*Joint session of the PAC for Particle Physics and the PAC for Nuclear Physics for the assessment of JINR neutrino physics projects 21 January 2021*

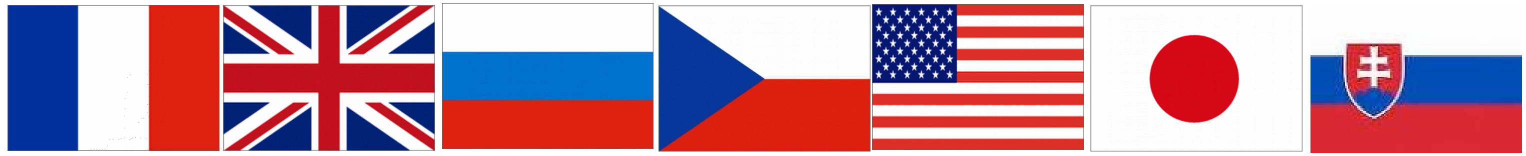
# Investigation of the 2β-decay processes of $^{82}$Se with the SuperNEMO detector

Extension of the SuperNEMO project
for the period 2022-2024

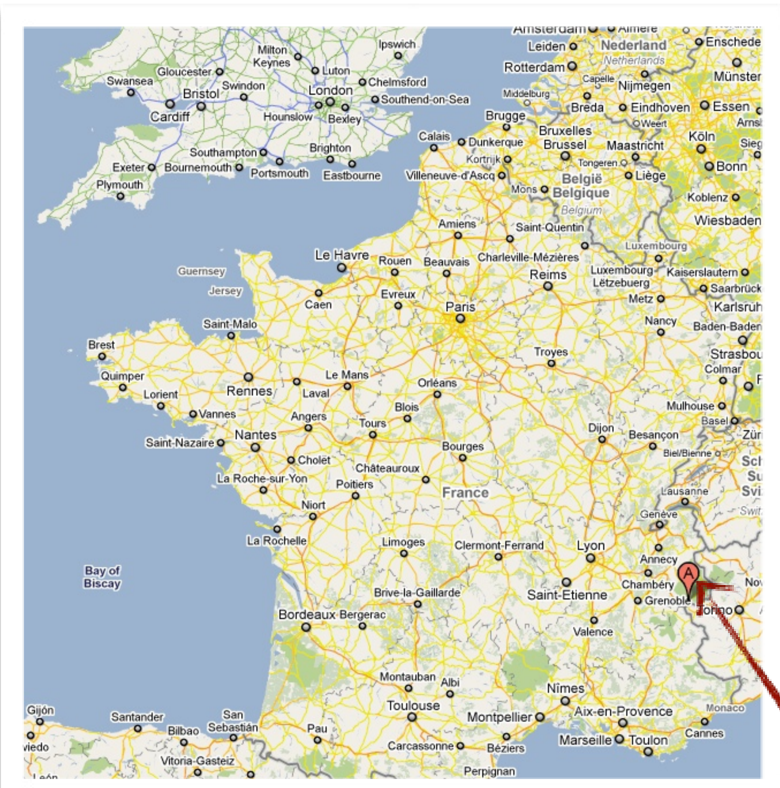
Speaker: **Victor Tretyak** (DLNP, JINR)

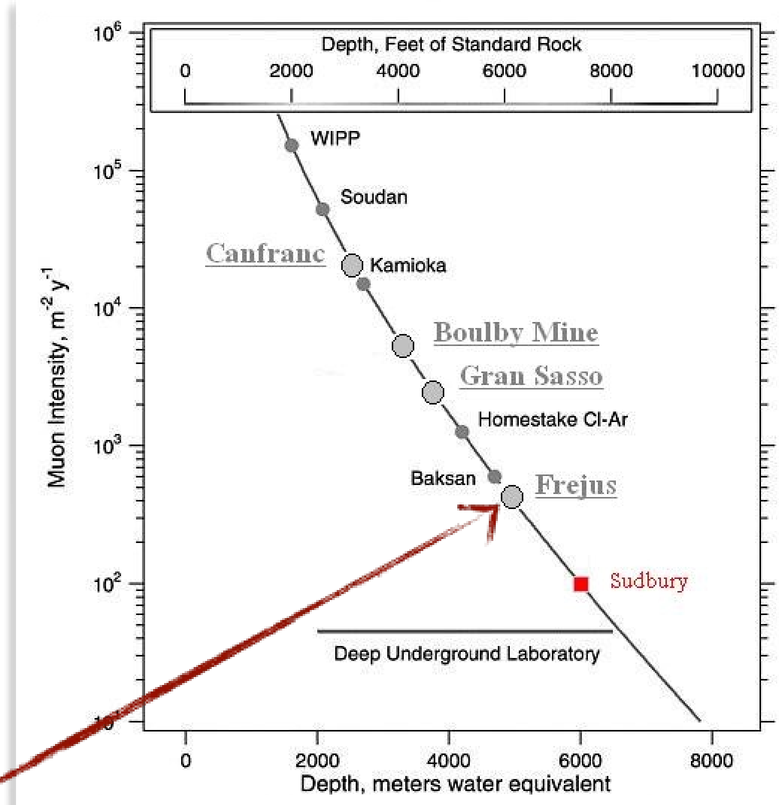
supernemo collaboration

supernemo collaboration



SuperNEMO – successor of NEMO-3 is international collaboration
95 participants from 7 countries, 22 institutions

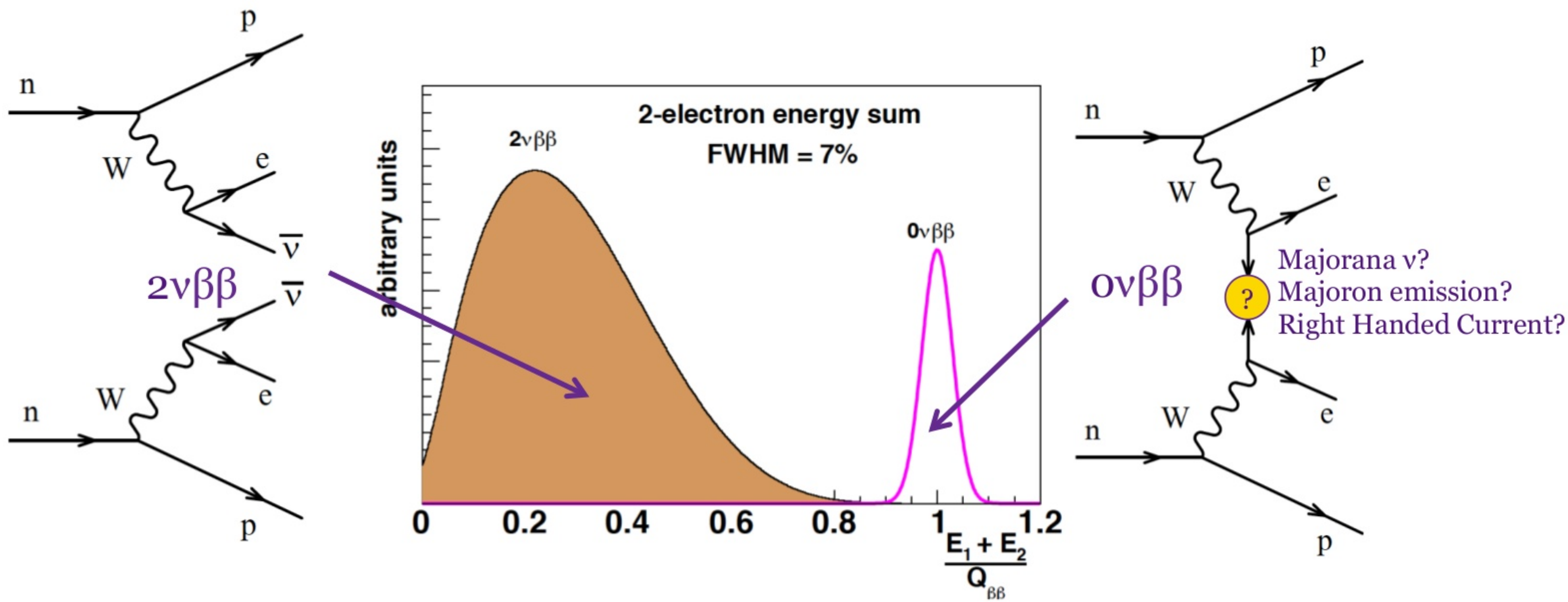





Laboratoire Souterrain de Modane (LSM) Modane, France
(Tunnel Frejus, depth of ~4,800 mwe )

