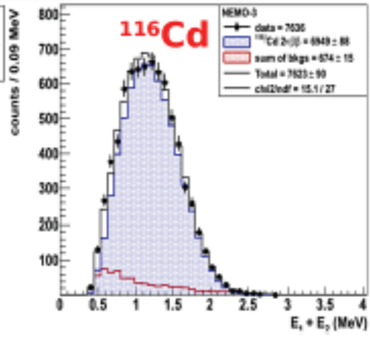


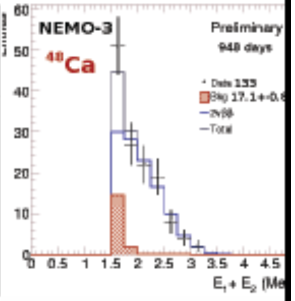




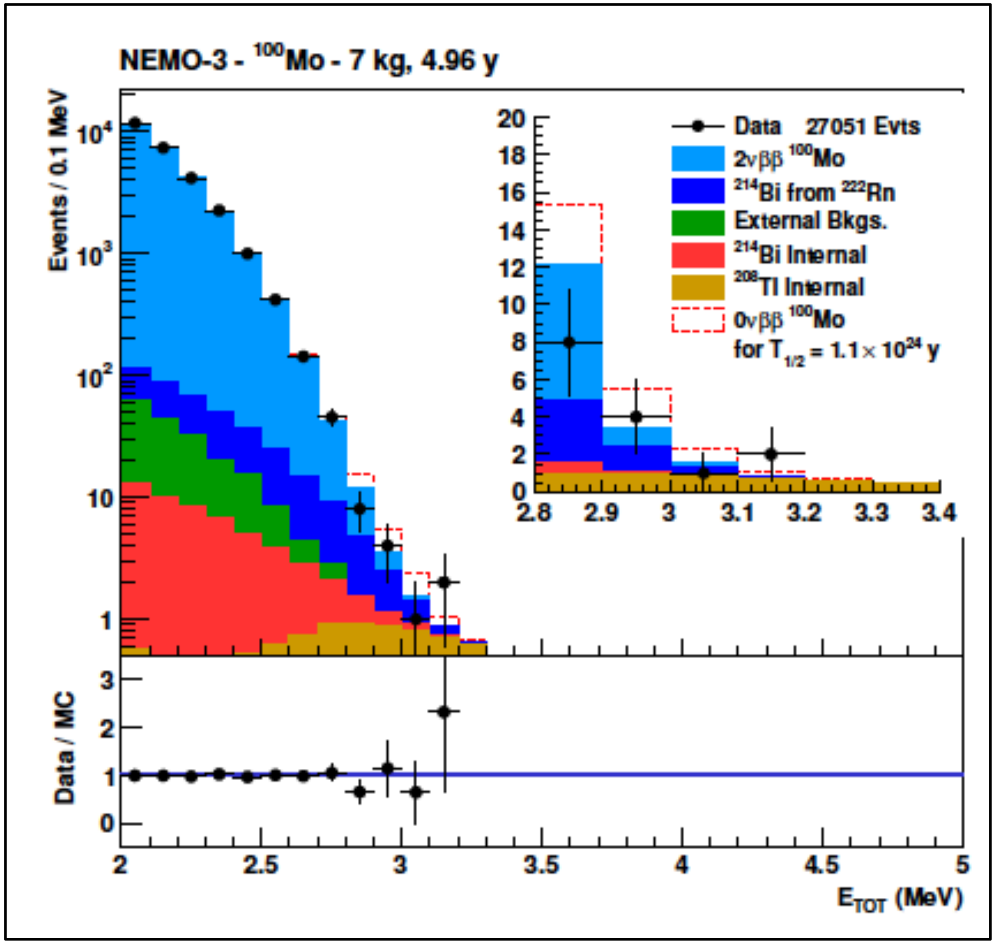
Crucial experimental input for
1) NME calculations
2) Ultimate background characterisation for 0ν



