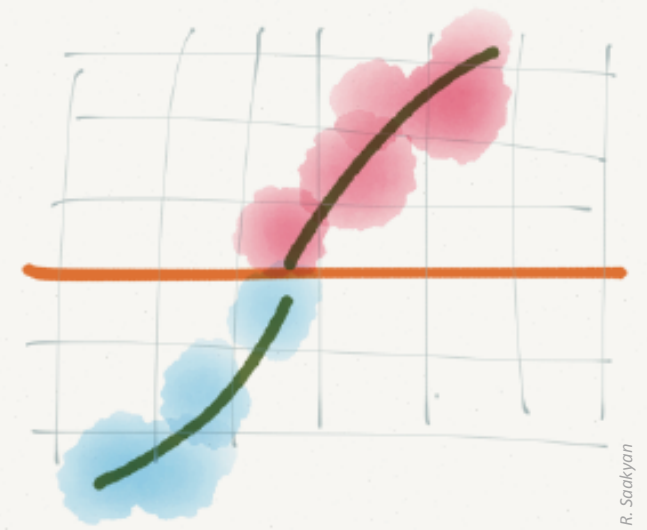
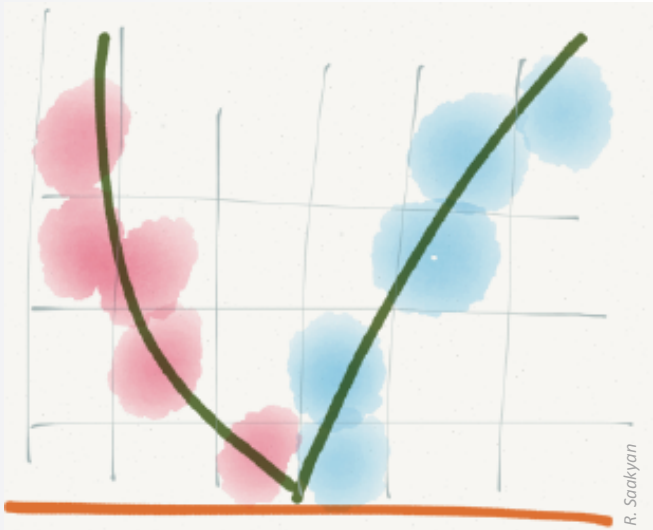
SuperNEMO





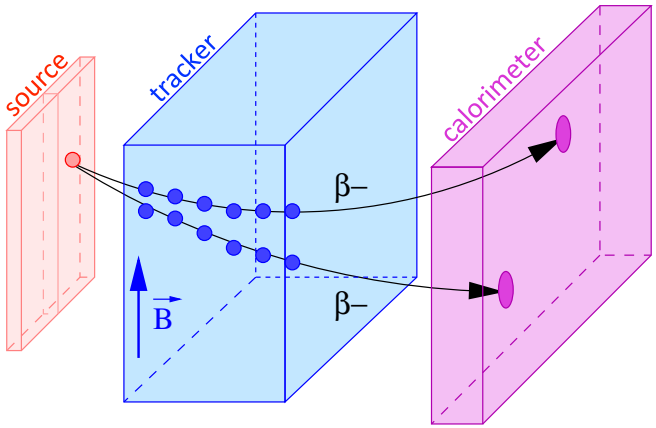
DBD workshop – APC – 04 September 2018

Christine Marquet

cnrs IN2P3 Les deux infinis
université de BORDEAUX
LP2iB ENBG

Tracker-calorimeter Technique

Key Features



- Particle ($e^{\pm}$, γ, α) identification
- Kinematic : $E_{individual}$, θ, tof

→ Full topological event reconstruction ⊕

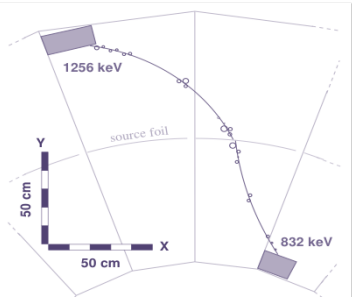
- Source separated from detector → (almost) Any isotope ⊕

- Poorer efficiency & energy resolution than “homogeneous” detectors ⊖

Tracker-calorimeter Technique

Full topological event reconstruction

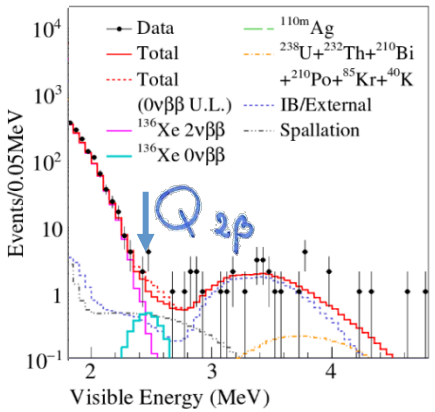
Signal signature : 2e-
« smoking gun » evidence