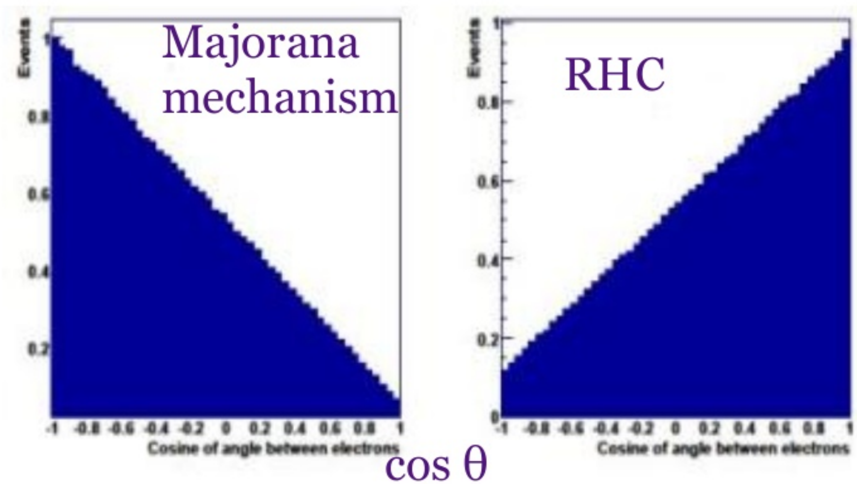
# Main purpose – search for 0νββ decay

$(A,Z) \rightarrow (A,Z+2) + 2e^{-}$ ⇒ $\Delta L=2,\ \nu \equiv \bar{\nu}$



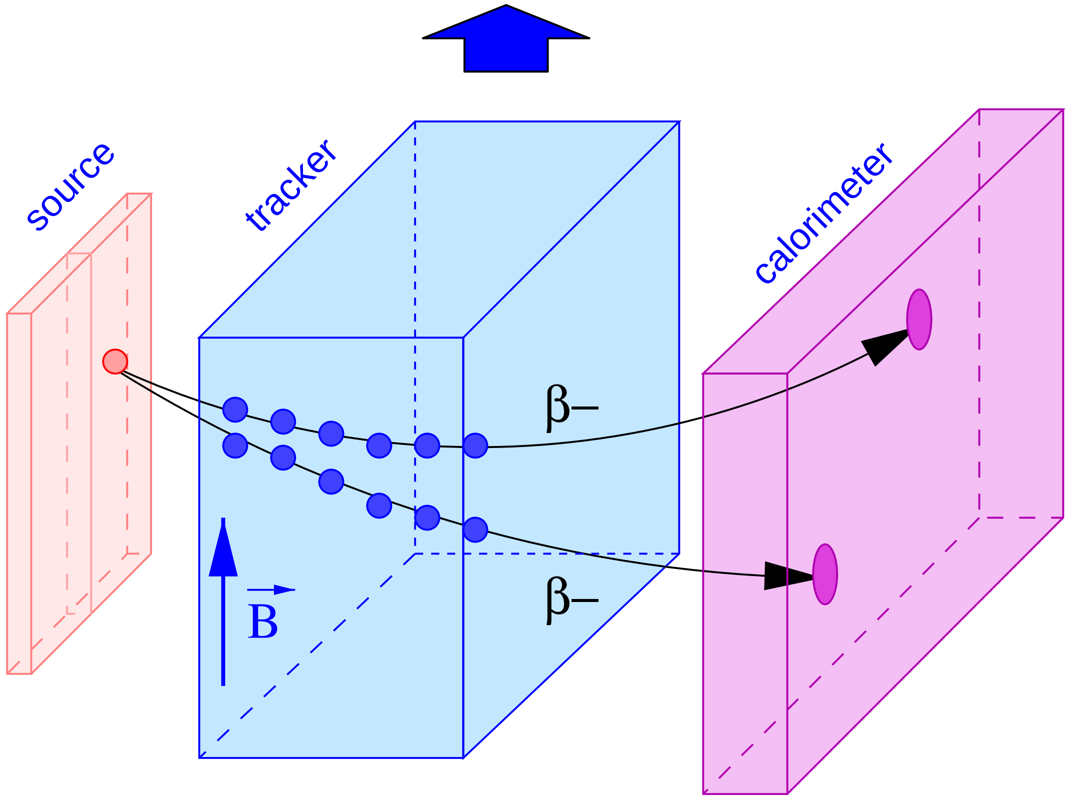

0νββ mechanisms have different kinematic signatures

- Electron energy spectrum
- Angles between electrons

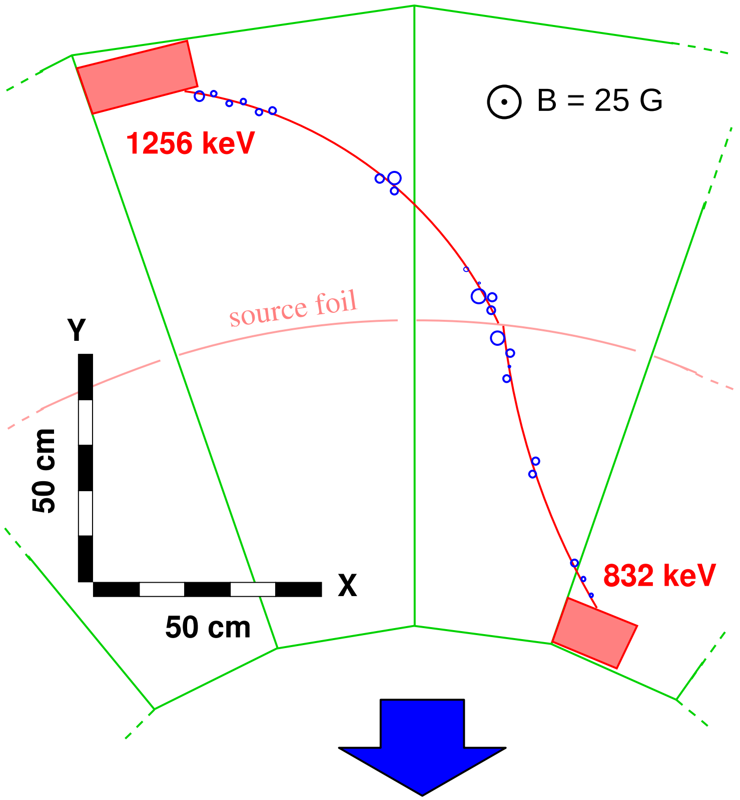


# Tracker-Calorimeter Technique

- Source separated from detector: (almost) any solid isotope can be hosted.
- Generally poorer energy resolution and efficiency than “homogeneous” detectors such as HPGe and bolometers.
- Full topological event reconstruction including $e^{\pm}$, $\gamma$-ray and $\alpha$-particle identification.

