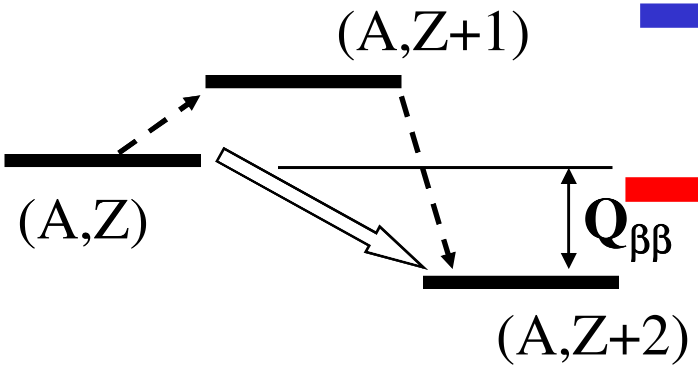
IPPP-Imperial meeting, 28.05.2009

Search for neutrinoless double beta decay: status of SuperNEMO project

Yu. Shitov, Imperial

Double beta decay basic statements



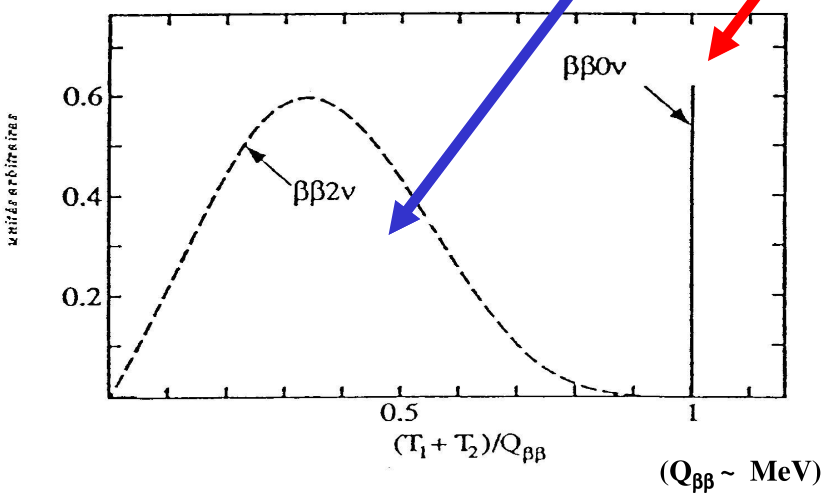
ββ2ν: allowed SM process $T_{1/2} \sim 10^{20}$y

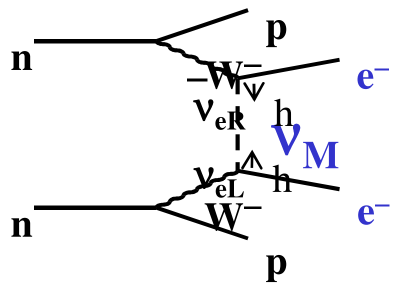
(A,Z)→(A,Z+2) + 2e⁻ + 2ν (2n → 2p + 2e⁻ + 2ν)

ββ0ν: beyond the SM $T_{1/2} \geq 10^{25}$y

(A,Z)→(A,Z+2) + 2e⁻ (2n → 2p + 2e⁻)

Massive Majorana neutrinos
(particle≡antiparticle)
Happiness for theoreticians
(many mechanisms proposed to describe the process)





Double beta decay basic equations

$$A^{0\nu} = (T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q_{\beta\beta}, Z)\,|M^{0\nu}|^2 \langle m_\nu \rangle^2 / m_e^2 \sim Q_{\beta\beta}{}^7 Z^2 |M^{0\nu}|^2$$

$$< m_\nu >= |U_{e1}|^2 m_1 + |U_{e2}|^2 e^{i\,\alpha_1} m_2 + |U_{e3}|^2 e^{i\,\alpha_2} m_3$$

- effective neutrino Majorana mass

$M^{0\nu}$: nuclear matrix element

$G^{0\nu}$: phase space factor

THEORY

$$T'^{0\nu}_{1/2}(y) > \frac{\ln 2 \,.\, \mathcal{N}}{k_{C.L.}} \cdot \frac{\varepsilon}{A} \cdot \sqrt{\frac{M \,.\, t}{N_{Bckg} \,.\, \Delta E}}$$

M : mass (g)

ε : efficiency

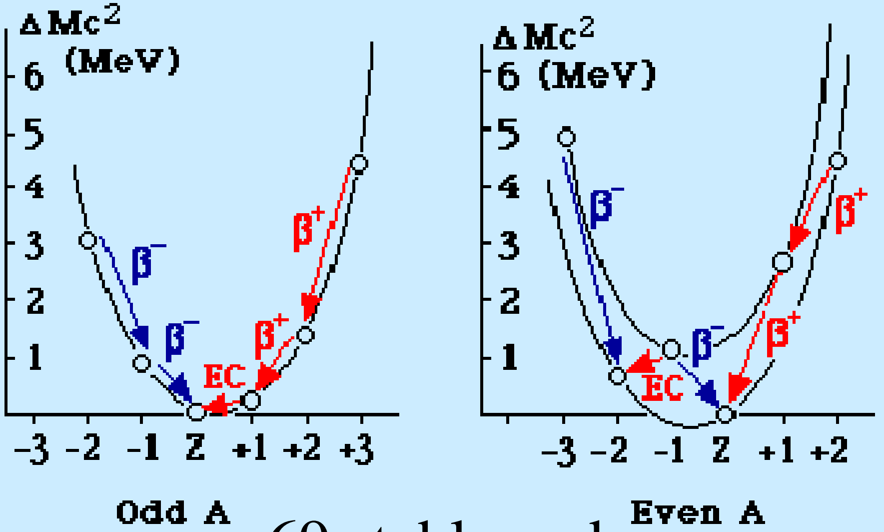
$K_{C.L.}$: confidence level

N : Avogadro number

t : exposition time (y)

N_{Bckg} : background events/ (keV/kg/y)

ΔE : energy resolution (keV)