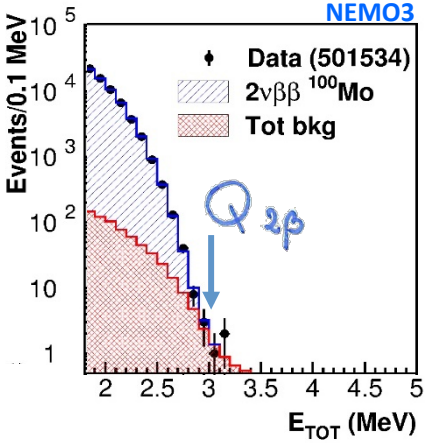
Candidate ^{100}Mo 2β Event in NEMO-3

Background
suppression & control

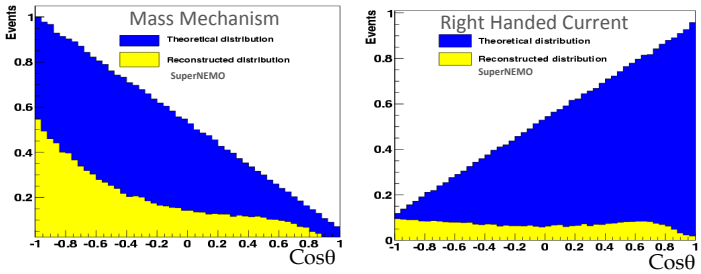
KamLAND-Zen

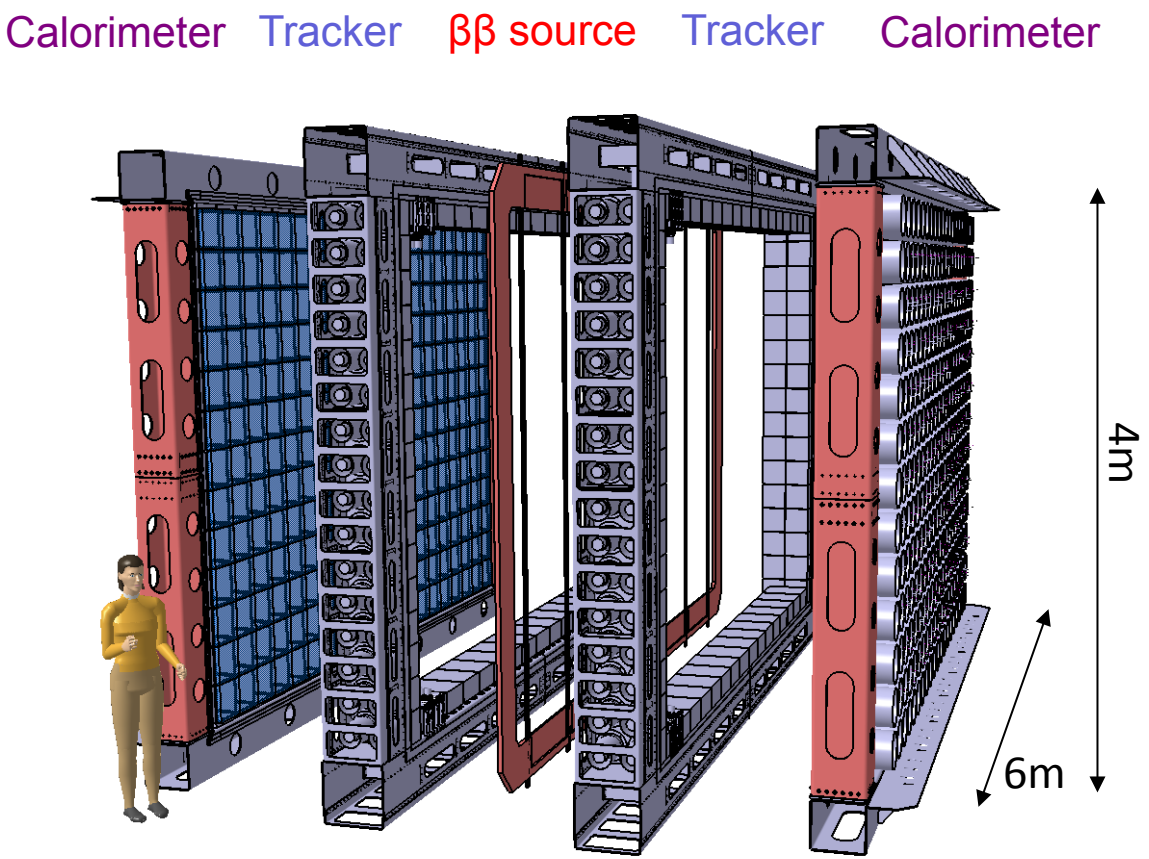


NEMO3

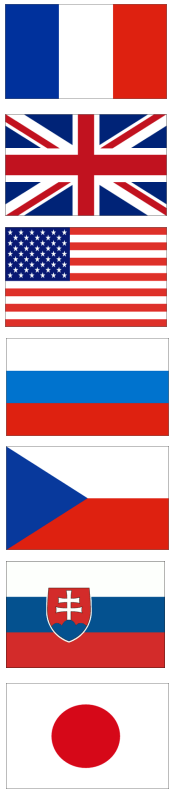


ββ0ν mechanisms



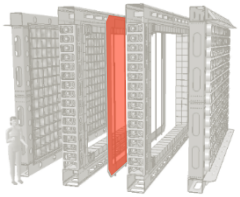


Demonstrator Module



22 laboratories
140 members

Located in Modane underground Laboratory (LSM) at ~4800 m.w.e



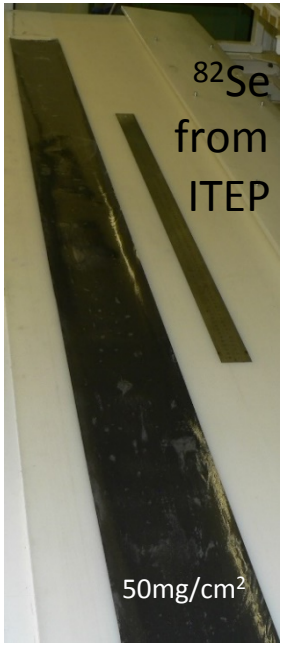
Source

6 kg of ^{82}Se

+ 0.333 kg of Cu

$Q_{2\beta}$=2.998 MeV

$T_{1/2}^{2\nu}$=9.6 10^{19} y



R&D on Purification methods

- Barium precipitation (INL, USA)
- Double distillation (ECP, Russia)
- Chromatographic via ion exchange (JINR, Russia)

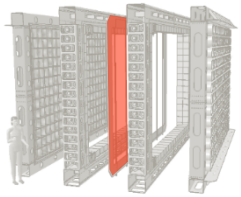
R&D on Source foil production 34 foils

- (^{82}Se + PVA) dried on irradiated mylar (ITEP, Russia)
- (^{82}Se + PVA) Molded and sandwiched into mylar (LAPP, France)

Achieved radiopurity 22±10 μBq/kg ^{208}Tl < 290 μBq/kg ^{214}Bi

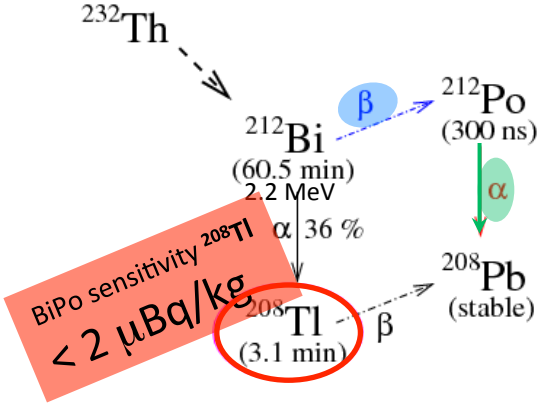
Radiopurity improvement / NEMO3 (> factor 10 for ^{82}Se, factor ~5 on ^{208}Tl for ^{100}Mo)

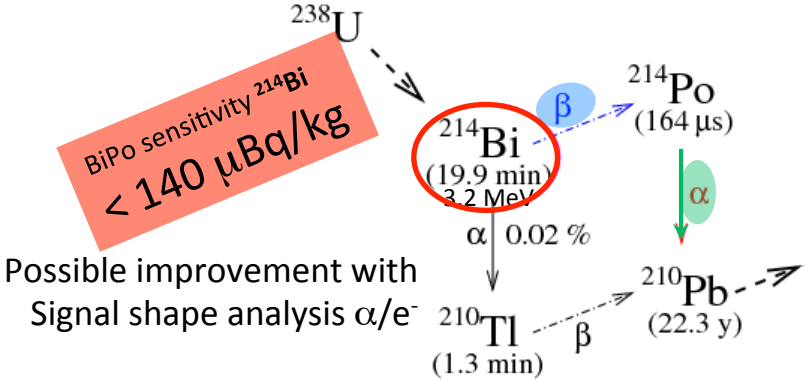
Improvement on chromatographic method should be possible (under study)