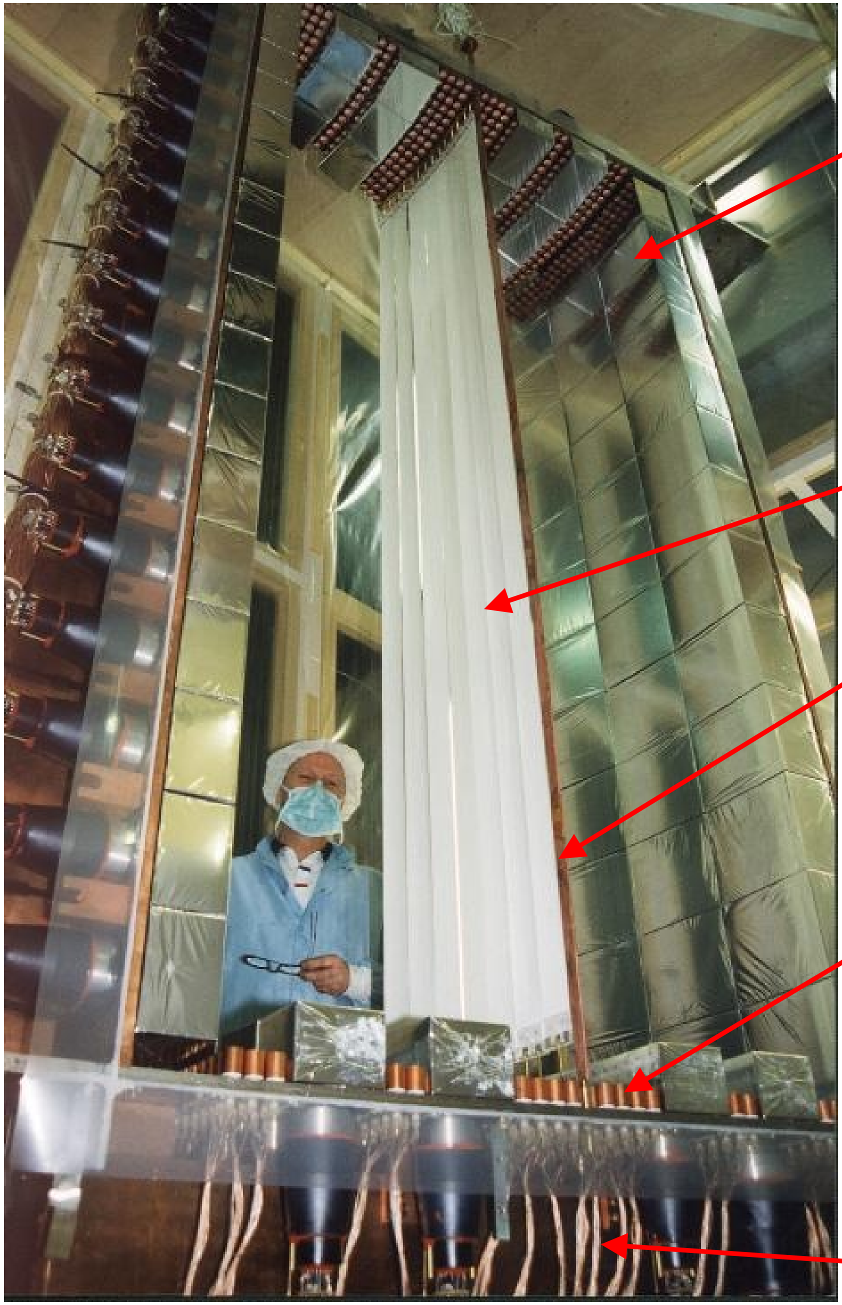



Candidate $^{100}$Mo Double-Beta Decay Event in NEMO-3




- Strong background suppression by particle identification, event characterisation & timing.
- Ability to disentangle different mechanisms for $0\nu\beta\beta$, by looking at variables other than $\Sigma E$.

# The NEMO-3 Experiment



- 5” low activity PMT coupled to PS scintillator blocks.
- Energy resolution :

$$\frac{\Delta E(\mathrm{FWHM})}{E} = \frac{14\%}{\sqrt{E(\mathrm{MeV})}}$$

- Source strips.
- Metallic or composite structure.

- Calibration tubes.
- Host $^{207}$Bi and other sources.

- Cathode rings surrounding each vertical anode wire.
- 3D tracker hits from transverse drift and longitudinal plasma propagation.
- 25 Gauss B-field

- Cu/Fe structure.


- Ran from 2003 to 2011.
- Surrounded by shielding and anti-radon enclosure.
- Located at 4800 m.w.e. at the Laboratoire Souterrain de Modane (LSM).
- $^{100}$Mo (7kg) ; $^{82}$Se (1kg)
- $^{116}$Cd, $^{150}$Nd, $^{48}$Ca, $^{96}$Zr, $^{130}$Te

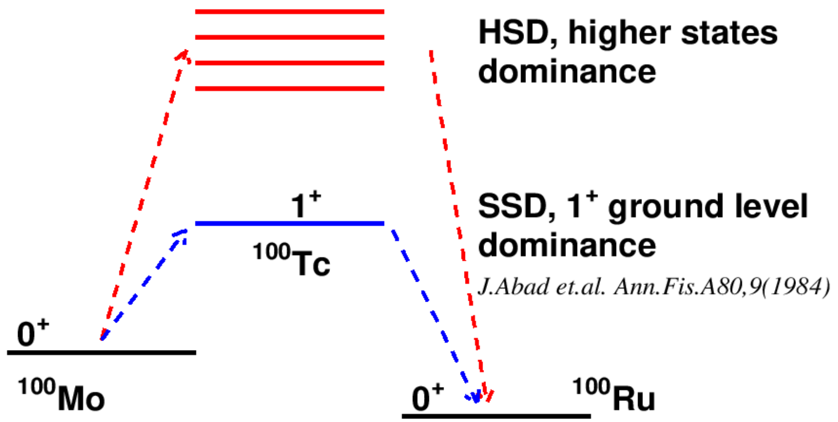
# Particle Data Book

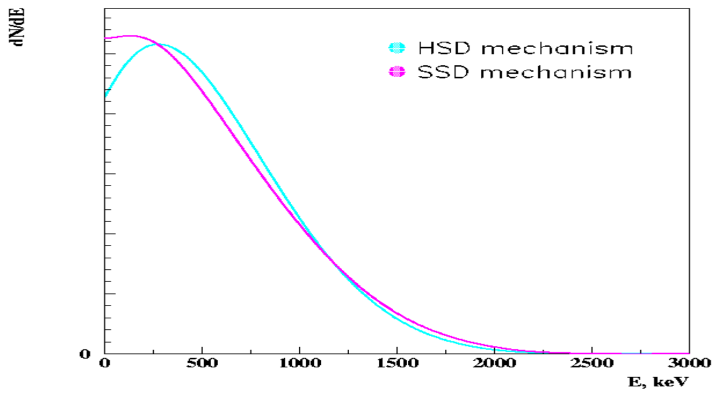
## Half-life measurements of the two-neutrino double-$\beta$ decay

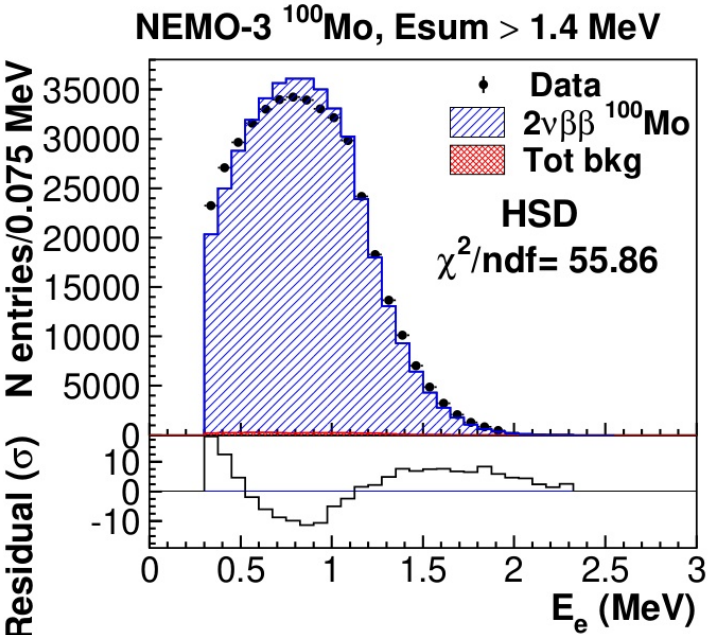
The measured half-life values for the transitions (Z,A) $\rightarrow$ (Z+2,A) + $2e^-$ + $2\overline{\nu}_e$ to the $0^+$ ground state of the final nucleus are listed. We also list the transitions to an excited state of the final nucleus ($0_i^+$, etc.). We report only the measuremetnts with the smallest (or comparable) uncertainty for each transition.