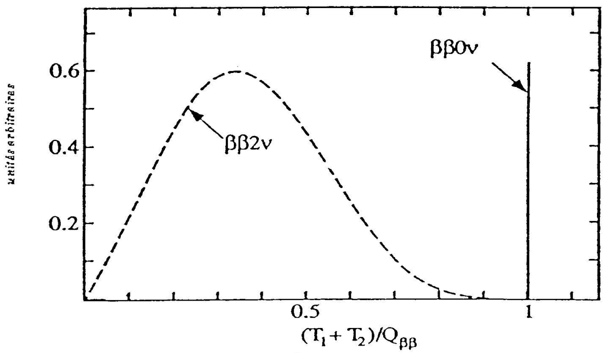


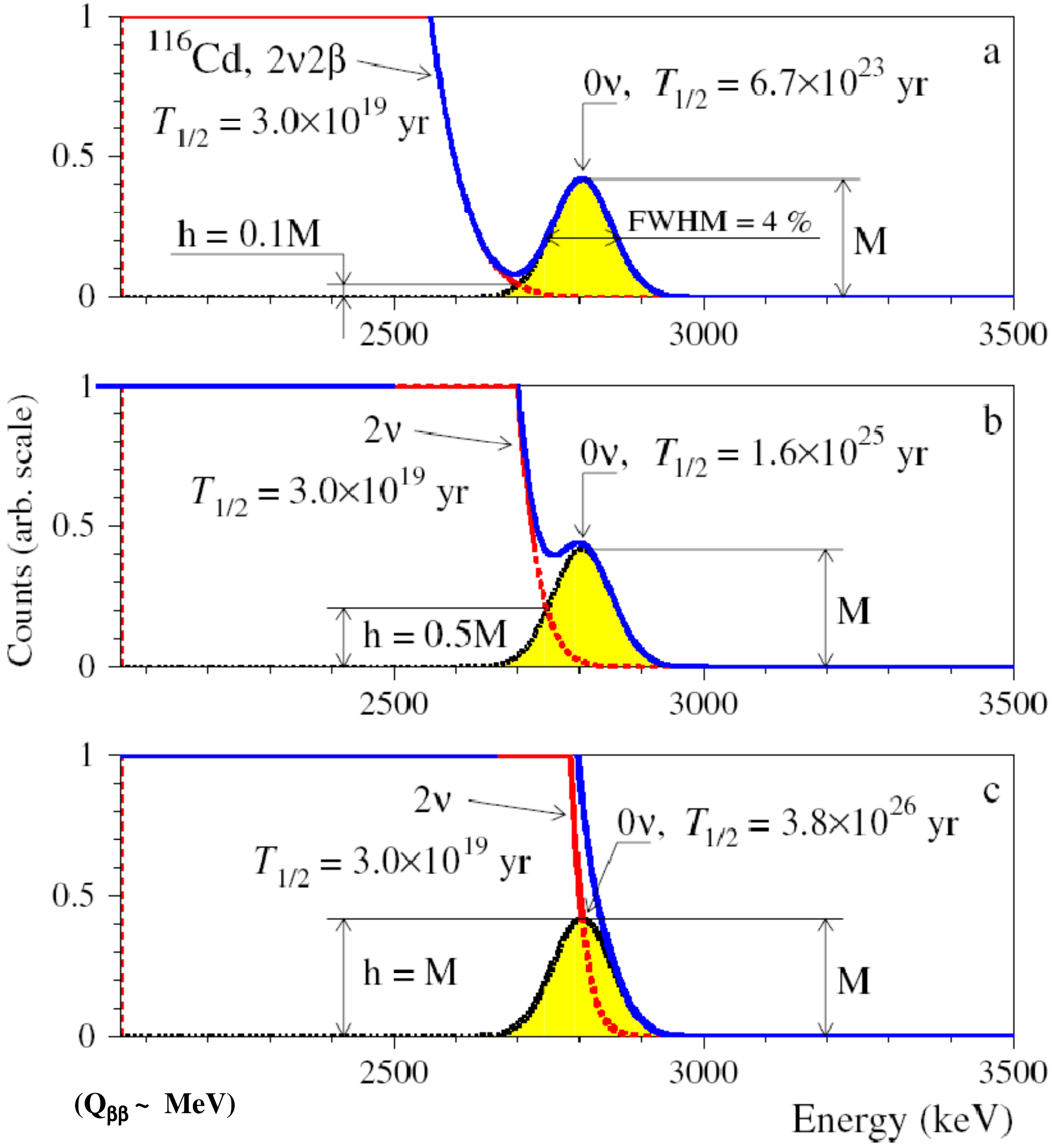
~ 69 stable and

28 α-unstable ββ isotopes

EXPERIMENT

Resolution as key point



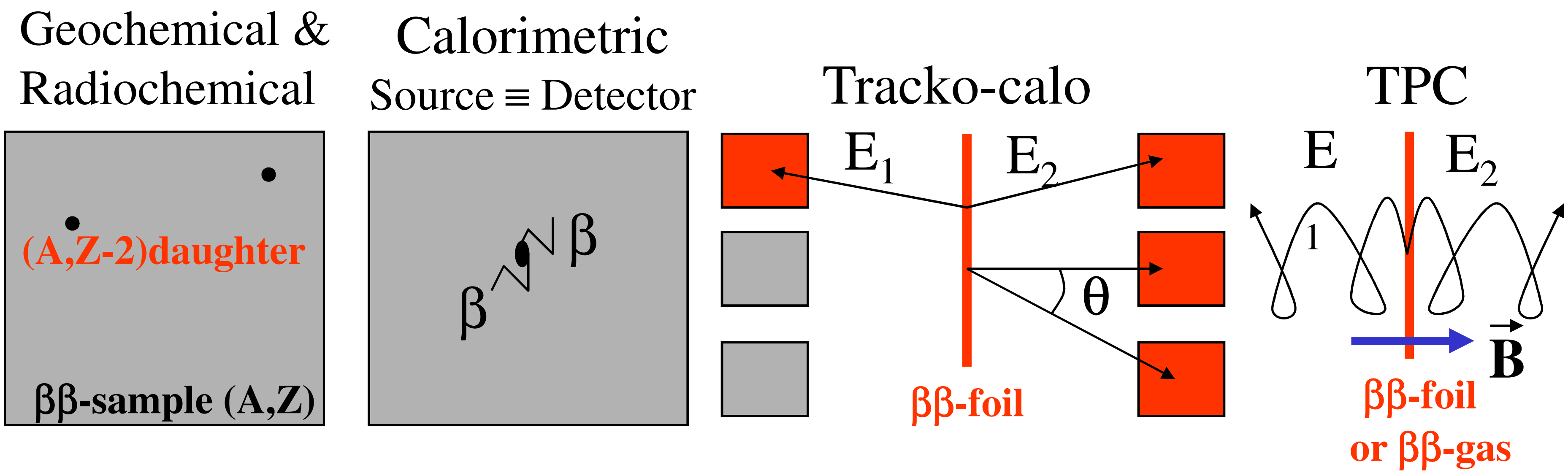


($Q_{\beta\beta}$ ~ MeV)

Avignone, King, Zdesenko, New Journal of Physics ***7*** *(2005) 6*

Experimental techniques to observe ββ-decay

Experimental methods



Experimental output

ββ-daughter rate **E1+E2 spectrum** **E1, E2, θ**

Calorimeter versus tracko-calo/TPC detectors

Calorimetric | Tracko-calo/TPC

Experimental advantages

Calorimetric:

- **Larger mass**
- **Better resolution**
- **high (~ 100%) efficiency**

Tracko-calo/TPC:

- **Real ββ-observation.**
- **Any ββ-source can be measured**
- **Potentially zero-background exp.**
- **Test of different ββ0ν mechanisms in the case of observation**

Experimental drawbacks

Calorimetric:

- **A few ββ-isotopes can be measured ^{76}Ge, ^{130}Te up to now.**
- **Unavoidable natural background.**
- **We don't see electrons, just energy released - no absolute proof, that we see ββ0ν-peak and not something else (γ-line)!**

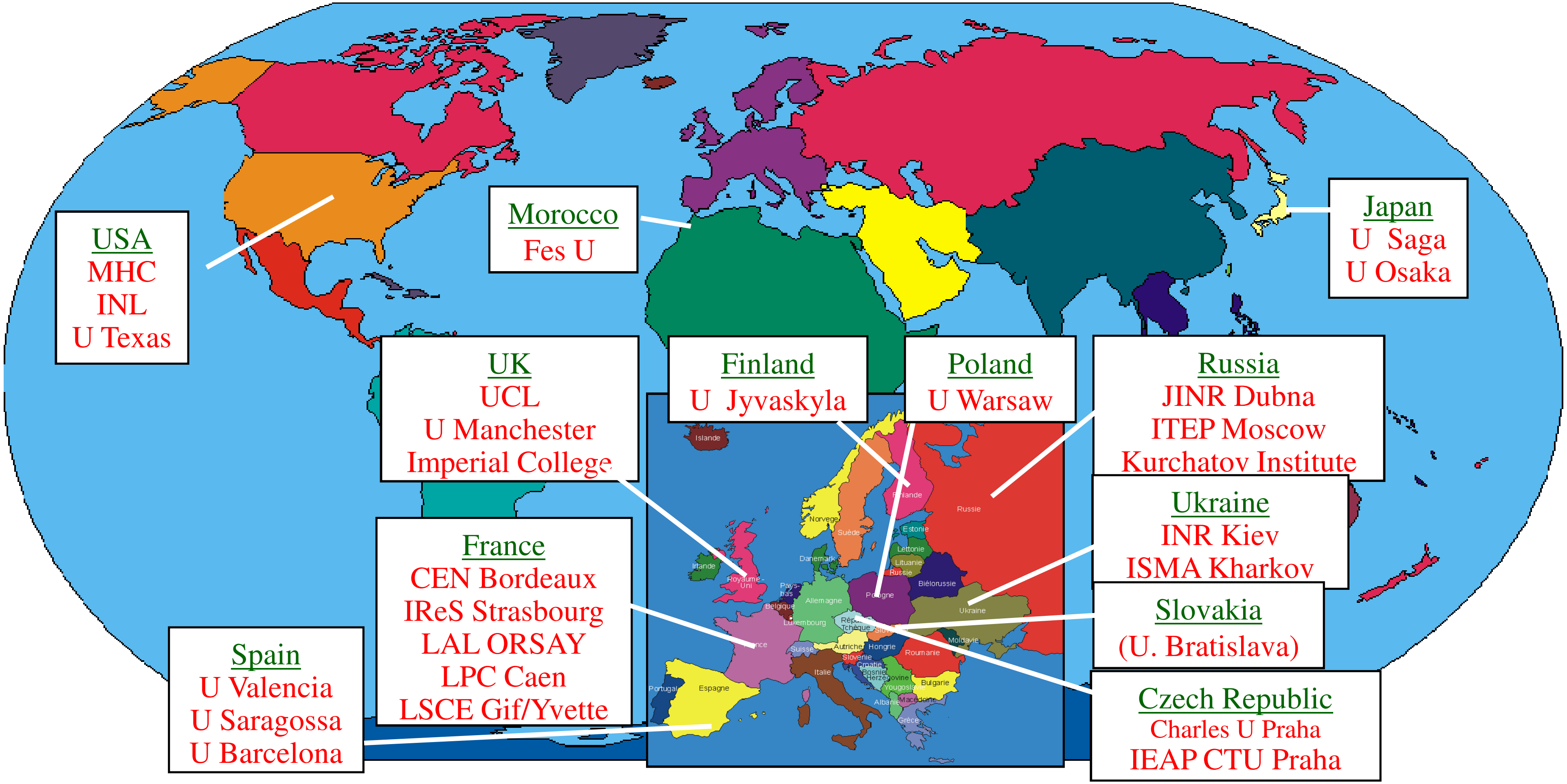
Tracko-calo/TPC:

- **difficult to accept large mass**
- **smaller efficiency**
- **worth resolution**

NEMO-3/SuperNEMO collaboration

Neutrino **E**ttore **M**ajorana **O**bservatory

(**N**eutrino **E**xperiment on **MO**lybdenum – historical name)

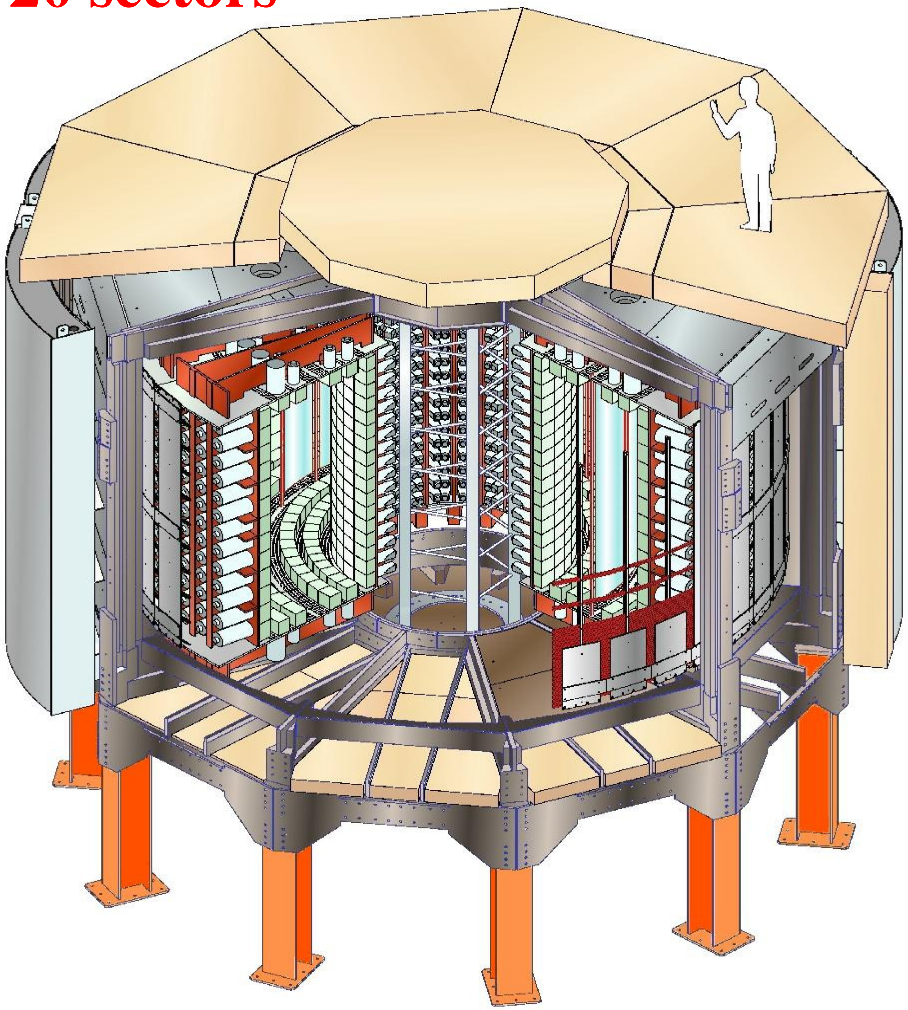


~ 80 physicists, 12 countries, 27 laboratories. R&D Program for 02/2006-07/2009 is being carring out. Major contributors: UK, France. Smaller but vital contributions from US, Russia, Czech Republic, Japan.