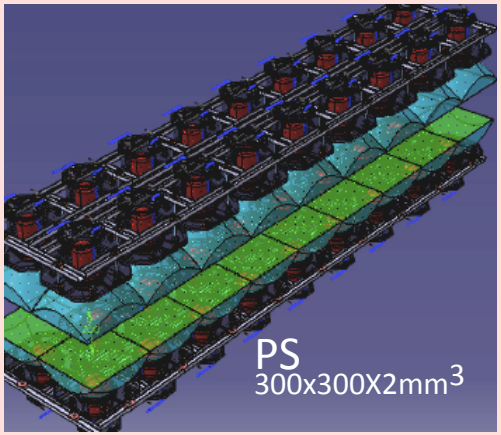
Source

BiPo detector: for ^{214}Bi & ^{208}Tl measurements of thin materials

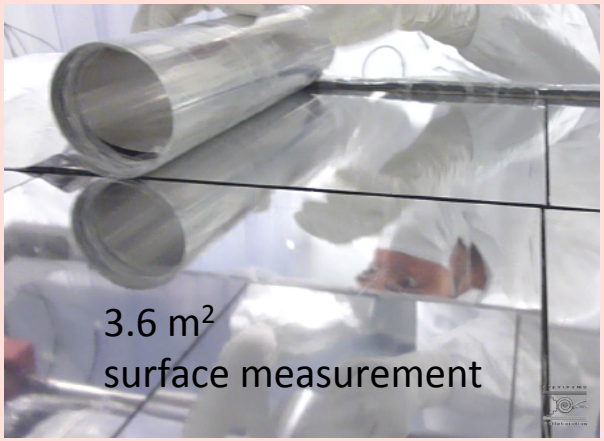




Possible improvement with
Signal shape analysis α/e⁻



40 X 2 Optical modules



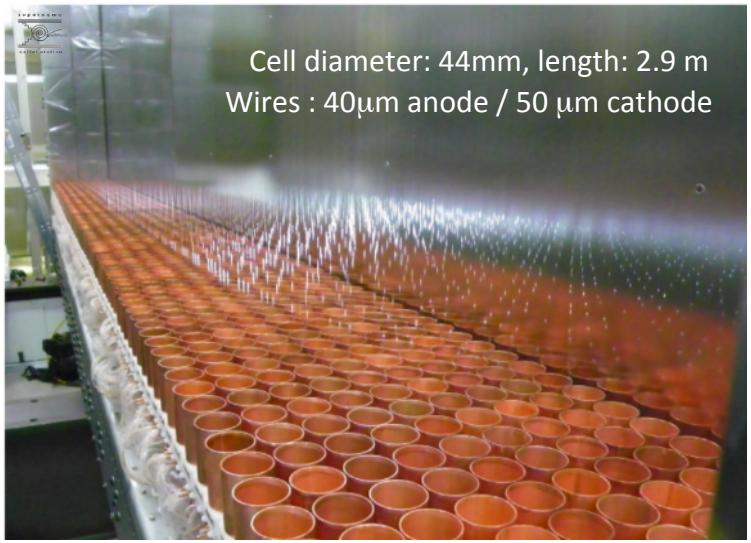
Rn tightness & Nitrogen flush

BiPo detector

At LSCanfranc

Tracker

2034 drift cells in Geiger mode



Radiopure (gamma & radon)

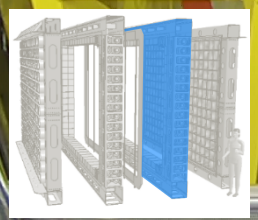
- Ultrapure materials : copper, steel, duracon
- Construction under clean constraints
- Sealing strategy