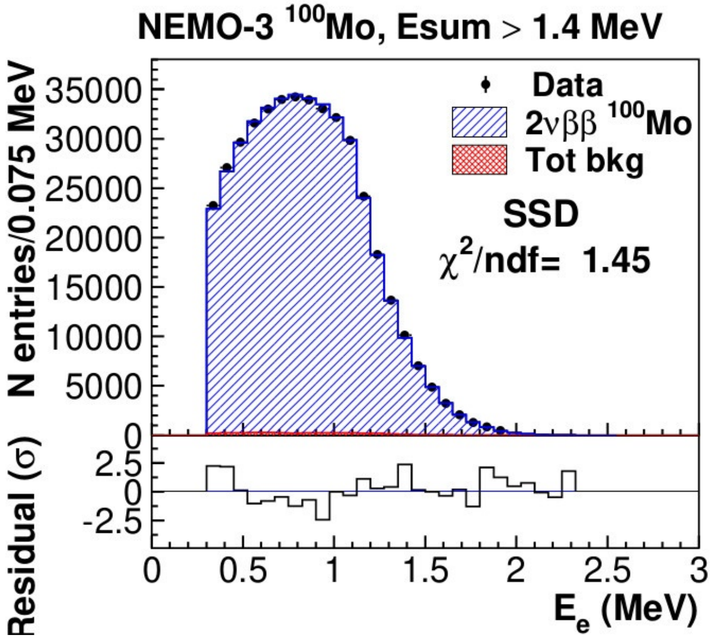
| $t_{1/2}(10^{21}$ yr) | | | *ISOTOPE* | *TRANSITION* | *METHOD* | *DOCUMENT ID* | |
|---|---|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| > 0.87 | | | $^{134}$Xe | | EXO-200 | [1] ALBERT | 17C |
| 0.82 | ±0.02 | ±0.06 | $^{130}$Te | | CUORE-0 | [2] ALDUINO | 17 |
| 0.00690 | ±0.00015 | ±0.00037 | $^{100}$Mo | | CUPID | [3] ARMENGAUD | 17 |
| 0.0274 | ±0.0004 | ±0.0018 | $^{116}$Cd | | NEMO-3 | [4] ARNOLD | 17 |
| 0.064 | $^{+0.007}_{-0.006}$ | $^{+0.012}_{-0.009}$ | $^{48}$Ca | | NEMO-3 | [5] ARNOLD | 16 |
| 0.00934 | ±0.00022 | $^{+0.00062}_{-0.00060}$ | $^{150}$Nd | | NEMO-3 | [6] ARNOLD | 16A |
| 1.926 | ±0.094 | | $^{76}$Ge | | GERDA | [7] AGOSTINI | 15A |
| 0.00693 | ±0.00004 | | $^{100}$Mo | | NEMO-3 | [8] ARNOLD | 15 |
| 2.165 | ±0.016 | ±0.059 | $^{136}$Xe | | EXO-200 | [9] ALBERT | 14 |
| 9.2 | $^{+5.5}_{-2.6}$ | ±1.3 | $^{78}$Kr | | BAKSAN | [10] GAVRILYAK | 13 |
| 2.38 | ±0.02 | ±0.14 | $^{136}$Xe | | KamLAND-Zen | [11] GANDO | 12A |
| 0.7 | ±0.09 | ±0.11 | $^{130}$Te | | NEMO-3 | [12] ARNOLD | 11 |
| 0.0235 | ±0.0014 | ±0.0016 | $^{96}$Zr | | NEMO-3 | [13] ARGYRIADES | 10 |
| 0.69 | $^{+0.10}_{-0.08}$ | ±0.07 | $^{100}$Mo | $0^+ \rightarrow 0_1^+$ | Ge coinc. | [14] BELLI | 10 |
| 0.57 | $^{+0.13}_{-0.09}$ | ±0.08 | $^{100}$Mo | $0^+ \rightarrow 0_1^+$ | NEMO-3 | [15] ARNOLD | 07 |
| 0.096 | ±0.003 | ±0.010 | $^{82}$Se | | NEMO-3 | [16] ARNOLD | 05A |
| 0.029 | $^{+0.004}_{-0.003}$ | | $^{116}$Cd | | $^{116}CdWO_4$ scint. | [17] DANEVICH | 03 |

# Ability to disentangle ββ-decay mechanisms




The HSD model is excluded with high confidence, while the SSD model is consistent with the NEMO-3 data.

***EPJ C79(2019)440***

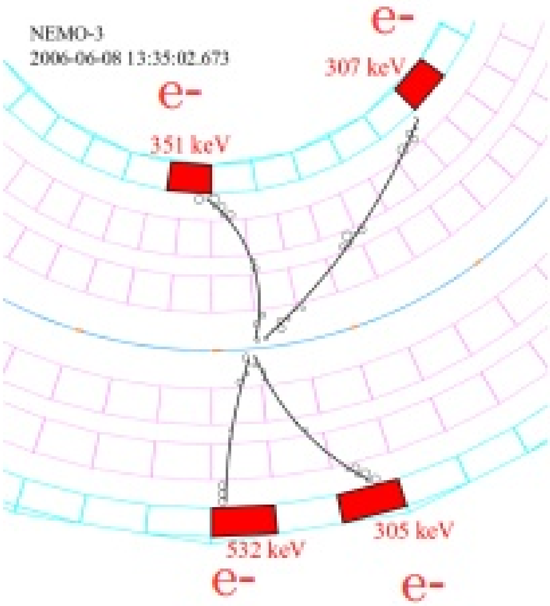
# Quadrupole neutrinoless 0ν4β-decay

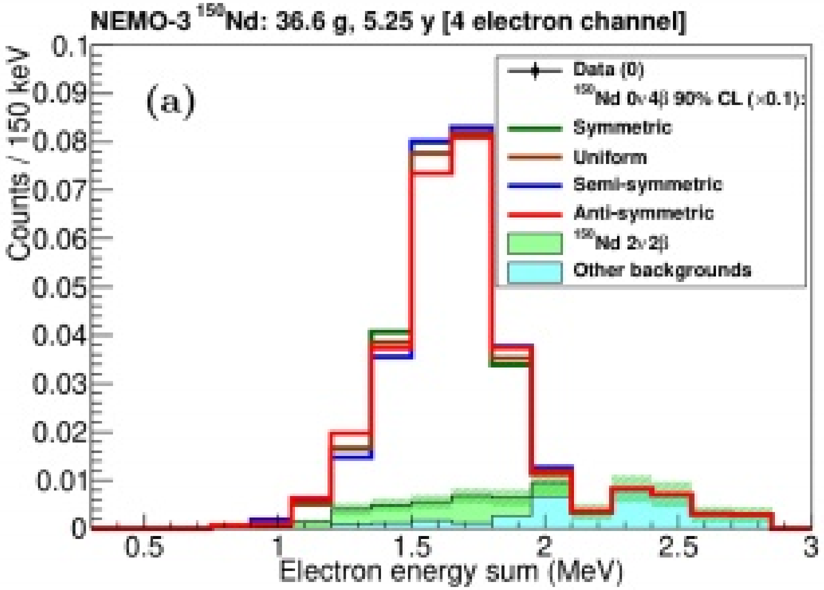
- Neutrinoless quadruple beta decay
  - Proposed by Heeck and Rodejohann [1]
  - Lepton number violating process
  - Neutrinos are Dirac particles and 0νββ is forbidden
  - The best candidate is $^{150}Nd \rightarrow {}^{150}Gd + 4e$ ($Q_{4\beta} = 2.079$ MeV)
- Exploit the unique ability of NEMO-3 to reconstruct the kinematics of each e-
- No evidence of this decay

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

According the model

- World's first limit on this process




[1] J. Heeck, W. Rodejohann, Europhys. Lett. 103, 32001 (2013).

***Phys.Rev.Lett. 119(2017)041801***

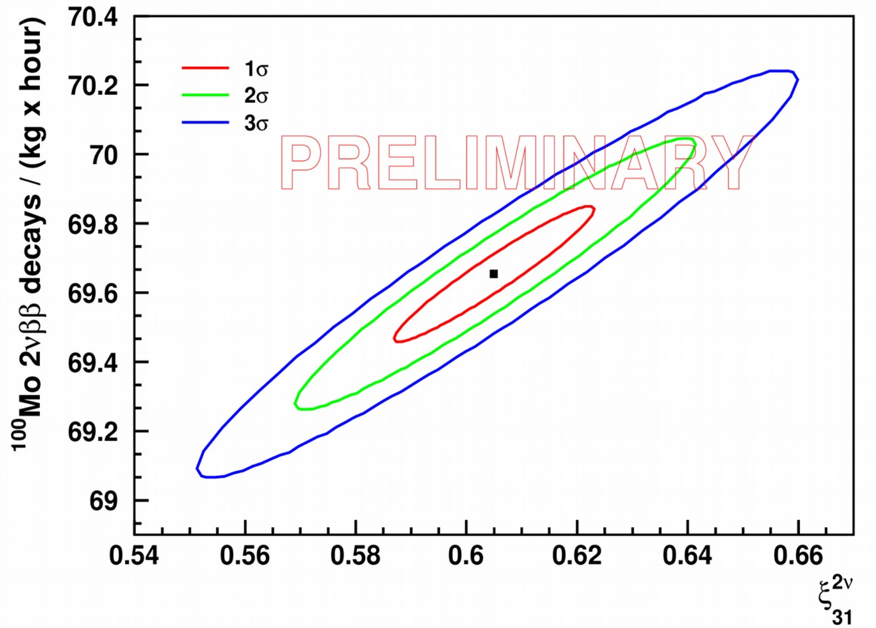
# Possibility to determine the effective axial-vector coupling constant