The NEMO3 detector

Fréjus Underground Laboratory : 4800 m.w.e.

20 sectors



Source: 10 kg of ββ isotopes
cylindrical, S = 20 m², 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

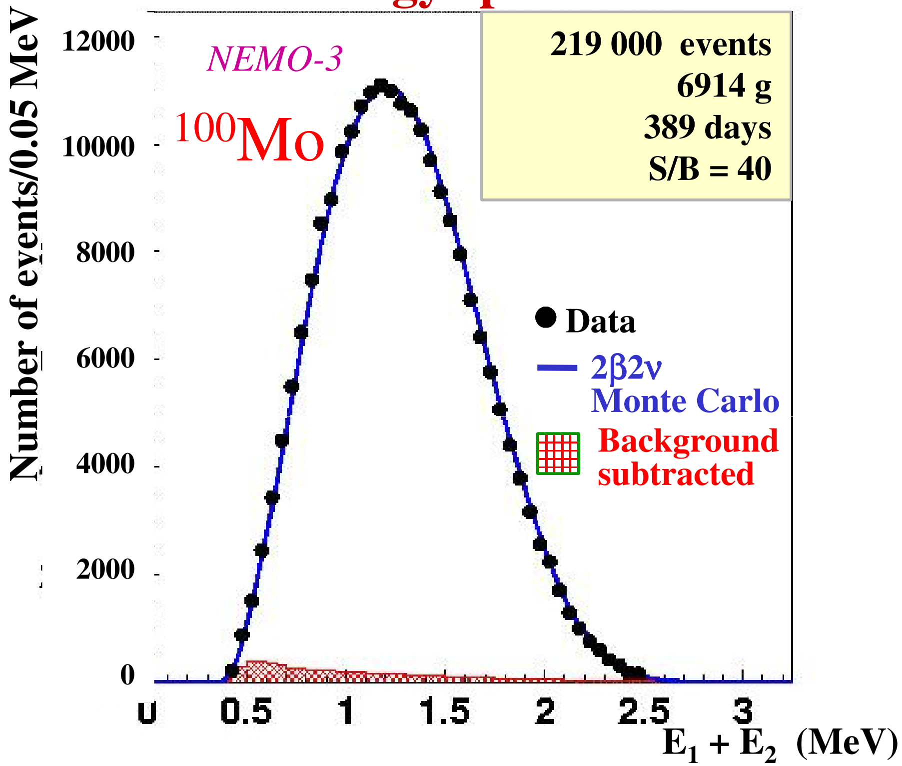
Magnetic field: 25 Gauss
Gamma shield: Pure Iron (18 cm)
Neutron shield: borated water (~30 cm) + Wood (Top/Bottom/Gapes between water tanks)

Able to identify e^-, e^+, γ and α–delayed

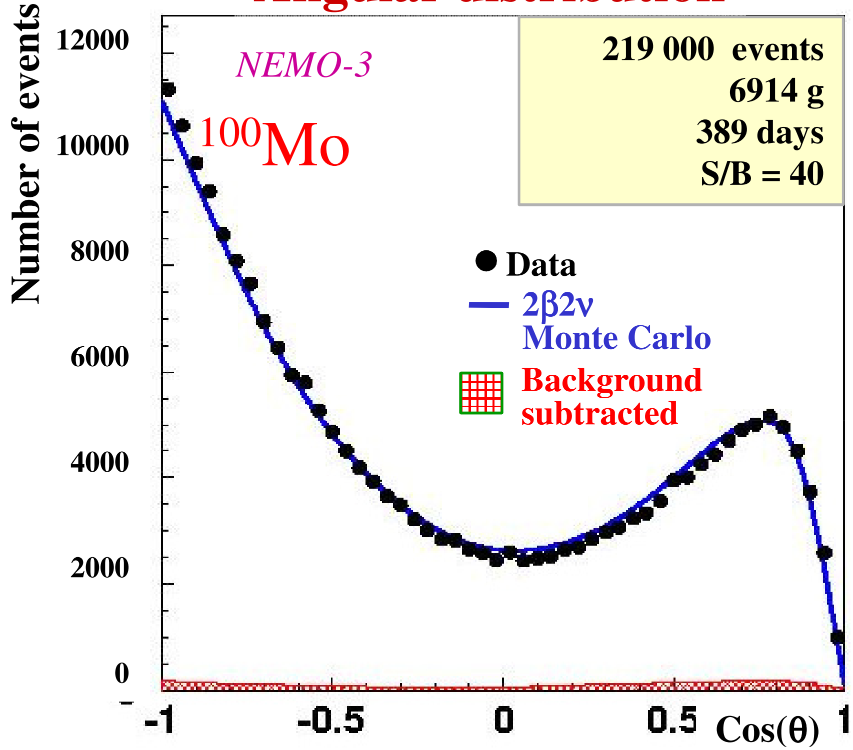
NEMO3 sector

^{100}Mo 2β2ν results

Sum energy spectrum



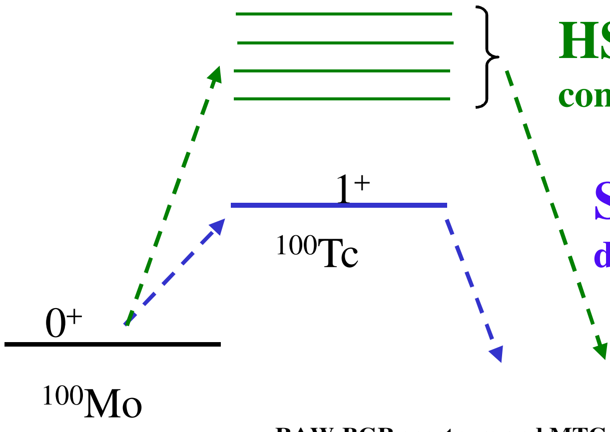
Angular distribution



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

«ββ factory» → tool for precision tests

^{100}Mo 2νββ single energy spectrum as probe of 2νββ mechanism

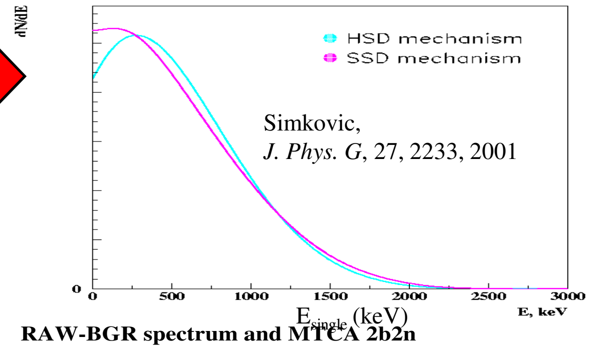


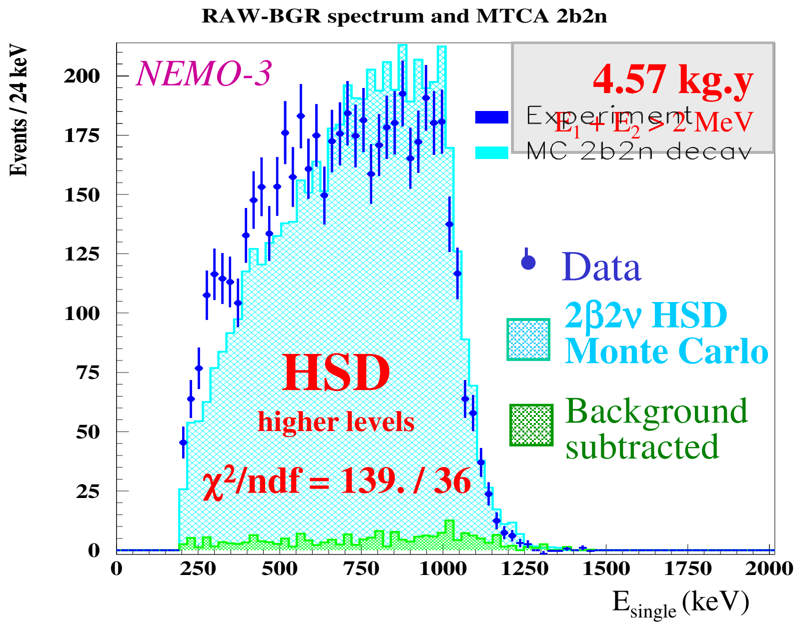
HSD, higher levels contribute to the decay