First Rn test : 0.16 ± 0.05 mBq/m^3
Objectives: 0.15 / NEMO3: 6.46±0.05 mBq/m^3

σ_l = 13 mm
σ_t = 7 mm

Prototype 90 cells
Higher length: 3.7 m

Robotic construction

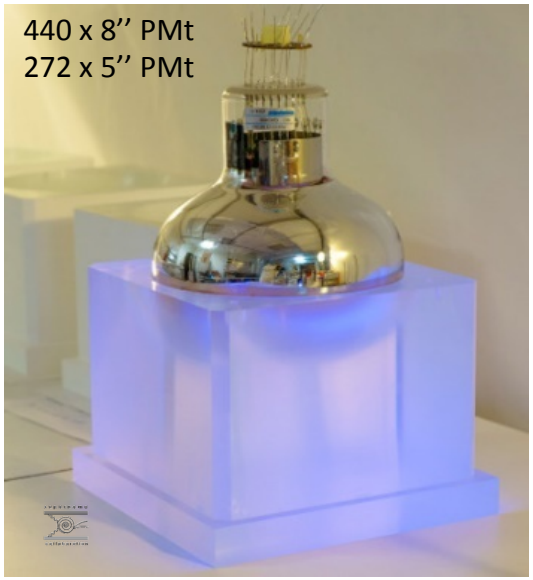


First Tracker

in LSM

supernemo collaboration

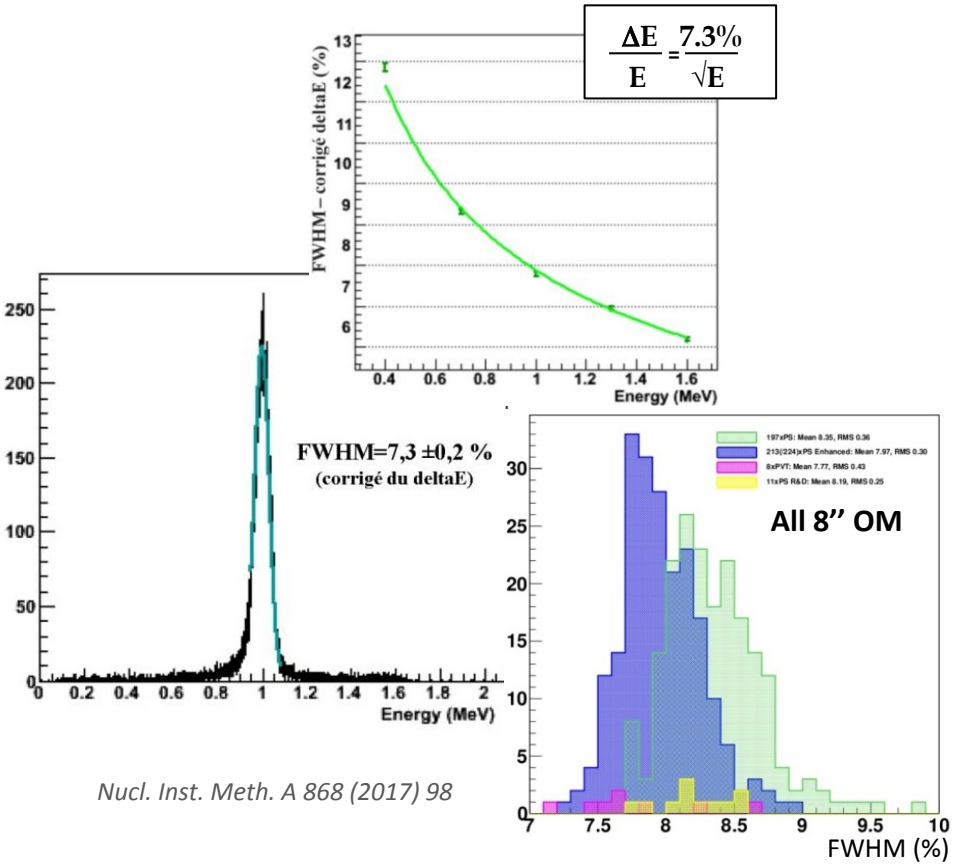
712 Optical modules



New PS (Envinet)
New PMts (Hamamatsu)
R&D on new radiopure glass

Time resolution : 400 ps @ 1 MeV
Calibration accuracy < 1%

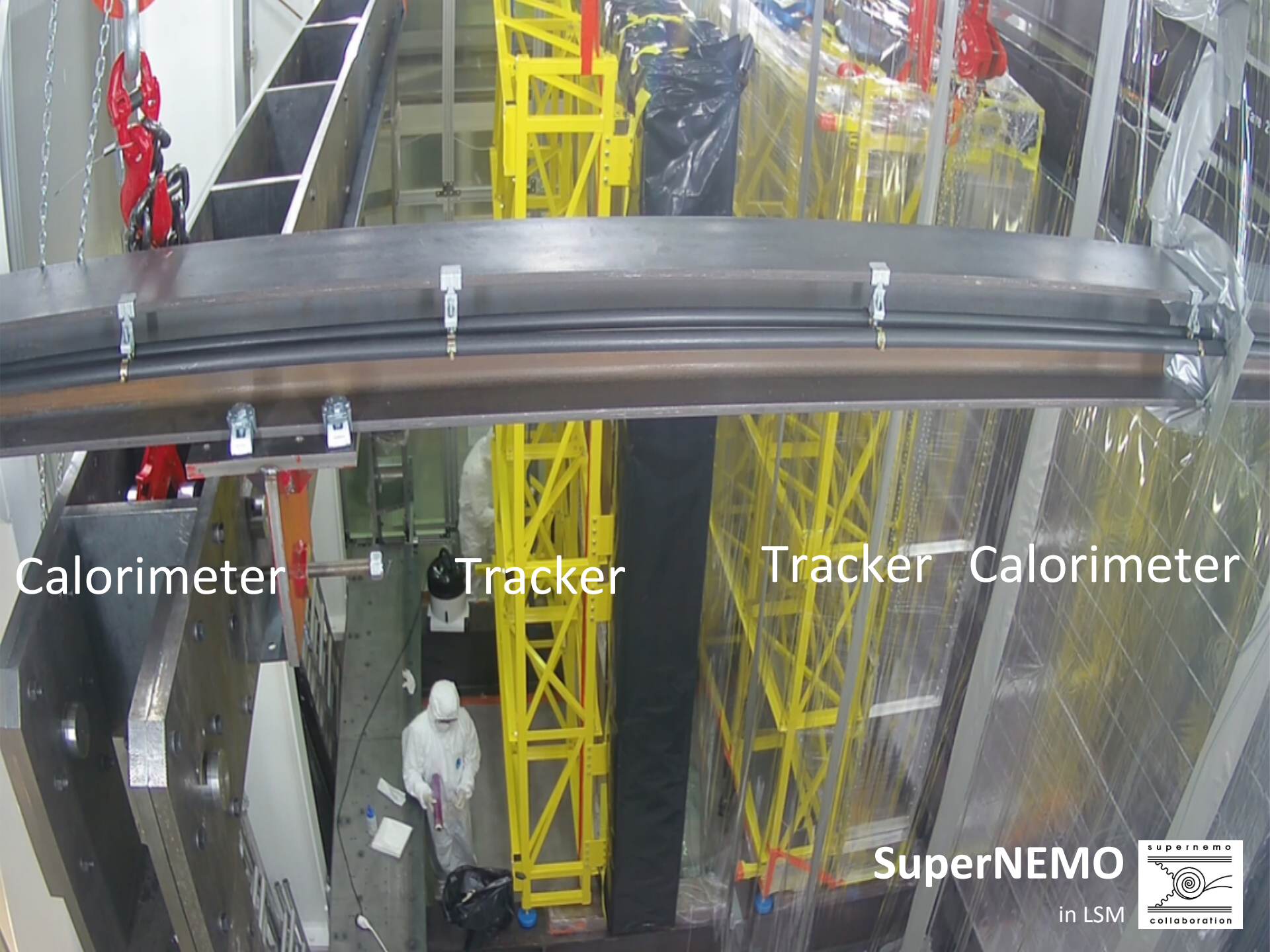
Energy resolution:
8% FWHM @ 1 MeV (15% NEMO3)