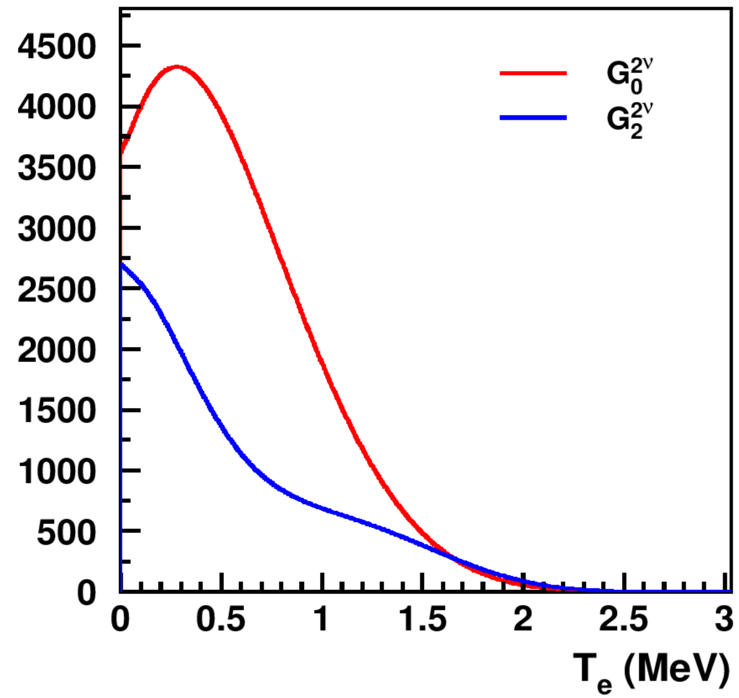
Following the paper *F.Šimkovic et al. Phys. Rev. C 97, 034315 (2018)*
the 2νββ decay rate may be expressed as:

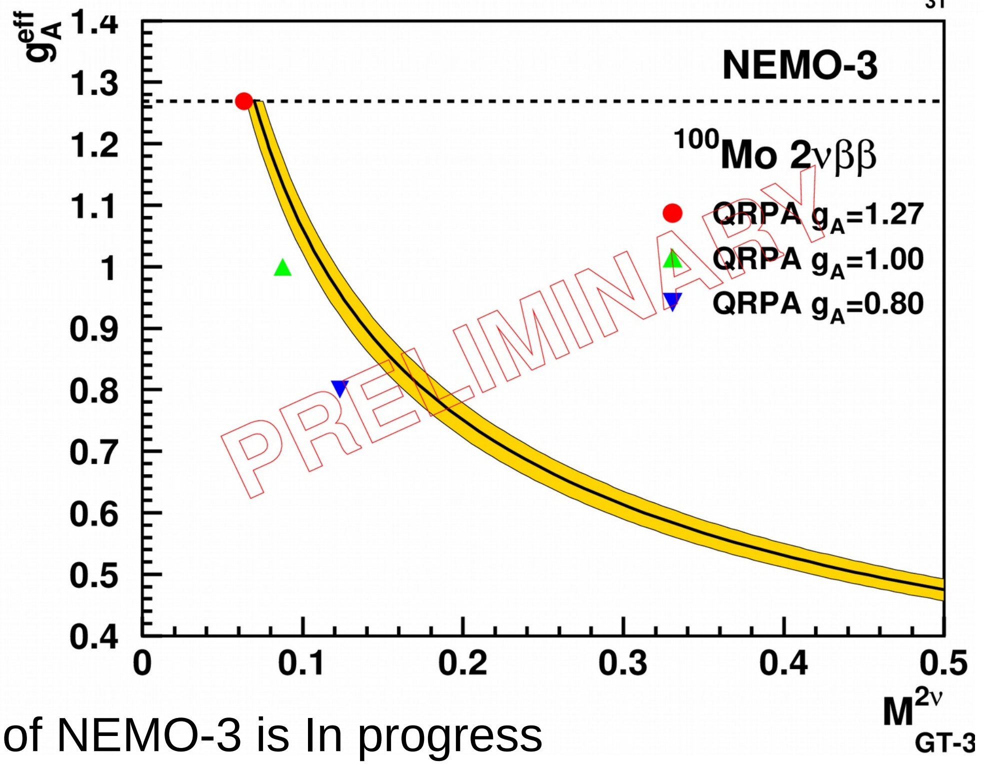
$$\left[T^{2\nu\beta\beta}_{1/2}\right]^{-1} \simeq \left(g_A^{\rm eff}\right)^4 \left|M^{2\nu}_{GT-3}\right|^2 \frac{1}{\left|\xi^{2\nu}_{31}\right|^2} \left(G^{2\nu}_0 + \xi^{2\nu}_{31} G^{2\nu}_2\right)$$

The parameter $\xi^{2\nu}_{31} = \dfrac{M^{2\nu}_{GT-3}}{M^{2\nu}_{GT-1}}$

may be determined from the fit of measured 2νββ-decay energy distributions.

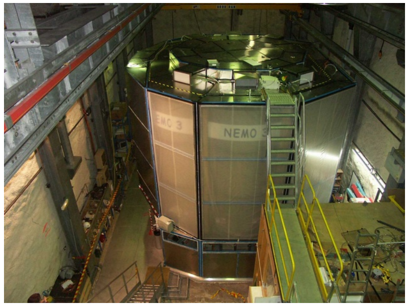
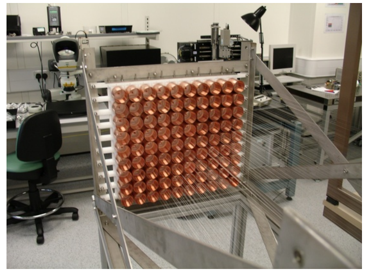