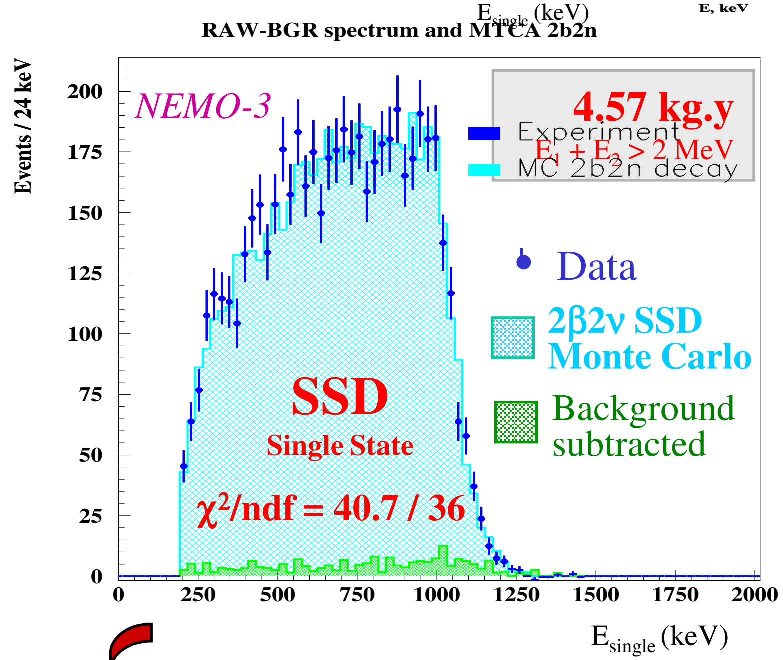
SSD, 1+ level dominates in the decay

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

Single electron spectrum different between SSD and HSD





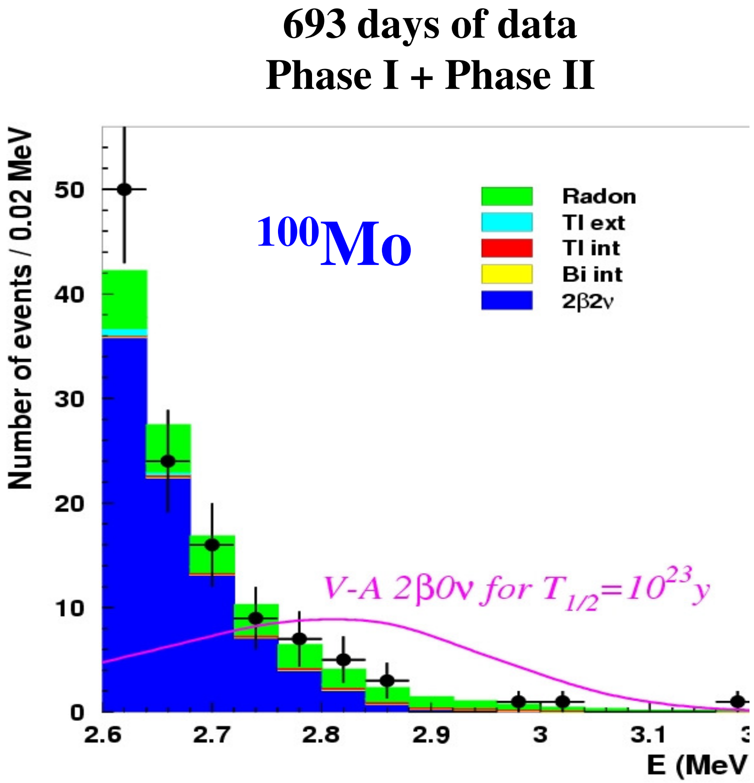


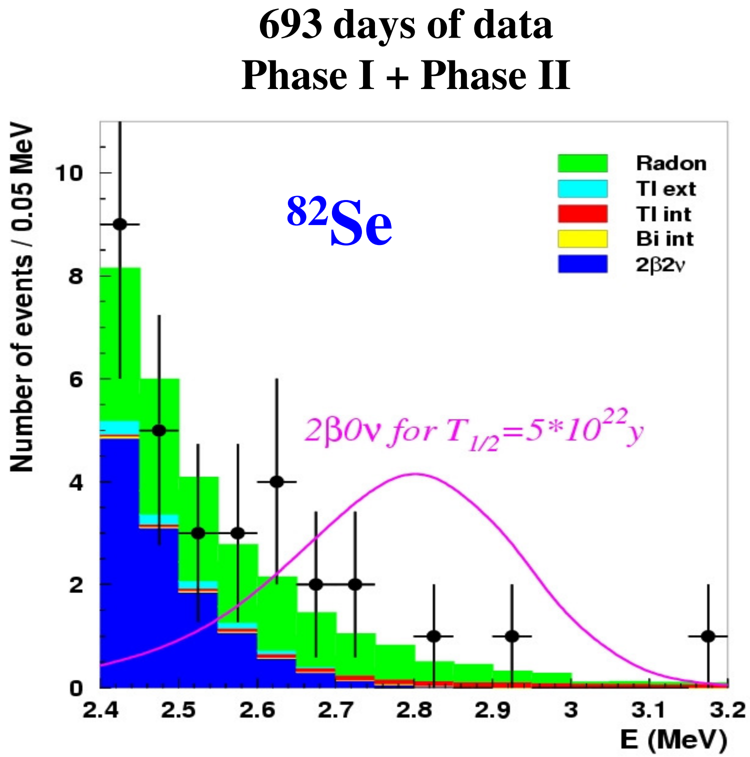
HSD: $T_{1/2} = 8.61 \pm 0.02\ (stat) \pm 0.60\ (syst) \times 10^{18}$ y

SSD: $T_{1/2} = 7.72 \pm 0.02\ (stat) \pm 0.54\ (syst) \times 10^{18}$ y

^{100}Mo 2β2ν single energy distribution in favour of Single State Dominant (SSD) decay

$0\nu2\beta$ limits (2003-2006)





$T_{1/2} > 5.8 \times 10^{23}$ y @ 90% C.L.

$\langle m_\nu \rangle < (0.8 - 1.3)$ eV [1-3]

$T_{1/2} > 2.1 \times 10^{23}$ y @ 90% C.L.

$\langle m_\nu \rangle < (1.4 - 2.2)$ eV [1-3]

Expected 2009 sensitivity:

$T_{1/2}(\beta\beta0\nu) \sim 1\text{-}2 \times 10^{24}$ (90 % CL)

$<m_\nu> < 0.3 - 1.3$ eV

From NEMO to SuperNEMO

NEMO-3		SuperNEMO
7 kg ^{100}Mo $T_{1/2}(\beta\beta2\nu) = 7.\ 10^{18}$ y	Mass of isotope	100-200 kg ^{82}Se||^{150}Nd $T_{1/2}(\beta\beta2\nu) = 10^{20}$ || 10^{19} y
FWHM ~ 12% at 3 MeV (dominated by calorimeter ~ 8%)	Energy resolution (FWHM of the $\beta\beta0\nu$ ray)	Total: FWHM ≤7 % at 1 MeV Calorimeter: ≤4 % at 3 MeV
$\varepsilon(\beta\beta0\nu) = 18$ %	Efficiency	$\varepsilon(\beta\beta0\nu)$ ~ 30 %
^{214}Bi < 300 μBq/kg ^{208}Tl < 20 μBq/kg	Internal contaminations in the source foils in ^{208}Tl and ^{214}Bi	(If ^{82}Se) ^{214}Bi < 10 μBq/kg ^{208}Tl < 2 μBq/kg
$\beta\beta2\nu$ ~ 2 cts / 7 kg / y (^{208}Tl, ^{214}Bi) ~ 0.5 cnts/7 kg/y	Background	$\beta\beta2\nu$=1, ^{208}Tl =0.5 ^{214}Bi=0.5 cnts/100 kg/y
$T_{1/2}(\beta\beta0\nu) > 2\times10^{24}$ y $\langle m_\nu\rangle < 0.3 – 1.3$ eV	Sensitivity	$T_{1/2}(\beta\beta0\nu) > (1\text{-}2)\times10^{26}$ y $\langle m_\nu\rangle < 40 – 110$ meV

NEMO-3 successful experience shows us that technique can be extrapolated for larger mass next generation detector to reach new sensitivity level.