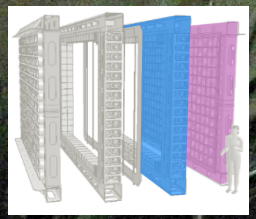


Nucl. Inst. Meth. A 868 (2017) 98

First calorimeter wall

in LSM

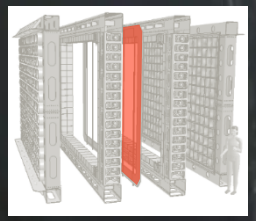

Calorimeter
Tracker
Tracker
Calorimeter
SuperNEMO
in LSM
supernemo
collaboration



SuperNEMO

in LSM

supernemo collaboration

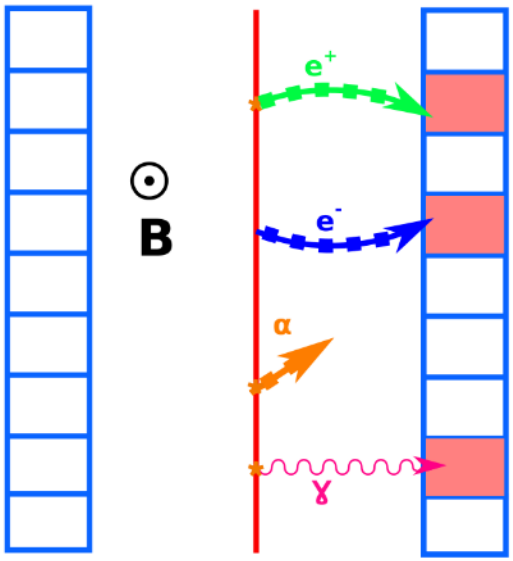


Source frame

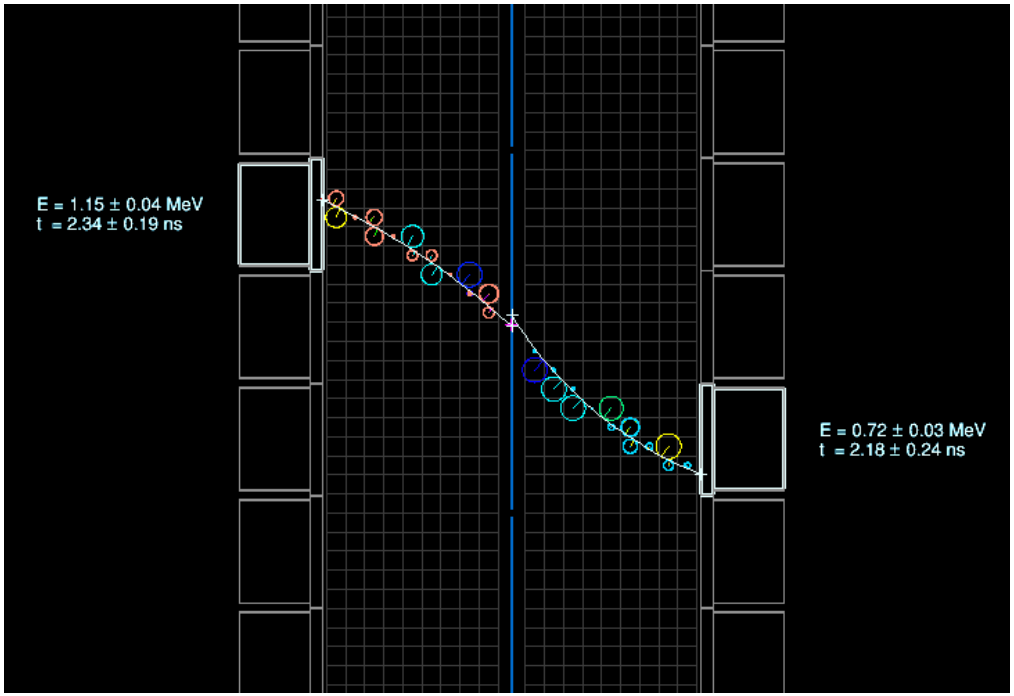
in LSM

Calibration vessels

Top of the detector - LSM



Particle identification

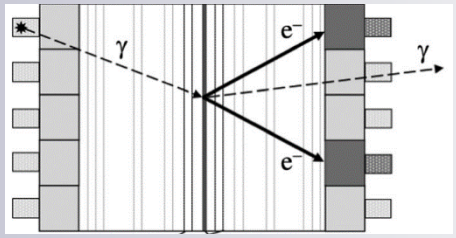


Simulated ββ event in SuperNEMO

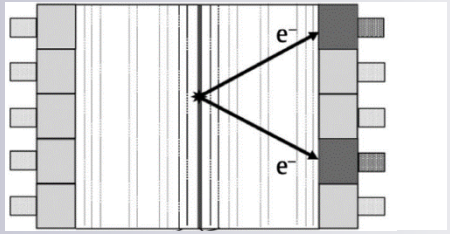
Background identification

Background sources

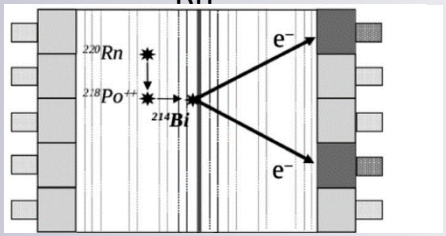
External: n, γ

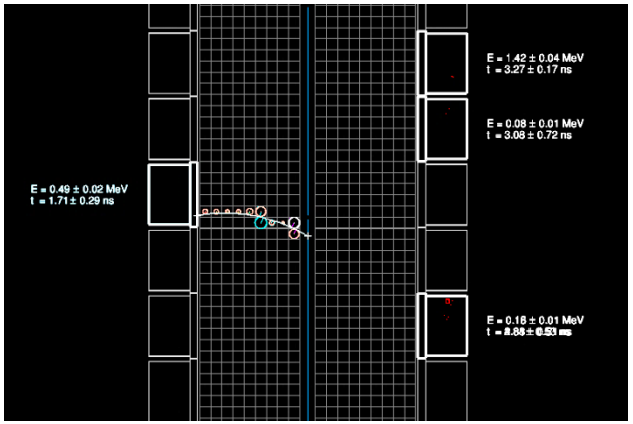


Internal β isotopes: ^{214}Bi, ^{208}Tl + 2ν



Rn



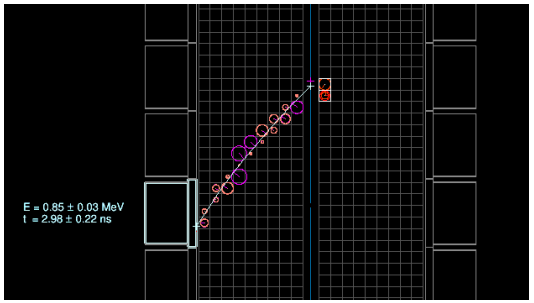


eγγγ event (SuperNEMO simulation)

Rejection
+
control
(dedicated channels)