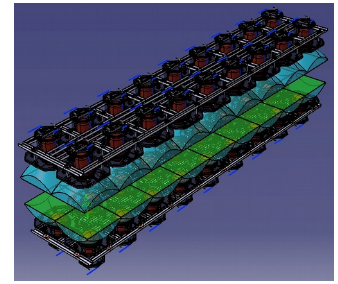




Analysis of $^{100}$Mo and $^{150}$Nd data of NEMO-3 is In progress

# From NEMO-3 to SuperNEMO



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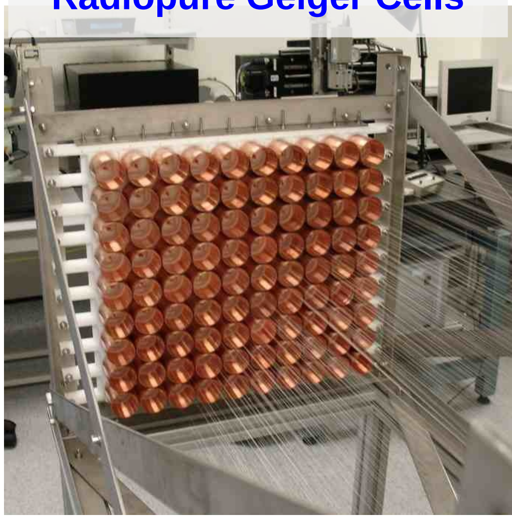
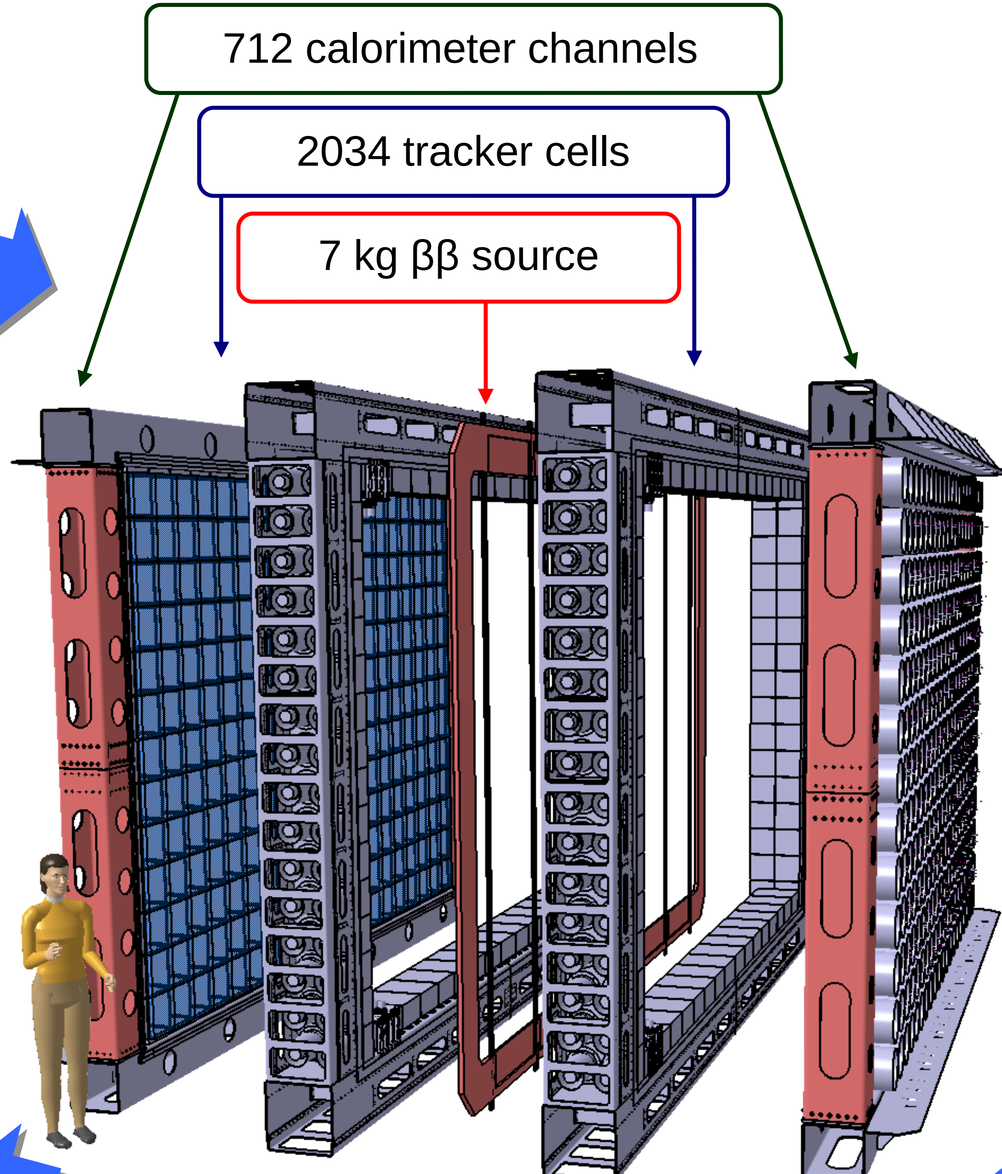
| NEMO-3 | | SuperNEMO |
|---|---|---|
| $^{100}$Mo | Isotope | $^{82}$Se (or $^{150}$Nd or $^{96}$Zr) |
| 7 kg | Isotope mass M | 100+kg |
| $^{208}$Tl: ~ 100 μBq/kg<br>$^{214}$Bi: < 300 μBq/kg | Contaminations in the ββ foil | $^{208}$Tl ≤ 2 μBq/kg<br>$^{214}$Bi ≤ 10 μBq/kg |
| Rn: 5 mBq/m$^3$ | Rn in the tracker | Rn ≤ 0.15 mBq/m$^3$ |
| 8% @ 3MeV | Energy resolution (FWHM) | 4% @ 3 MeV |
| $T_{1/2}(\beta\beta0\nu) > 1.1 \times 10^{24}$ y<br>$<m_\nu> < 0.3 – 0.6$ eV | Sensitivity | $T_{1/2}(\beta\beta0\nu) > 1 \times 10^{26}$ y<br>$<m_\nu> < 0.04 - 0.1$ eV |

# SuperNEMO Demonstrator

**Tracking Detector**
**Radiopure Geiger Cells**



**Calo. Optical Module**
**FWHM 7-8 % @ 1 MeV**



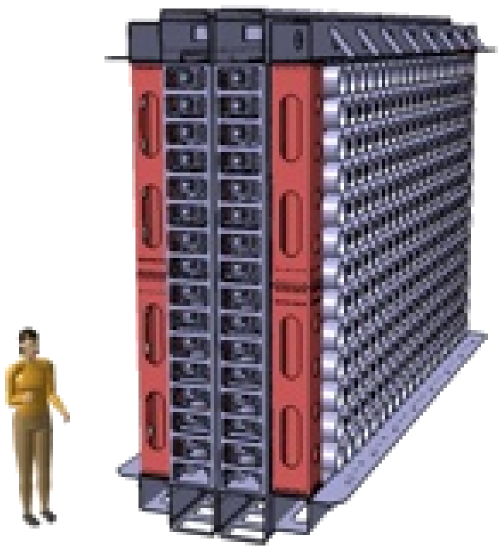

**Demonstrator Module**

Also :

- Change isotope $^{100}$Mo ⟶ $^{82}$Se
- Reduce radon in gas by factor 30
- Improved efficiency, calibration etc.

**"BiPo" Detector**
**Measure source foil contamination to $^{208}$Tl ≤ 2 μBq/kg**
**$^{214}$Bi ≤ 10 μBq/kg**

# SuperNEMO Demonstrator Physics Scope



## Search for 0νββ

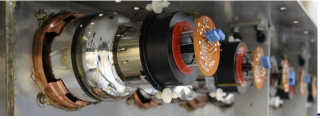
- Sensitivity goal of Demonstrator Module (2.5 year run) 17.5 kg×yr initial exposure for the standard mass mechanism:

$$T^{0\nu}_{1/2} > 5.9 \times 10^{24} \ \text{yr} \quad \langle m_\nu \rangle < 0.20 - 0.55\,\text{eV}$$

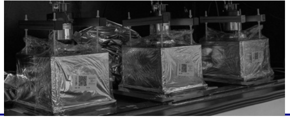
- Searches for the 0ν signal for other mechanisms including heavy composite Majorana neutrinos, Majorons, RH currents, R-parity violating SUSY models.

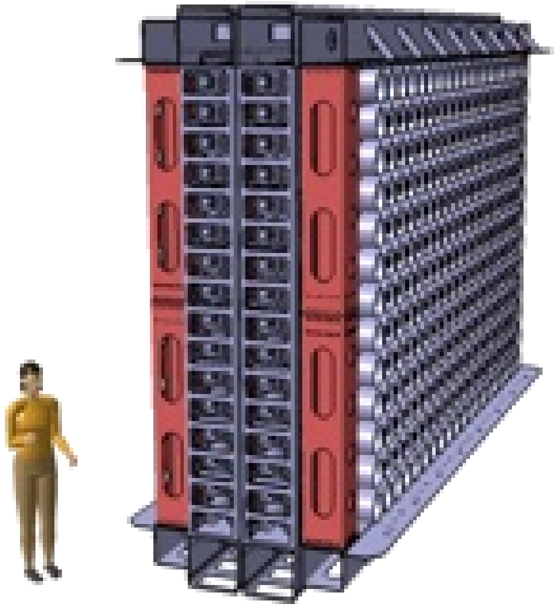
## Detailed study of 2νββ

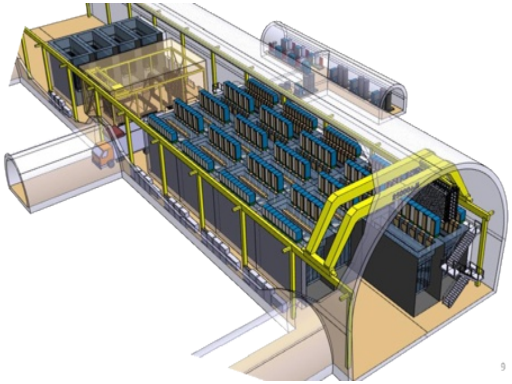
- Disentangle Single-state vs Higher-state mechanism in the $^{82}$Se 2νββ decay @ 5σ.
- The measurement of $g_A$ parameter, essential for the NME calculation (*F.Šimkovic et al. Phys. Rev. C 97, 034315 (2018)*)
- Precision measurements on 2νββ decay (energy of each electron, angular correlation) to look for deviations from standard model and the search of exotic decays including Lorenz invariance violation, bosonic neutrino, exotic charge currents (*Frank F. Deppisch, Lukas Graf, Fedor Simkovic, Phys.Rev.Lett. 125 (2020) 17, 171801*)



# SuperNEMO Future Directions







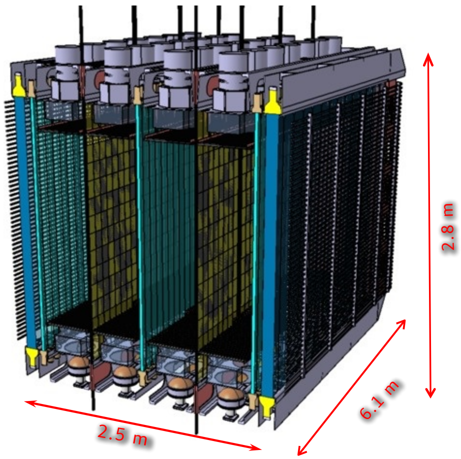
Full SuperNEMO

500 kg×yr :

$$T^{0\nu}_{1/2} > 10^{26}\ \mathrm{yr}$$

$$\langle m_\nu \rangle < 40 - 110\,\mathrm{meV}$$

Alternative Designs





- A **unique approach** with access to fundamental nuclear physics.
- The best technique for **exploring a signal.**
- Continued R&D is essential.