SUPERNEMO R&D is in progress since 2006

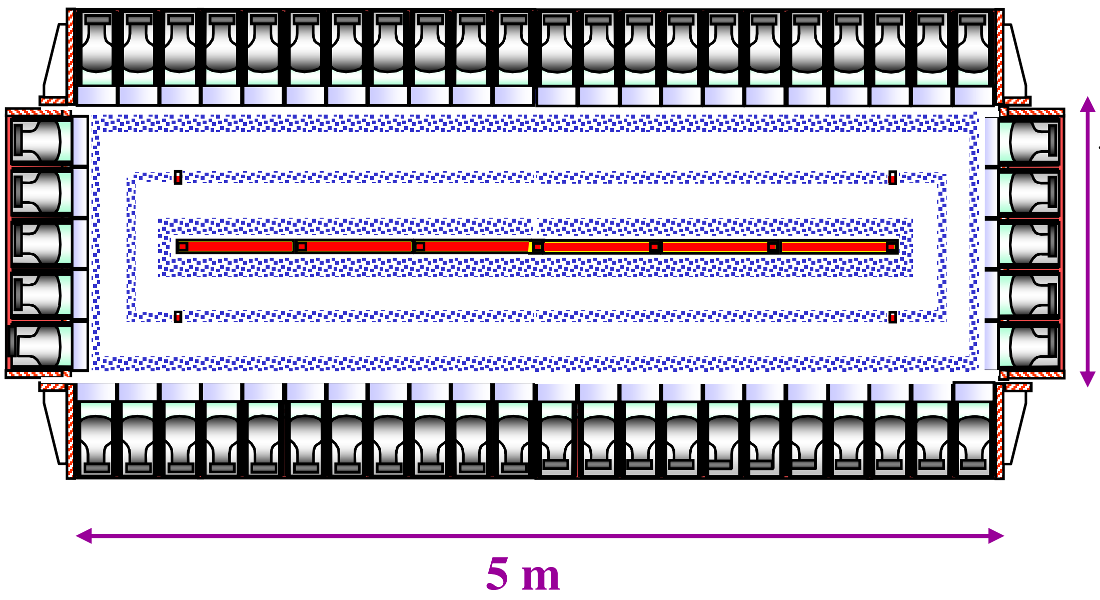
SuperNEMO basic design

Plane geometry

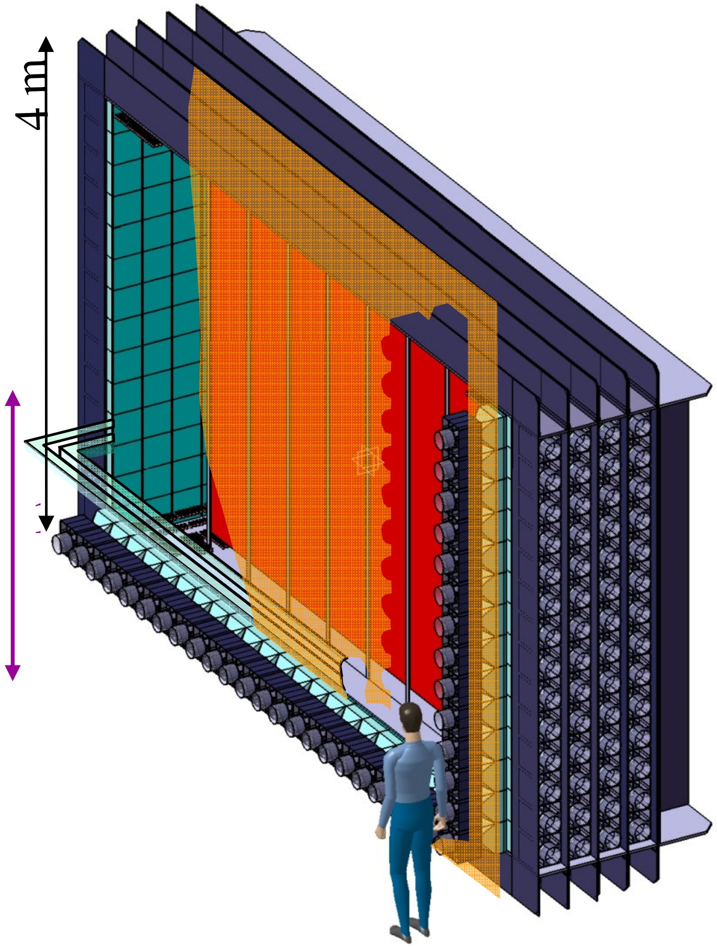
Source (40 mg/cm²) 12m², tracking volume (~3000 channels) and calorimeter

Modular (~5 kg of enriched isotope/module)

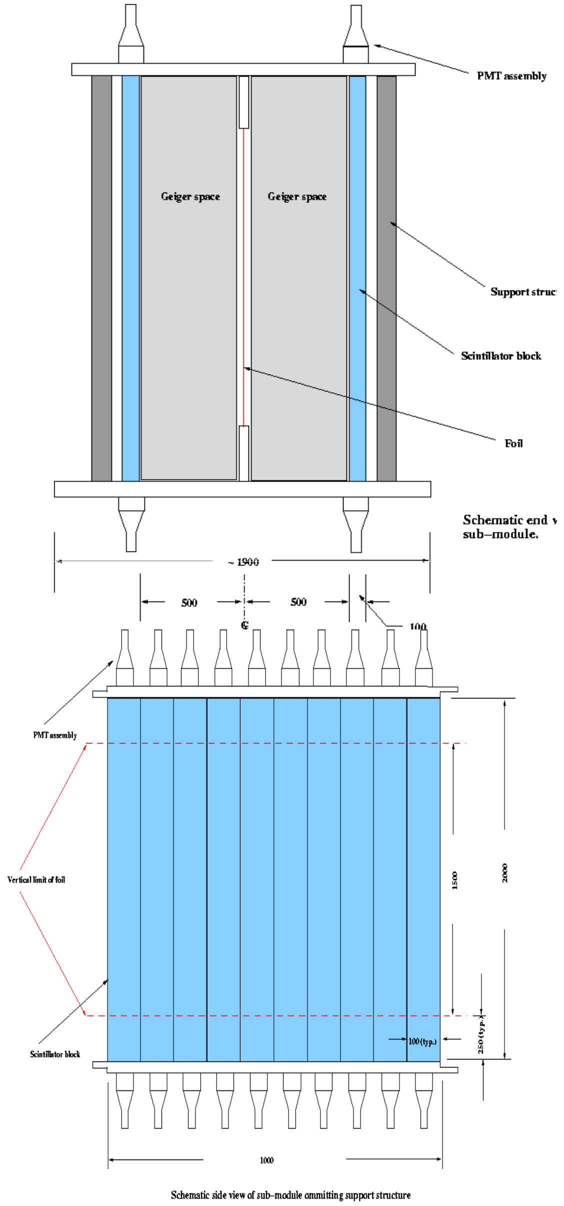
100 kg: 20 modules
~ 60 000 channels for drift chamber
~ 12 000/20 000 channels for 5"/8" PMT

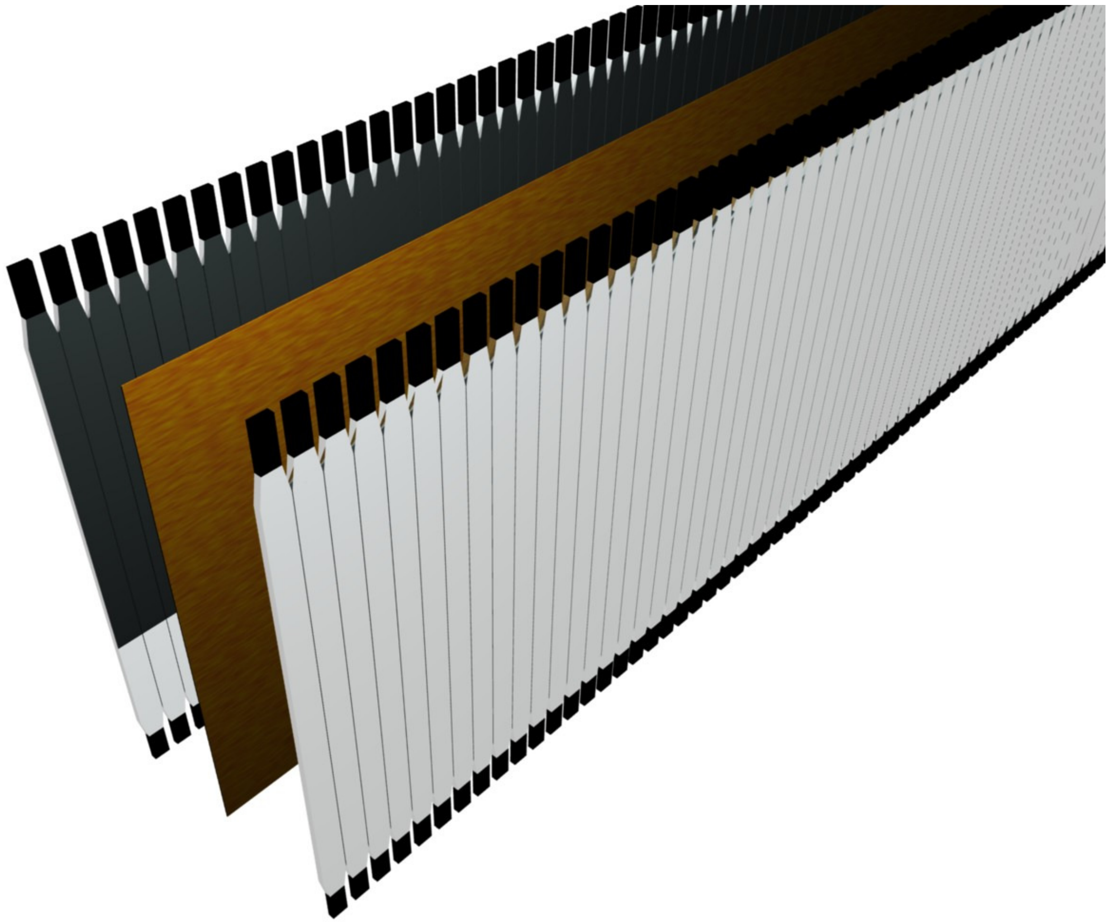


Top view



Alternative SuperNEMO sandwich bar design

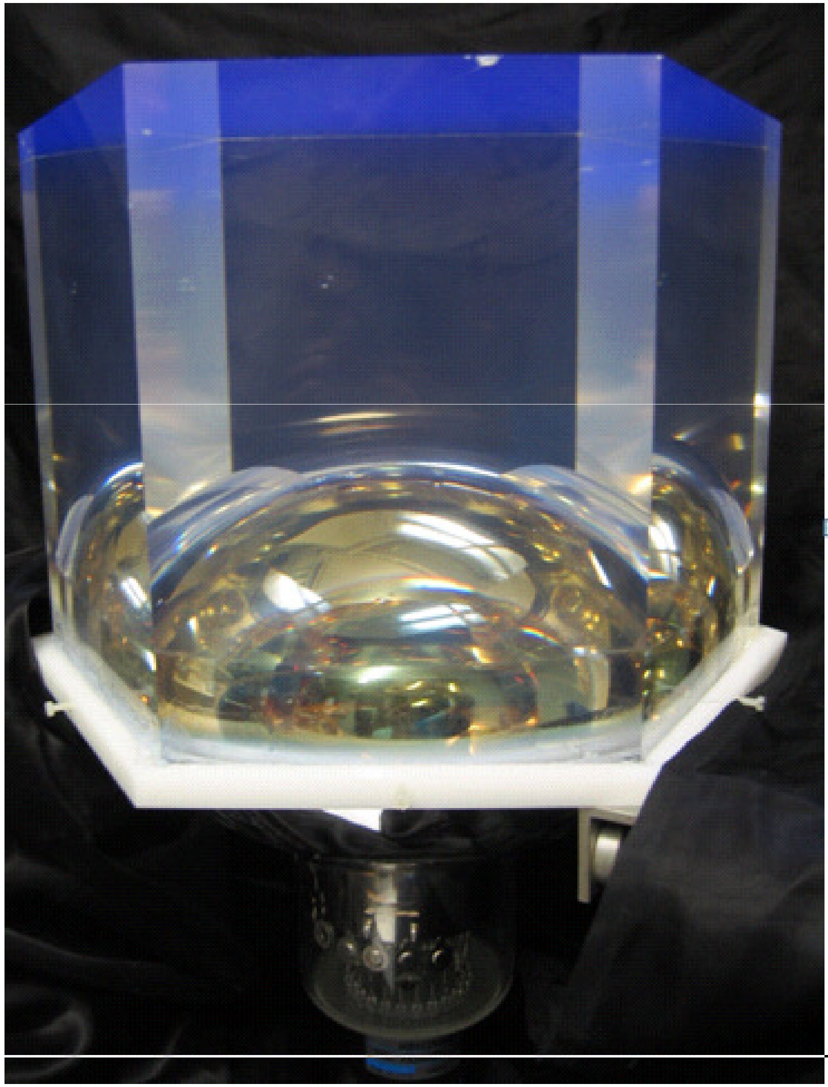




SC bars double sided with PM. Only ~ 3000 relatively cheap (3"||5") PM (~12000 8" PM in basic design). More compact, cheaper, less background from PM, but worse resolution (~10-11%).