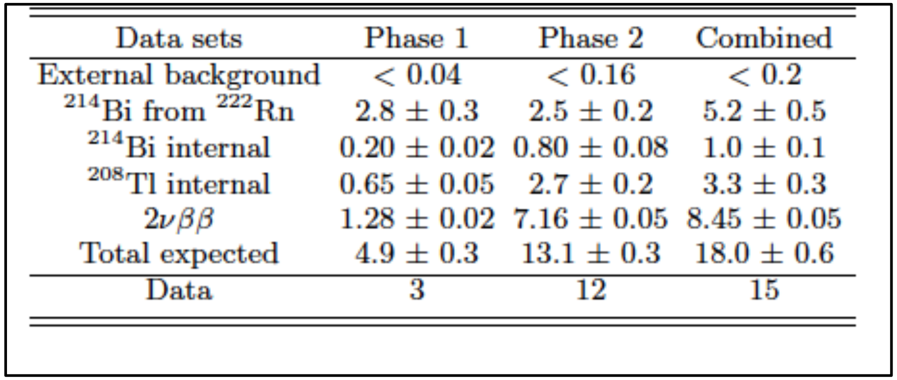




NEMO3 Results



Background contributions

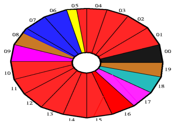


Data sets	Phase 1	Phase 2	Combined
External background	< 0.04	< 0.16	< 0.2
^{214}Bi from ^{222}Rn	2.8 ± 0.3	2.5 ± 0.2	5.2 ± 0.5
^{214}Bi internal	0.20 ± 0.02	0.80 ± 0.08	1.0 ± 0.1
^{208}Tl internal	0.65 ± 0.05	2.7 ± 0.2	3.3 ± 0.3
$2\nu\beta\beta$	1.28 ± 0.02	7.16 ± 0.05	8.45 ± 0.05
Total expected	4.9 ± 0.3	13.1 ± 0.3	18.0 ± 0.6
Data	3	12	15