External	<0.1
Radon	0.20
^{214}Bi	0.04
^{208}Tl	0.04
2β2ν	0.10
Total	<0.50

SuperNEMO 17.5 kg.an

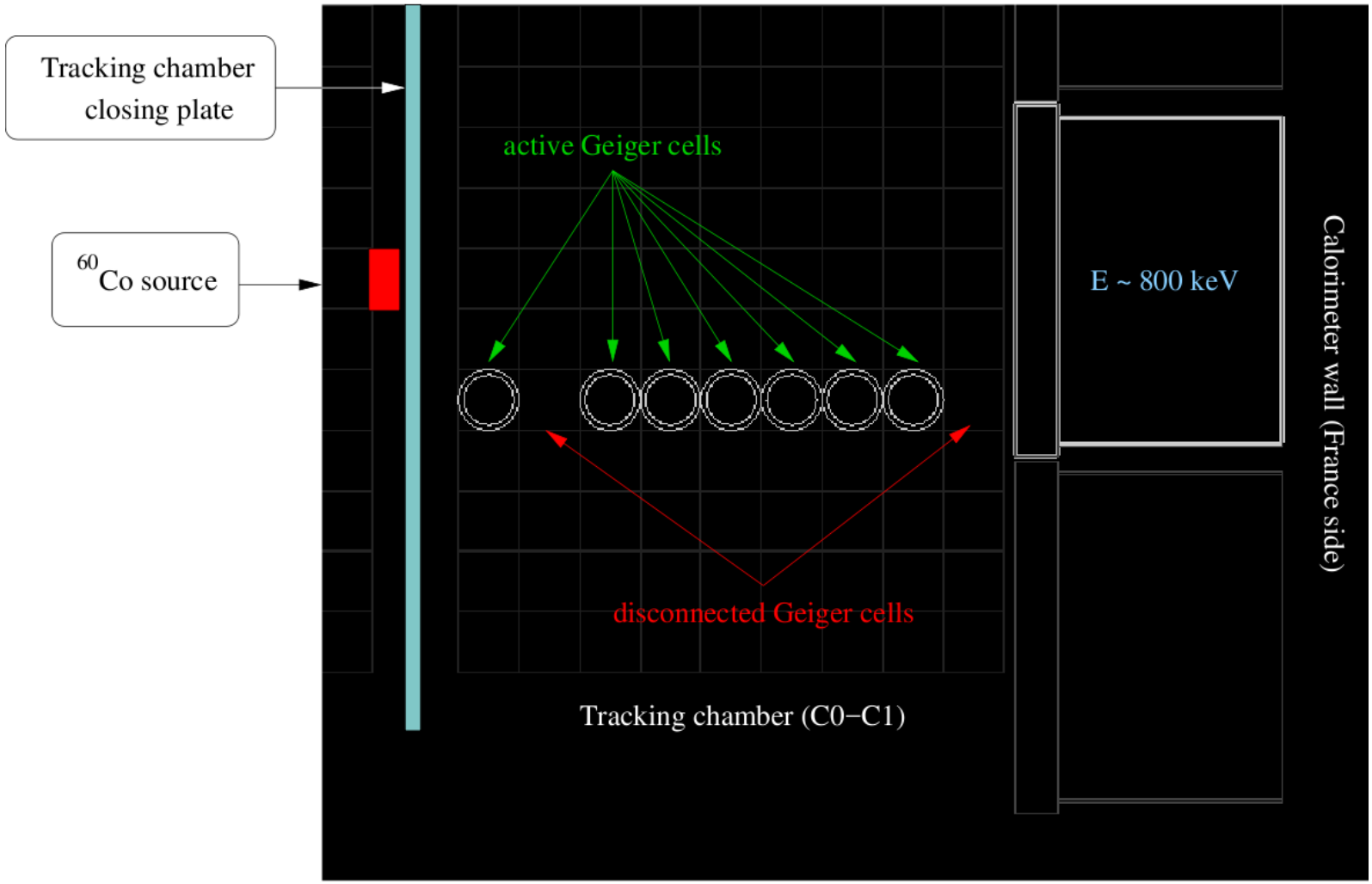


eα event (SuperNEMO simulation)

6 10^{-5} events kg^{-1} y^{-1} keV^{-1}

NEMO3: 10^{-3} events kg^{-1} y^{-1} keV^{-1}

First track


Tracking chamber closing plate
^{60}Co source
active Geiger cells
E ~ 800 keV
Calorimeter wall (France side)
disconnected Geiger cells
Tracking chamber (C0−C1)

SuperNEMO Phase 1: 6kg ^{82}Se (2018-2020)

Detector closure : September 2018

- Test the detector performances (background : 1 year)

^{82}Se 17.5 kg.y $T_{1/2}(0\nu) > 5\ 10^{24}$ y $\langle m_\nu \rangle < 0.26\text{-}0.51$ eV

NEMO3 ^{82}Se: $T_{1/2}(0\nu) > 0.25\ 10^{24}$ y $\langle m_\nu \rangle < 1.2\text{-}2.3$ eV

SuperNEMO Phase 2: few kg of ^{150}Nd in the demonstrator

Enrichment under progress in Russia : new centrifugation method

Sensitivity of 6kg ^{150}Nd ~ 12 kg ^{82}Se

First investigation with high exposure

SuperNEMO Phase 3 : 100 kg scale

R&D on the compactness (cost, efficiency…)

Improvement on energy resolution feasible

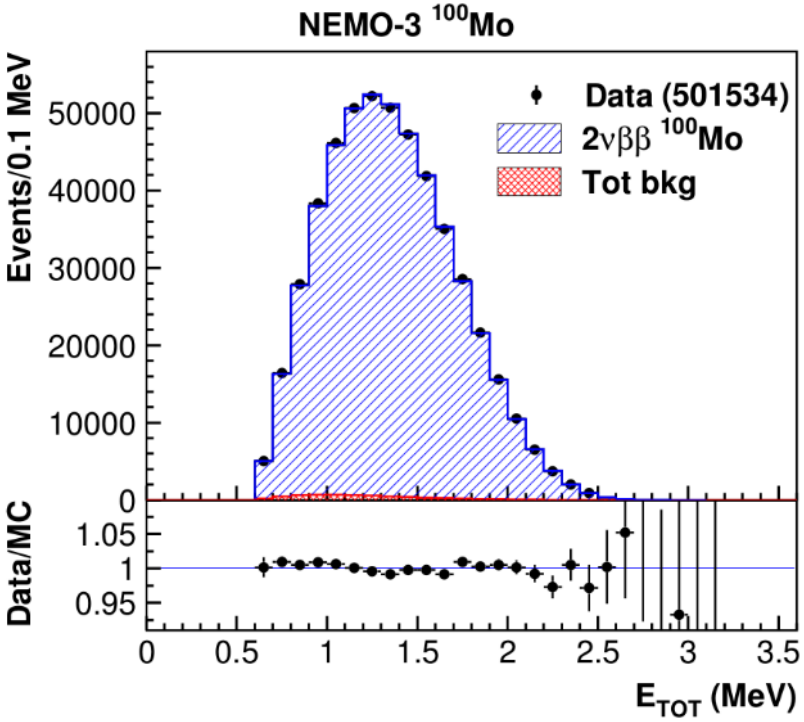
Goal : $\langle m_\nu \rangle < 0.05$ eV

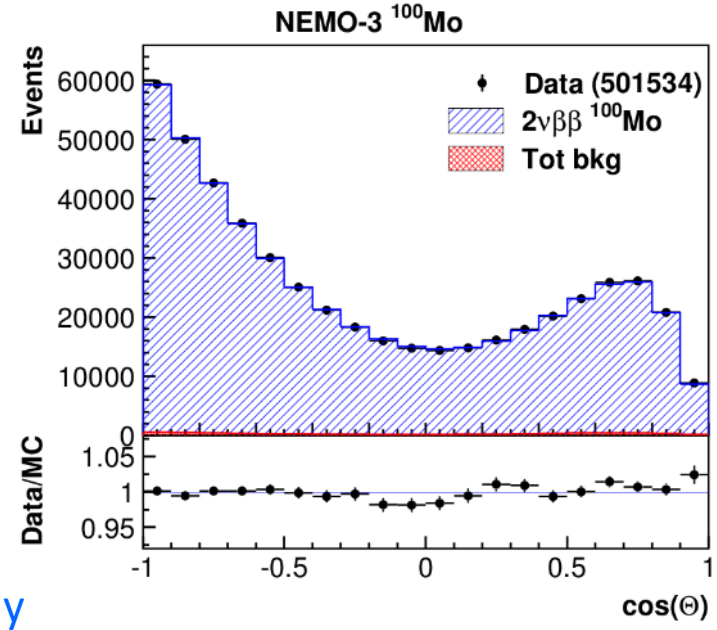
Unique experiment: ++ if signal in another experiment