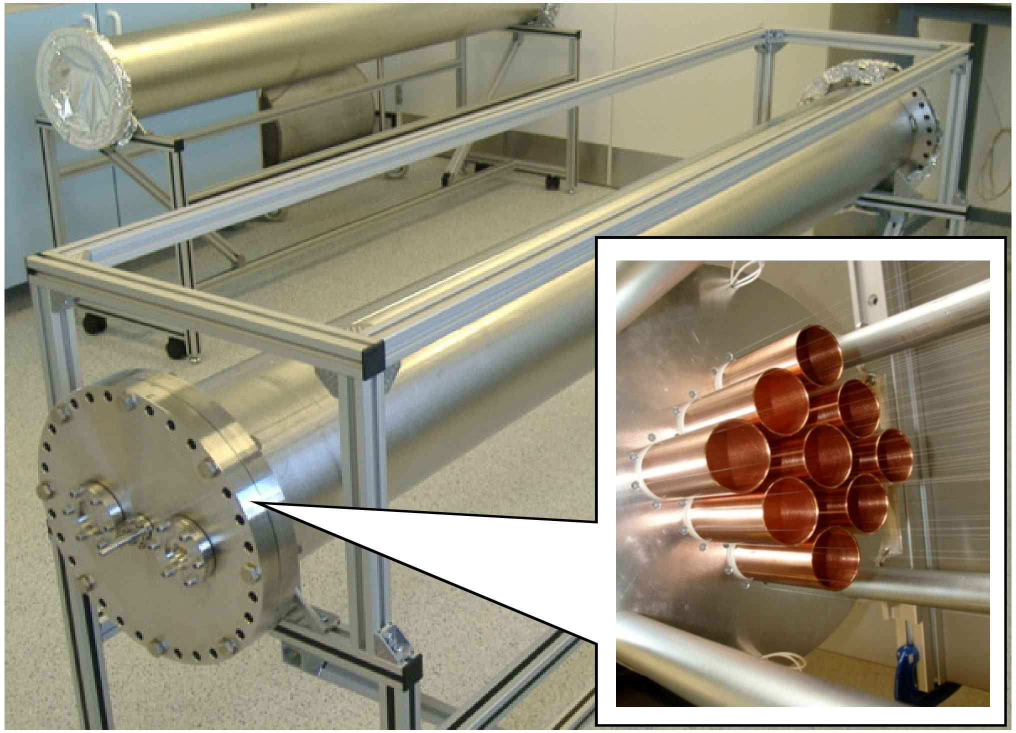
Calorimeter R&D

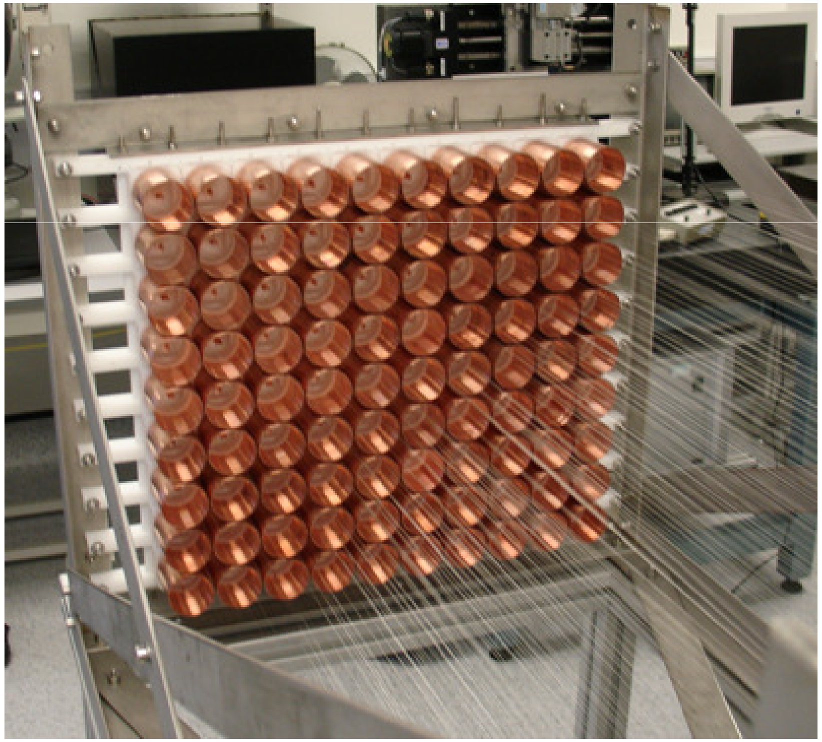
Baseline design detecting cell with required parameters has been designed



Tracker R&D

SuperNEMO tracker (major UK responsibility) has been developed including all accessories required (mechanics, electronics, wiring robot, etc.) 90-cell prototype has been built and testing now.

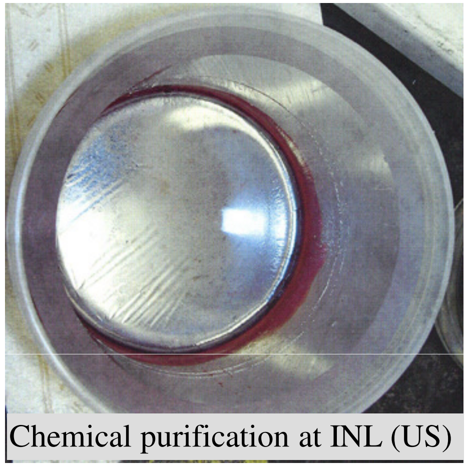




R&D for ^{82}Se sources

SuperNEMO collaboration has 6 kg of ^{82}Se with technology in hand for full chain of source production: enrichment -> purification -> foil preparation

Purification



Chemical purification at INL (US)

Enrichment

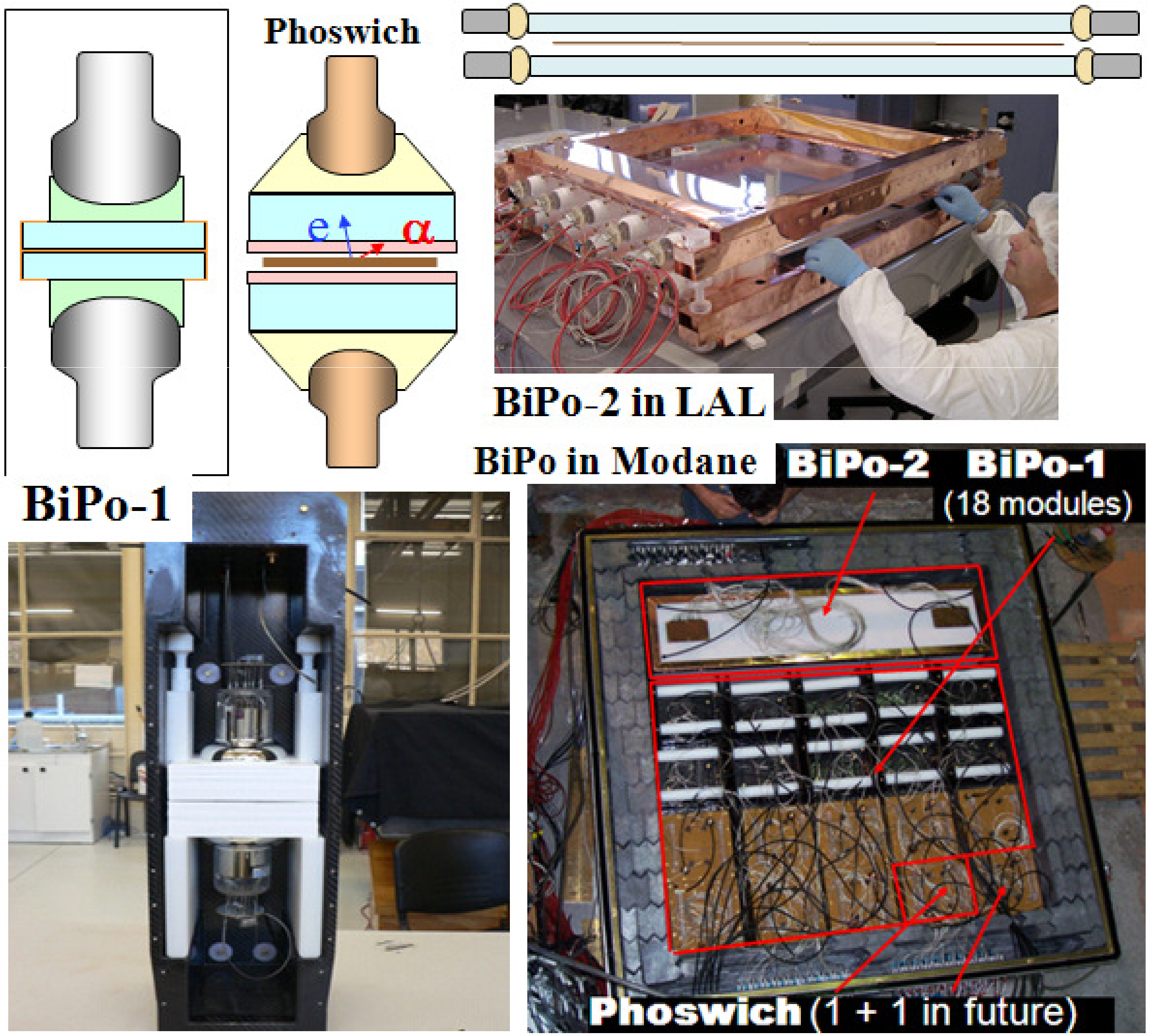
ECP (Electro-Chemical Plant, Svetlana)
Zelenogorsk (Siberia)