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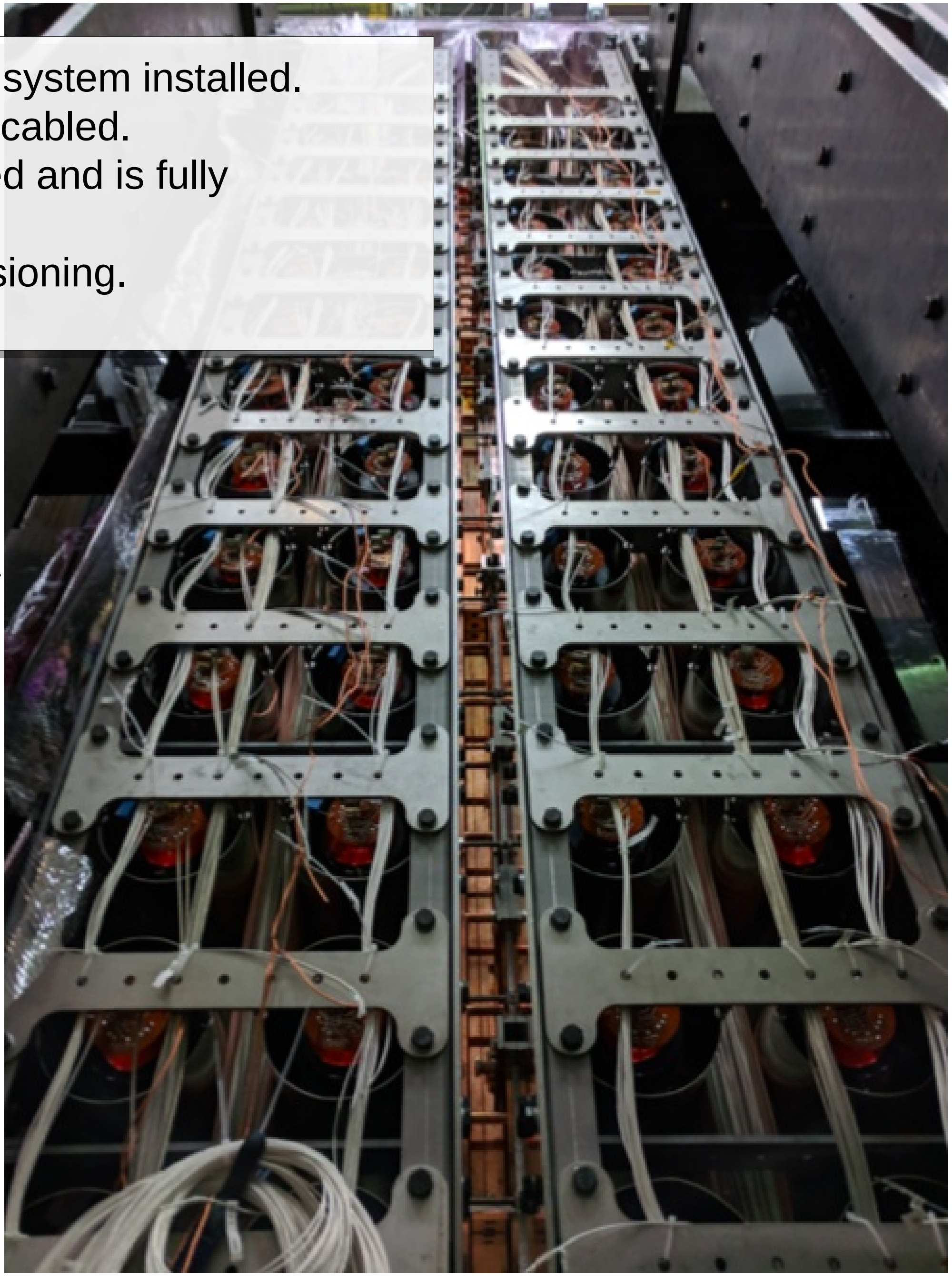
# Status of SuperNEMO Demonstrator

- Source foils & calibration system installed.
- Detector closed and fully cabled.
- Calorimeter commissioned and is fully operational.
- Tracker is under commissioning.



# Working schedule

- The first half of 2021 - completion of assembly and commissioning of the Demonstrator without external shielding. The calibration of the Demonstrator, the launch of data taking in a configuration without external shielding.
- The second half of 2021 - the creation of external shielding of the Demonstrator.
- 2022 – start calibration and data collection in the full configuration of the Demonstrator.
- 2022-2024 - data taking, data analysis, background assessment, control of backgrounds, publication of results for the Demonstrator.
- During the whole period - R&D on the centrifuge method of $^{96}Zr$ enrichment, improvement of the purification technique of $^{82}Se$ (100 kg) and mass production of plastic scintillators.

# JINR contribution

- R&D and production of 720 plastic scintillator blocks for the Demonstrator calorimeter (in cooperation with the University of Prague).
- Manufacturing of 60 optical modules for the VETO system (scintillator + PMN 5“ R6594 HAMAMATSU).
- Acquisition of 100 PMT 8“ R5912-03 HAMAMATSU for the calorimeter.
- Purchase of 7 crates for the electronics of the calorimeter.
- Purchase 1.5 kg of enriched $^{82}$Se to create sources.
- A unique $^{82}$Se purification technique has been developed and implemented. A clean room has been built , and 3.5 kg of $^{82}$Se has been purified, used to create the sources of the Demonstrator.
- Manufacturing of signal and HV cables for the tracker.
- Development, creation and maintenance of equipment for low-background measurements: germanium, radon, neutron detectors in LSM.
- Iron passive shielding against gammas is now being developed and will be created.
- Essential contribution in software development, simulations, data base creation and data analysis.

# SWOT analysis

## Strengths

- The complete kinematics of the double beta decay process is reconstructed.
- Full topological event reconstruction including $e^+$, $e^-$, $\gamma$-ray and $\alpha$-particle identification.
- Excellent background suppression by particle identification, event characterisation and timing. Radon suppression by anti-radon factory.
- Modular design (20 independent modules) allows to increase the number of modules as they are ready.

## Weaknesses

- Low efficiency of recording the process of $0\nu\beta\beta$-decay - 25%.
- Low energy resolution of the calorimeter, FWHM = 8% for 1 MeV electrons. As a result - the non-removable background from the continuous spectrum of $2\nu\beta\beta$-decay.

## Opportunities

- In case of $0\nu$ signal discovery the SuperNEMO may provide the way for the full characterisation of $0\nu\beta\beta$, to determine the underlying physics mechanism. Almost any solid isotope can be hosted in SuperNEMO detector.

## Threats

- The main threats and risks to the project are associated with further restrictions due to the COVID-19 pandemic. Specifically, due to travel restrictions of the personnel as well as restrictions for the underground laboratory access that may lead to further delays with completion of the shielding construction and physics data taking.