- to provide DBD « smoking gun » evidence … on (almost) any isotope
- To identify the DBD mechanism
- By-products : gA …

NEMO3 : **5 10^5** $2\beta2\nu$ events (34.3 kg.y of ^{100}Mo)

S/B=79



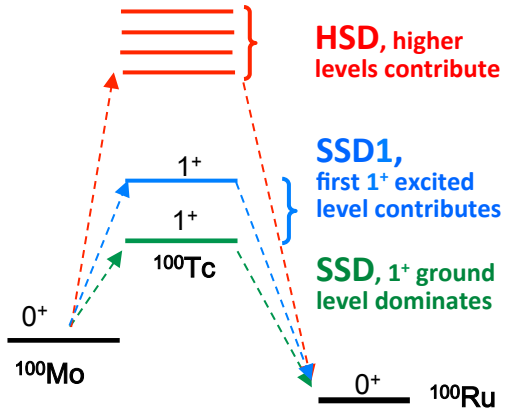


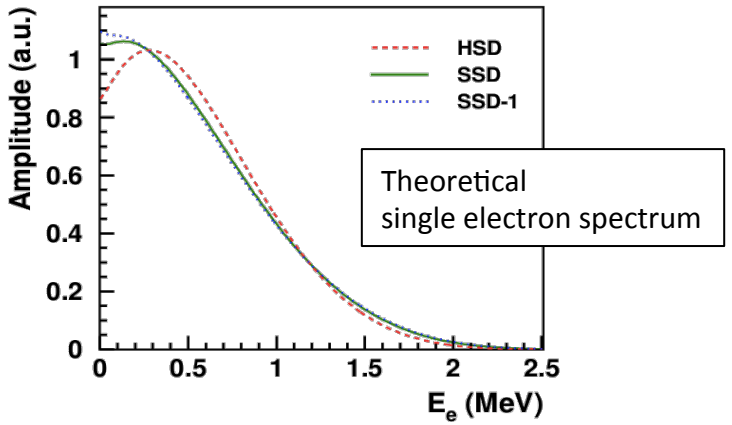
$T_{1/2} = (6.81 \pm 0.01(stat) \pm 0.46(syst)) \times 10^{18}$ y

First precise measurement of the angular distribution

To be published (2018)

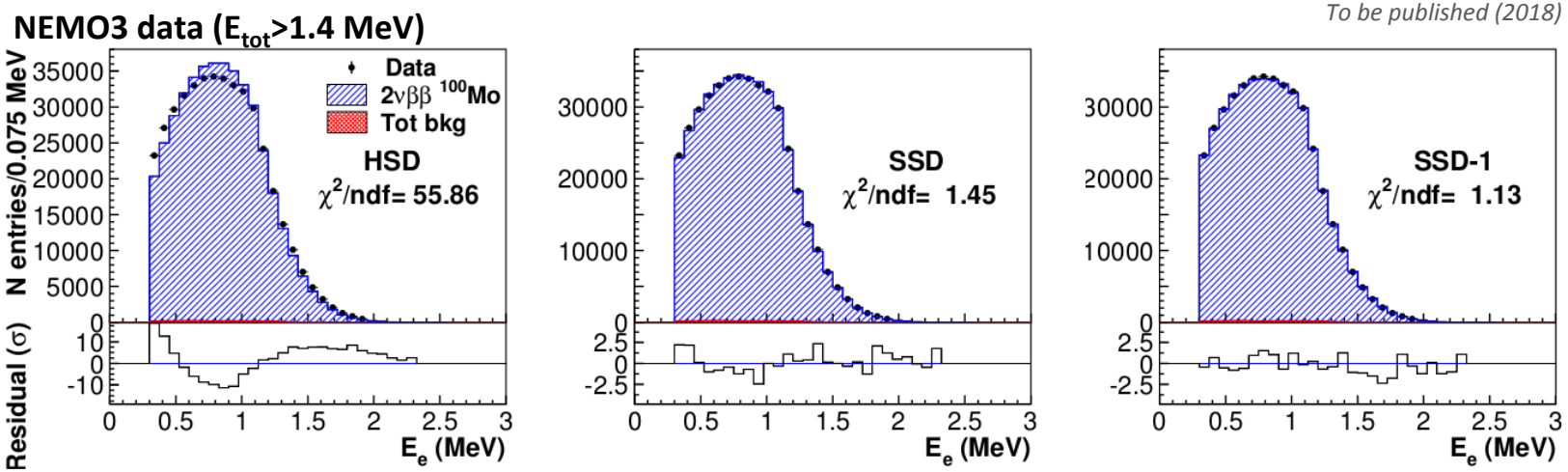
$\beta\beta(2\nu)$ SSD/HSD



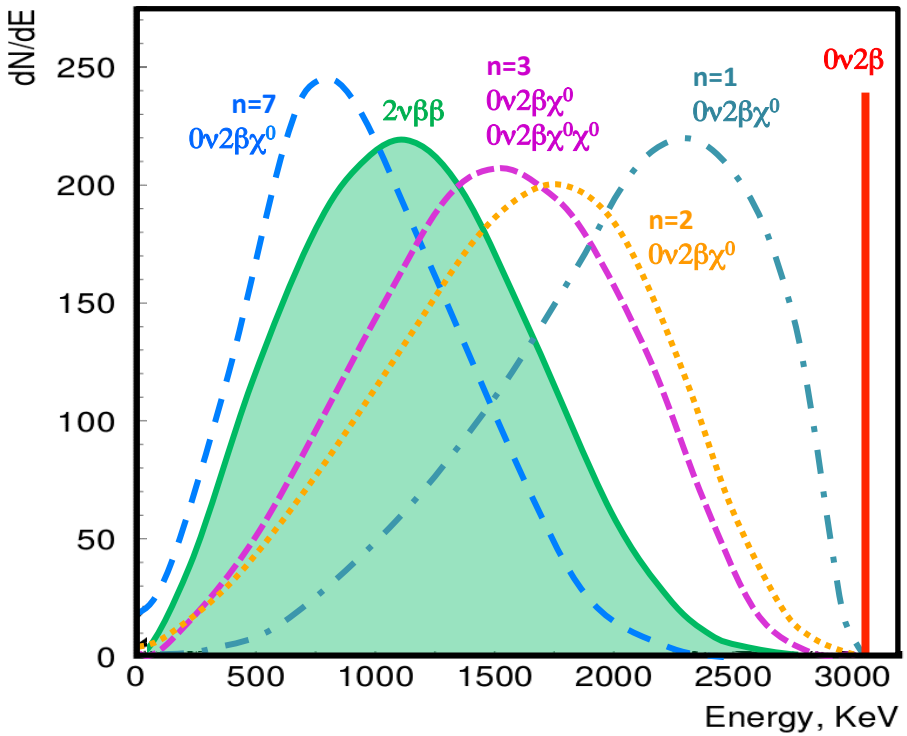


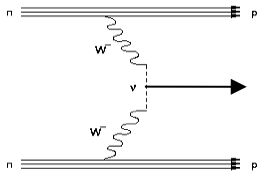
HSD mechanism rejected from ^{100}Mo single e$^-$ spectra