Background : 3. 10^{-2} evt/y/mole/FWHM

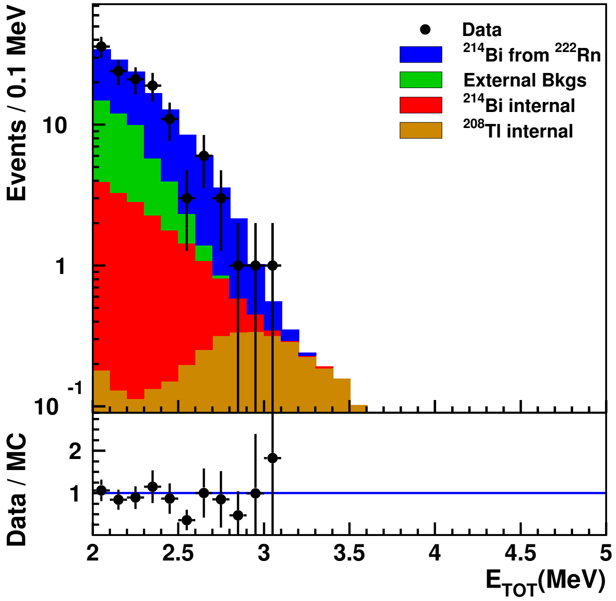
No background beyond 3.2 MeV

Main background components : ββ(2ν) and radon



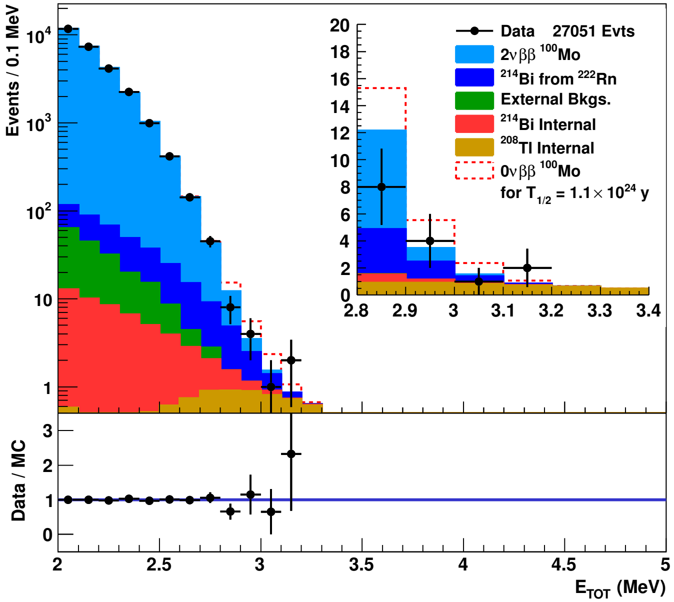
NEMO3 background

- Cu + Te sector



- Background checks
- No events with E > 3.1 MeV
- Exposure of 13.5 kg*y

- ^{100}Mo sectors

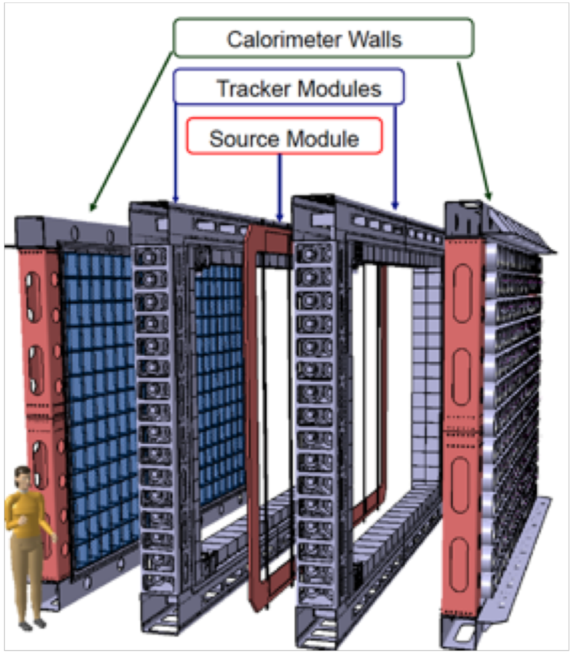


- No events with E > 3.2 MeV
- Exposure of 34.7 kg*y
- Background-free technique for high energy $Q_{\beta\beta}$ isotopes: ^{48}Ca: 4.268 MeV
  ^{150}Nd: 3.371 MeV
  ^{96}Zr: 3.356 MeV

SuperNEMO collaboration

LAL, Universit´e Paris-Sud 11, CNRS/IN2P3, Orsay, France
INL, Idaho Falls, Idaho, USA
ITEP, Moscow, Russia
University College London, United Kingdom
Joint Institute for Nuclear Research, Dubna, Russia
University of Zaragoza, Spain
LPC Caen, ENSICAEN, Université de Caen, France
CENBG, Université de Bordeaux, France
University of Manchester, United Kingdom
Tokushima University, Japan
FMFI, Comenius University, Bratislava, Slovakia
KEK, Tsukuba, Japan
USMBA, Fes, Morocco
Fukui University, Japan
UTFSM, Valparaiso, Chile
KEK,1-1 Oho, Tsukuba, Ibaraki 305-0801 Japan
USMBA, Fes, Morocco
Fukui University, Japan
University of Warwick, United Kingdom
Osaka University, Osaka, Japan
Saga University, Saga, Japan
FMFI, Comenius University, Bratislava, Slovakia
Imperial College London, United Kingdom
IUF, Paris, France
Jyväskylä UniversityFinland
INR, Kyiv, Ukraine
Charles University in Prague, Czech Republic

SuperNEMO demonstrator



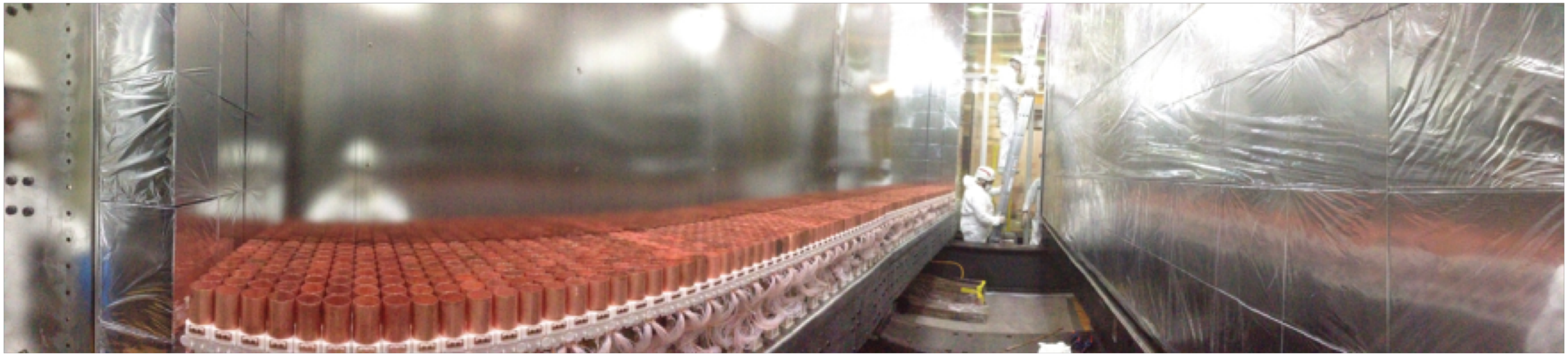
Demonstrator : 7 kg of ^{82}Se
^{150}Nd and ^{96}Zr possible in future

Expected sensitivity for 14 kg.year of ^{82}Se

No background expected

$T_{1/2} > 6\ 10^{24}$ yr   (90 % CL)