Source foil preparation

Installation of NEMO3 foils (LSM)

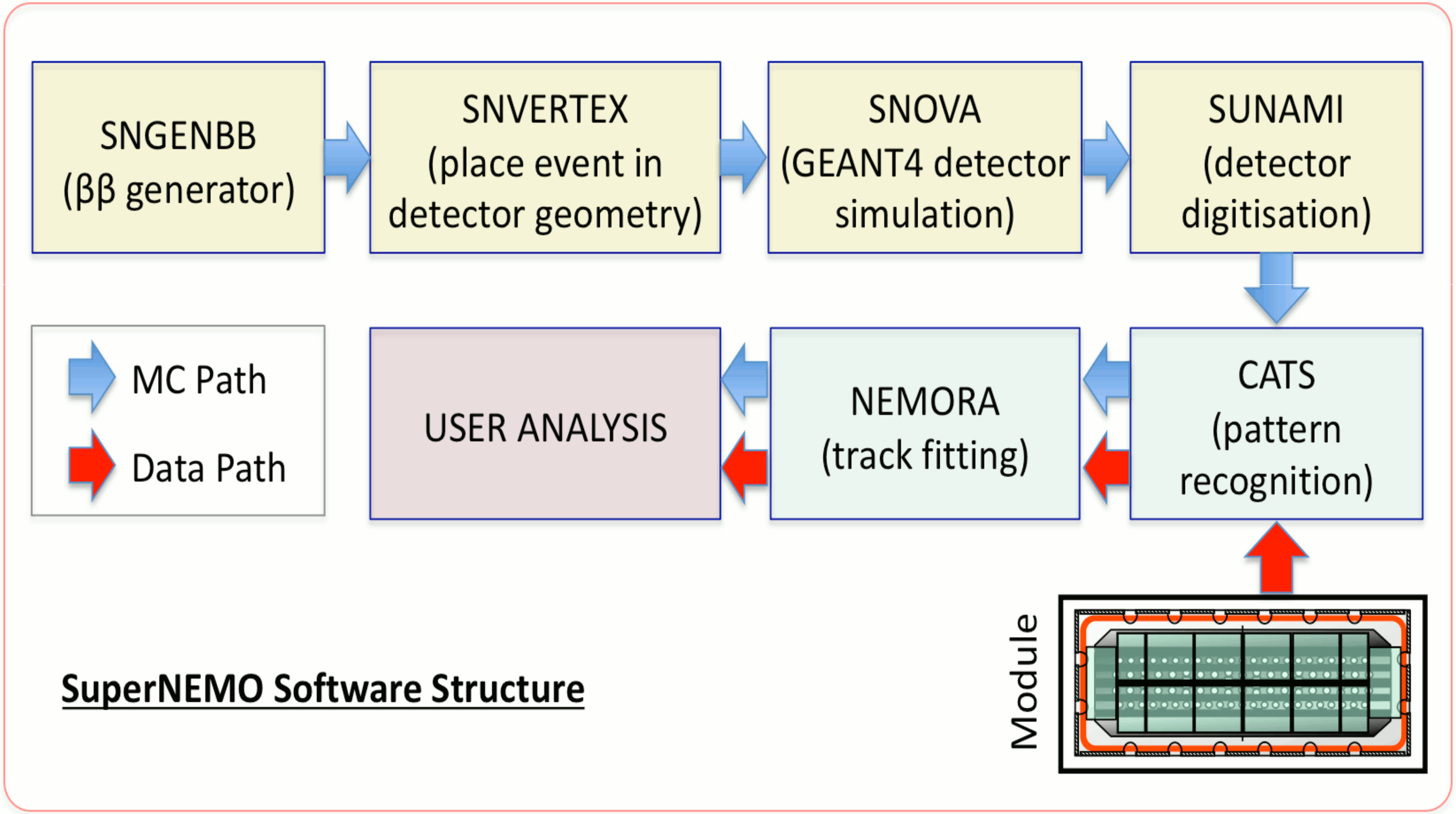
Low background measurement R&D

Prototype of setup for measurement of extra low levels (a few μBq/kg) of radio impurities in SuperNEMO source foils (BiPo) has been developed and successively tested



Simulations

SuperNEMO SoftWare (SNSW) package has been developed and large scale simulations (GRID-based) is in progress

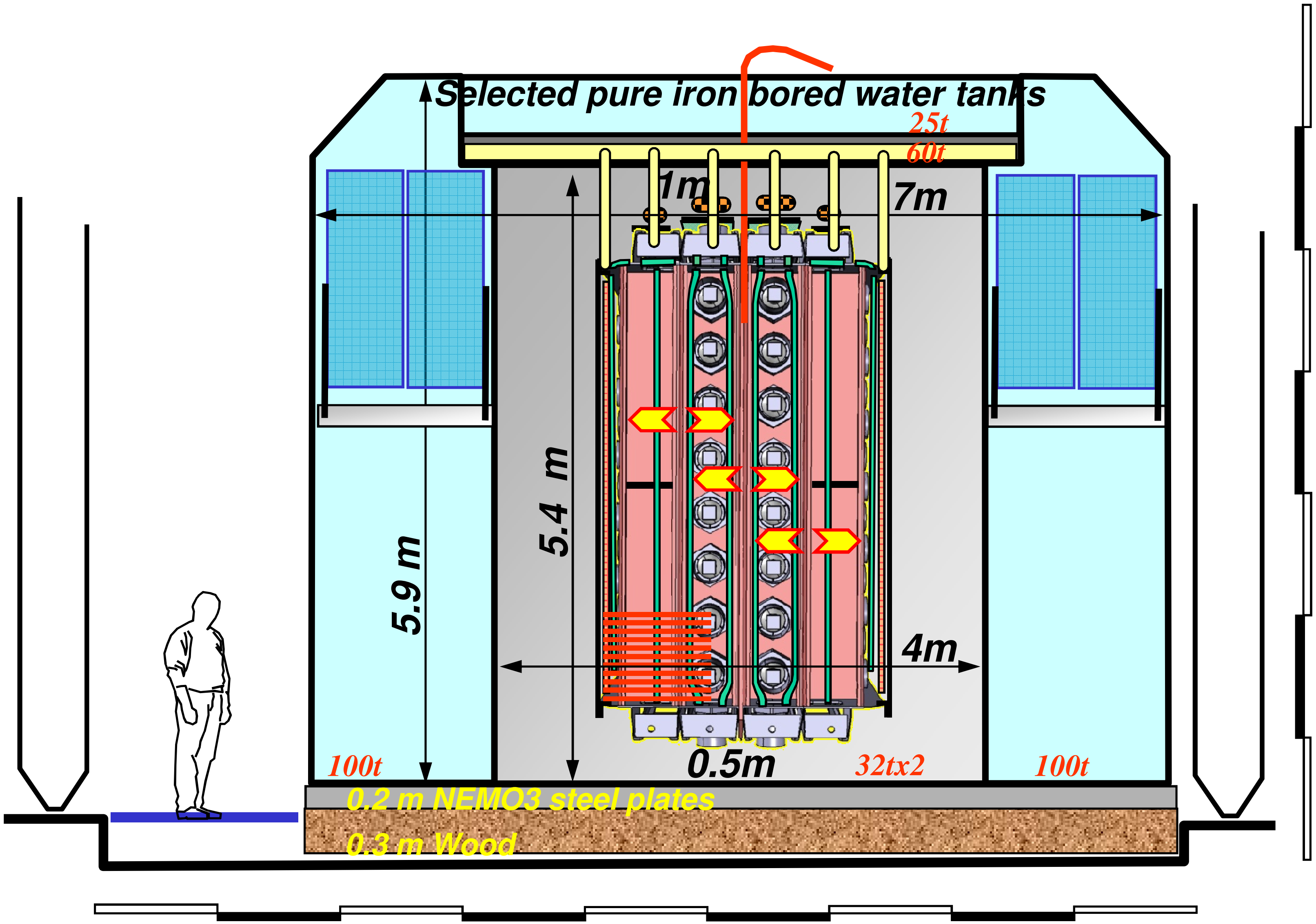


Pre-production prototype (demonstrator module)