To be published (2018)



$\beta\beta(0\nu)$ with Majoron emission





Majoron coupling constant

NEMO3

$\langle g_{ee} \rangle < (1,6\text{-}4,2)\ 10^{-5}$

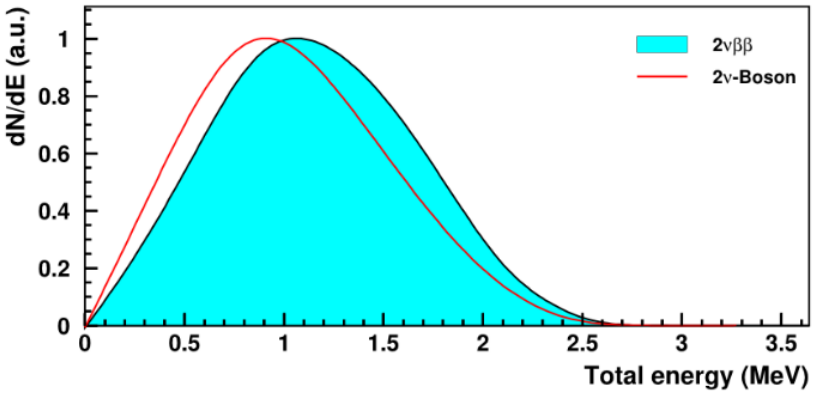
n=1, $0\nu2\beta\chi^0$

Phys. Rev. D 89 (2014) 111101

Pauli principle violation ? (stronger for ν)

Bosonic component impact on ββ2ν : - total rates of the decays
- energy dsitributions
- angular distributions

^{100}Mo (0+ g.s.)



NEMO3

$P^{2\nu}_{tot} = \cos^4\chi\, P^{2\nu}_{f} + \sin^4\chi\, P^{2\nu}_{b}$

$\mathbf{Sin^2\chi < 0.27}$

Pure bosonic statistics excluded

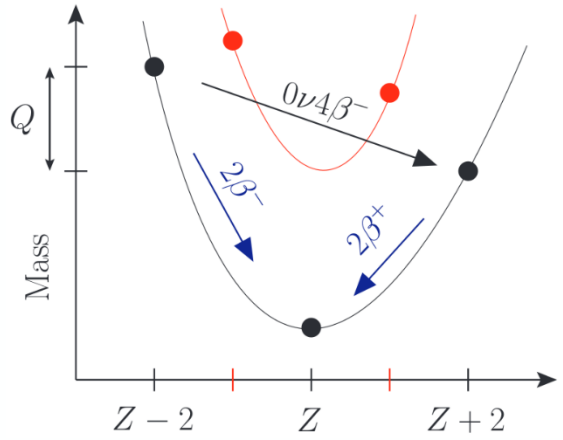
Remark : higher expected bosonic sensitivity for ^{100}Mo ββ2ν to **excited 2^+_1 state**

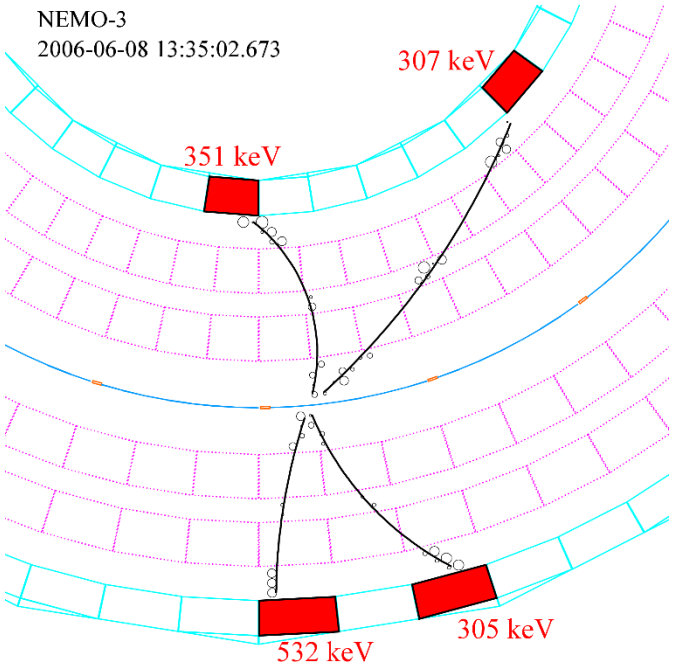
Expected $T_{1/2}(2^+_1$,pure bosonic)= 2.4 10^{22} y
Expected $T_{1/2}(2^+_1$,pure fermionic)= 1.7 10^{23} y

BUT limit today : $T_{1/2}(2^+_1) > 2.5\ 10^{21}$ y

Neutrinoless quadruple beta decay

- Proposed by Heeck and Rodejohann
  Europhys. Lett. 103, (2013) 32001
- Lepton number violating process
- Dirac neutrinos & $0\nu2\beta$ forbidden
- Best candidate: $^{150}Nd \rightarrow {}^{150}Gd + 4e$
  $Q_{4\beta}$=2.079 MeV





NEMO3

$T_{1/2}^{0\nu4\beta} > (1.1 – 3.2)\ 10^{21}$ y

World's first limit

Phys. Rev. Lett. 119 (2017) 041801

CONCLUSIONS

SuperNEMO : a unique tracker-calorimeter experiment

- 2 electron **visualisation**: DBD « smoking gun » evidence
- Identification of the **DBD mechanism** (light neutrino, V+A, SUSY, Majoron…)
- **By-products** of DBD Physics : HSD/SSD; 4β, bosonic neutrinos excited states…

Data taking this year

- Most precise study of ^{82}**Se** (6kg)
- New isotope like ^{150}**Nd** is considered
- Lessons for a arger scale experiment (under study)

SuperNEMO R&D results in new technical improvements on:

- **Radiopurity control** : BiPo detector, HPGe, Radon set-up (emanantion, concentration, diffusion)
- **Source** enrichment (^{150}Nd), purification methods
- Development of **new material** : radiopure glass, scintillators
- New **He gas recycling** method…