$\langle m_\nu \rangle < 0.16 – 0.40$ eV

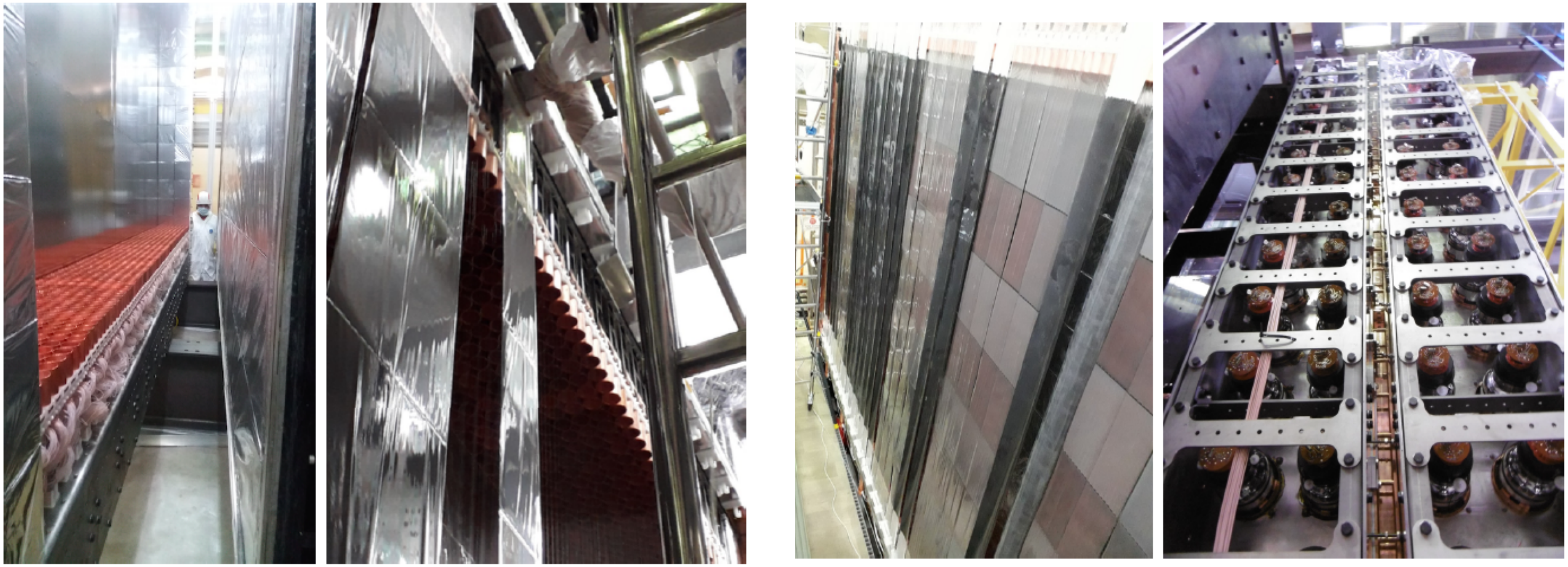


SuperNEMO calorimeter

Calorimeter “brick”

$\Delta E/E$:4% at $Q_{\beta\beta}$ (8% NEMO3)
440 8’’ PMT and 150 5’’ PMT
Scintillation light simulation
Digitisation of the pulses

SuperNEMO sources



7 kg of ^{82}Se
Radiopurity measure by BiPo detector limits about few tens of μBq/kg in 208Tl
Final radiopurity meausred by the detector itself

Detector is assembly and closed
Commissioning in progress, data taking this spring

Demonstrator physical goals

0νββ: $T_{1/2} > 6 \times 10^{24}$ years; $\langle m_\nu \rangle < 160\text{-}400$ meV

Exotic 0νββ mechanisms

2νββ: SSD/HSD discrimination at 5σ level

Probe nuclear physics by measuring g_A

Lorentz invariance violation test

Alternative isotopes: ^{150}Nd and ^{48}Ca, with high $Q_{\beta\beta}$

0ν4β: for ^{150}Nd

Summary

- tracko-calo allows to measure the full kinematics
- High background rejection allows precision measurements with ββ(2β)
- NEMO3 allows to extract nuclear physics data (HSD vs SSD)
- First limit for quadriple beta decay
- Mesurement of all kinematics parameters: possibility to determine the process in case of signal
- SuperNEMO will start data taking this Spring
- Presently difficult tp extrapolate tracking detector at high mass
  but how to believe a ββ(0ν) signal without identification of electrons ?