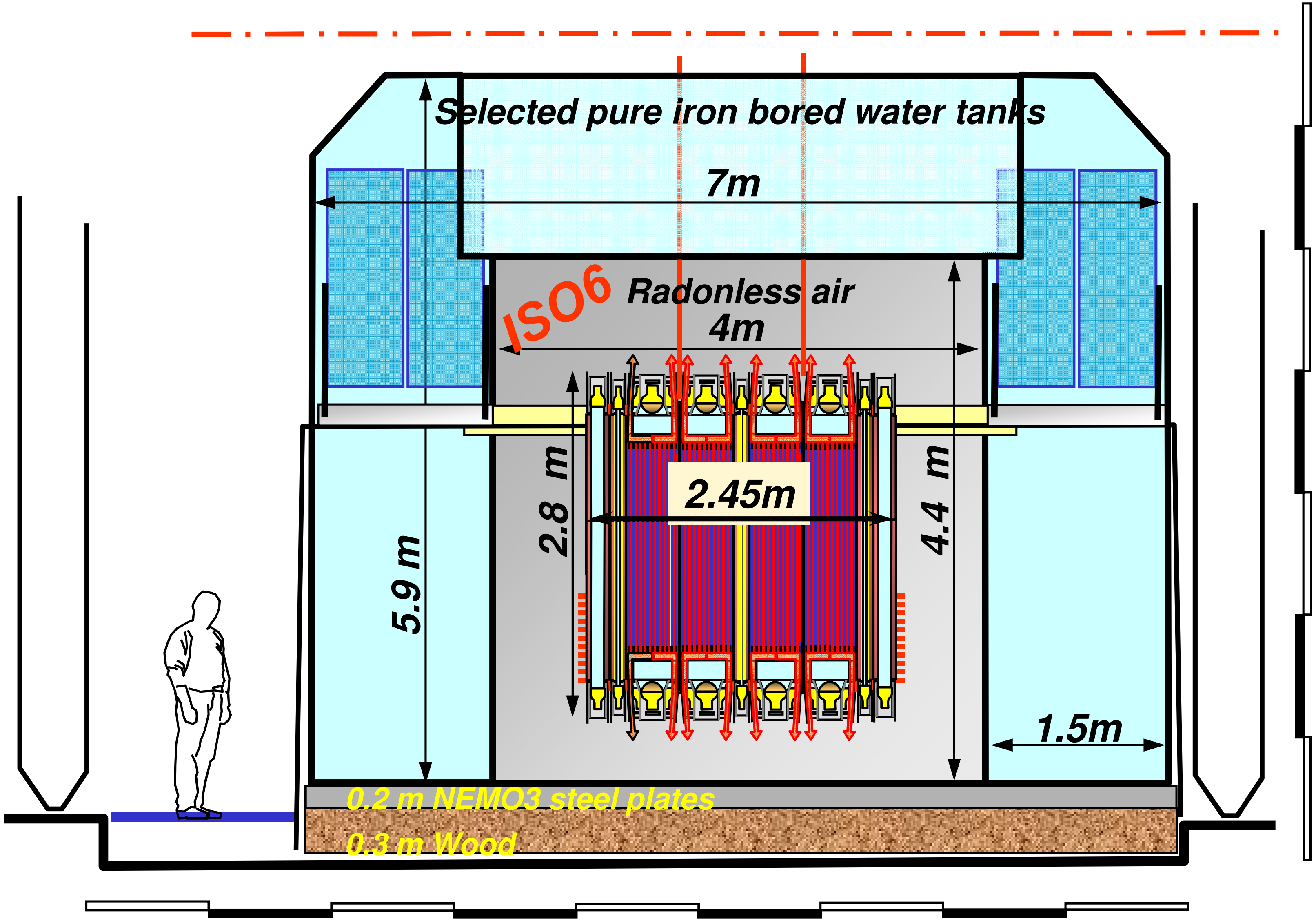
SuperNEMO UK proposal has been submitted in April 2009. The main goals of demonstrator (2009-2011) are:

- **To demonstrate the feasibility of large scale detector component production with required performance parameters (e.g. calorimeter energy and time resolution, tracker efficiency and purity).**
- **To measure background contributions from the detector components.**
- **To finalize the detector design.**
- **To produce a competitive physics measurement with ^{82}Se covering the region of the Klapdor group claim (1yr of data taking with 6kg of ^{82}Se in the demonstrator module will have a similar sensitivity to GERDA Phase-I).**

Baseline design of demonstrator in LSM



Alternative bar design of demonstrator in LSM

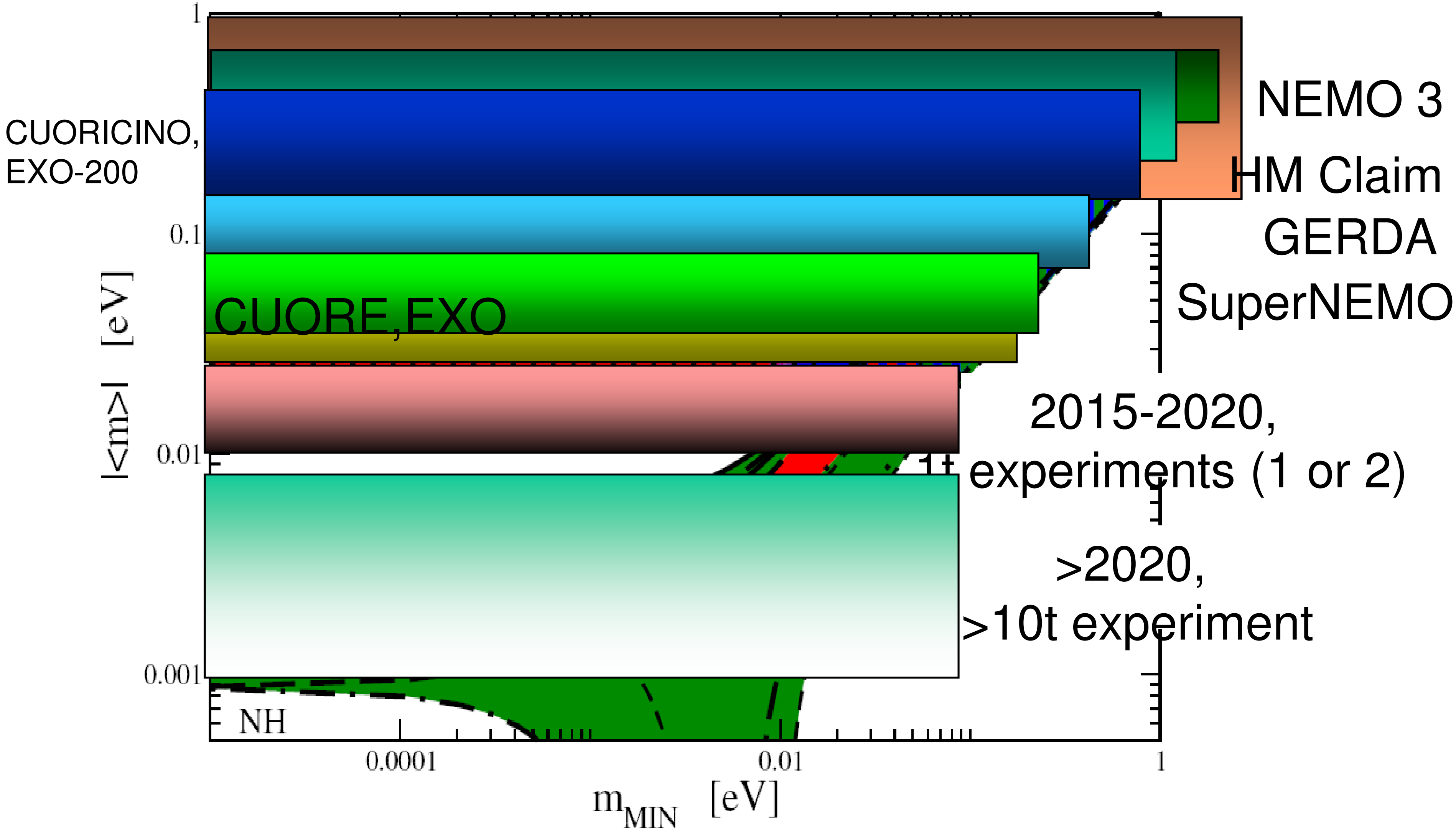


World leading double beta-decay projects

Experiment	Isotope	kg	$T_{1/2}$ yr, 90% CL	m_ν*, meV	Start-up timescale	Status
HM	^{76}Ge	15	$>1.9\ 10^{25}$	230-560	1990	finished
KDHK claim	^{76}Ge	15	$(0.7\text{-}4.2)\ 10^{25}$ (3σ)	150-920	1990	finished
CUORICINO	^{130}Te	11	$>2.4\ 10^{24}$	200-900	2002	finished
NEMO 3	^{100}Mo	7	$2\ 10^{24}$ (expect. 2009)	300-1300	2003	running
CUORE	^{130}Te	210	$1.3\ 10^{26}$	40-92	2011	approved
GERDA, Phase I	^{76}Ge	15	$3\ 10^{25}$	180-440	2009	approved
Phase II	^{76}Ge	~31	$2\ 10^{26}$	70-170	2011	approved
EXO 200	^{136}Xe	160	$6.4\ 10^{25}$	270-380	2008	approved
EXO 1t	^{136}Xe	800	$2\ 10^{27}$	50-68	2015	R&D
SuperNEMO	^{82}Se/^{150}Nd	100+	$(1\text{-}2)\ 10^{26}$	40-110	2011	R&D
COBRA	^{116}Cd	151	$1.5\ 10^{26}$	38-96	?	R&D

** Matrix elements from MEDEX'07 or provided by experiments*

Roadmap for double beta-decay projects



S. Pascoli, S.T.P., 2006

Conclusion

- The 0νββ–decay is a test of physics beyond the Standard Model by the search of the leptonic number violation and would determine the nature of the neutrino (Majorana), absolute neutrino mass scale and neutrino hierarchy.

- Several experiments are needed to measure different sources with several techniques.

- NEMO-3 technique can be extrapolated at ~100 kg to be sensitive to (1-2)×10^{26} y Only tracko-calo (SuperNEMO) and gas TPC can directly register 0νββ-decay. In the case of discovery only direct methods will allow to determine the process leading to ββ(0ν) : light neutrino exchange, right-handed current, supersymmetry, etc.

- 3-year SuperNEMO R&D program is carrying out and it is in good shape. Key challenges are calorimeter resolution, isotope choice, and radio purity. Based on design study results full proposal for 100+ kg detector in 2009. "Last minute" isotope change possible. E.g. CUORE sees the signal in ^{130}Te.

-First module - 2011

-All 20 modules ~2013

-Target SuperNEMO sensitivity: 20-110 meV by 2016, which is competitive with the other next generation 0νββ-experiments.