# Human resources

| N | Person | Status | Subjects | FTE |
|---|---|---|---|---|
| 1 | O.I. Kochetov | JINR Project Leader | calorimeter, data analysis, databases | 1.0 |
| 2 | Yu.A.Shitov | Senior Researcher | software, data analysis, databases | 0.1 |
| 3 | V.B.Brudanin | Senior Researcher | calorimeter, data analysis | 0.1 |
| 4 | A.A. Smolnikov | Senior Researcher | calorimeter, data analysis, simulation | 0.3 |
| 5 | A.A. Klimenko | Senior Researcher | software, data analysis | 0.3 |
| 6 | V.I. Tretyak | Senior Researcher | software, data analysis, simulation | 1.0 |
| 7 | D.V. Karaivanov | Researcher | radiochemistry, $^{82}$Se-purification, sources | 0.4 |
| 8 | A.V. Rahimov | PhD student | radiochemistry, $^{82}$Se purification, sources | 0.6 |
| 9 | D.V. Filosofov | Senior Researcher | radiochemistry, $^{82}$Se purification, sources | 0.3 |
| 10 | N.A. Mirzaev | Researcher | radiochemistry, $^{82}$Se purification, sources | 0.4 |
| 11 | A.V. Salamatin | Senior Researcher | electronics, cables | 0.4 |
| 12 | V.V. Timkin | Researcher | calorimeter, VETO system and cables | 1.0 |
| 13 | I.B. Nemchenok | Senior Researcher | PS production, calorimeter and VETO system | 0.2 |
| 14 | I.I. Kamnev | Engineer | PS production, calorimeter and VETO system | 0.3 |
| 15 | O.I. Vagina | Engineer | PS production, calorimeter and VETO system | 0.3 |
| **In total** | | | | **6.7** |

# Financial resources

**Schedule proposal and resources required for the implementation of the SuperNEMO Project**

| List of parts and devices; Resources; Financial sources | | | Cost of parts (K US$), resources needs | Allocation of resources and money | | |
|---|---|---|---|---|---|---|
| | | | | 1st year | 2nd year | 3rd year |
| Main parts and equipment | 1. Materials for Demonstrator iron shielding (radioactively pure iron) | | 200 | 200 | 0 | 0 |
| | 2. Spectroscopic electronics for test stands of PS&PMTs | | 20 | 20 | 0 | 0 |
| | 3. Borated polystyrene for neutron shielding of the Demonstrator | | 30 | 30 | 0 | 0 |
| | 4. Materials&Equipment for Demonstrator maintenance under JINR responsibility (2 Radon detectors, two HPGe spectrometer,) and carrying out calibrations, including creation of calibration sources. Radiochemical equipment. | | 60 | 20 | 20 | 20 |
| | **Total** | | **310** | **270** | **20** | **20** |
| Resources | Norm-hours | JINR workshop | 0 | 0 | 0 | 0 |
| | | DLNP workshop | 600 | 300 | 150 | 150 |
| Financial sources | JINR budget | Budget spending | 310 | 270 | 20 | 20 |
| | Off-budget sources | Grants; Other sources (these funds are not currently guaranteed) | *30* | *10* | *10* | *10* |

**Estimated expenditures for the SuperNEMO project**

| # | Designation for outlays | Total cost | 1 year | 2 year | 3 year |
|---|---|---|---|---|---|
| | Direct expenses for the project | | | | |
| 1. | Networking | 6.0 KUS$ | 2.0 | 2.0 | 2.0 |
| 2. | DLNP workshop | 600 norm-hour | 300 | 150 | 150 |
| 3. | JINR workshop | 0 | 0 | 0 | 0 |
| 4. | Materials | 290.0 KUS$ | 250.0 | 20.0 | 20.0 |
| 5. | Equipment | 20.0 KUS$ | 20.0 | 0.0 | 0.0 |
| 6. | Collaboration fee | 60.0 KUS$ | 20.0 | 20.0 | 20.0 |
| 7. | Travel expenses | 60.0 KUS$ | 30.0 | 15.0 | 15.0 |
| | **Total** | **436.0 KUS$** | **322.0 KUS$** | **57.0 KUS$** | **57.0 KUS$** |

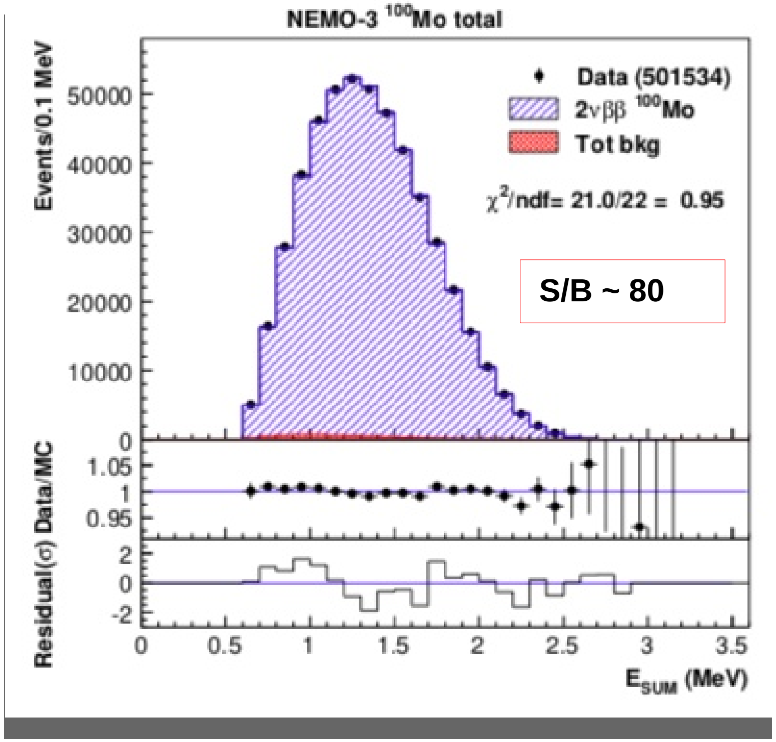
Expected salary of SuperNEMO team is 113.9 kUS$ per year taking into account 1FTE=17kUS$. It includes spending on technical personnel not listed in the project. 1US$ = 64RUB assumed in the estimation.

# Summary

- The NEMO/SuperNEMO experiments are based on a unique track-calorimetric method for the investigation of ββ-processes, which has been successfully developed for decades. It allows to reconstruct the complete pattern of ββ-decay and to test its mechanism.
- The main task of  Demonstrator (the first module) of the SuperNEMO is to validate the technique of background suppression, as well as physical measurements. With 7 kg of $^{82}Se$ in 2.5 years it is planned to achieve sensitivity to the effective neutrino mass at the level of 0.20 - 0.55 eV.
- The Demonstrator is in the final stages of commissioning in the underground laboratory and will start this year.
- The creation of the Demonstrator became possible with the decisive contribution of JINR to a number of working tasks: calorimeter, tracker, sources, shielding, etc.
- The success of the Demonstrator opens the opportunity for the full SuperNEMO detector: measurement of 100 kg of the source in 20 modules with a sensitivity of 40-110 meV to the effective Majorana neutrino mass.

# Backup slides

# Detailed study of $^{100}$Mo 2νββ



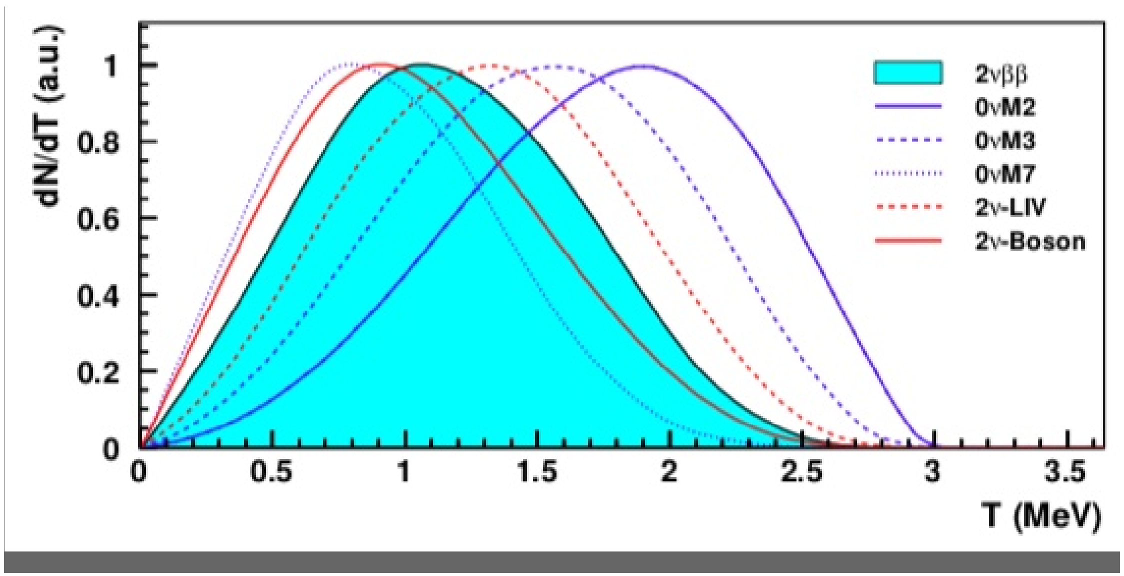

- Final results on $^{100}$Mo (6.9 kg): ***EPJ C79(2019)440***

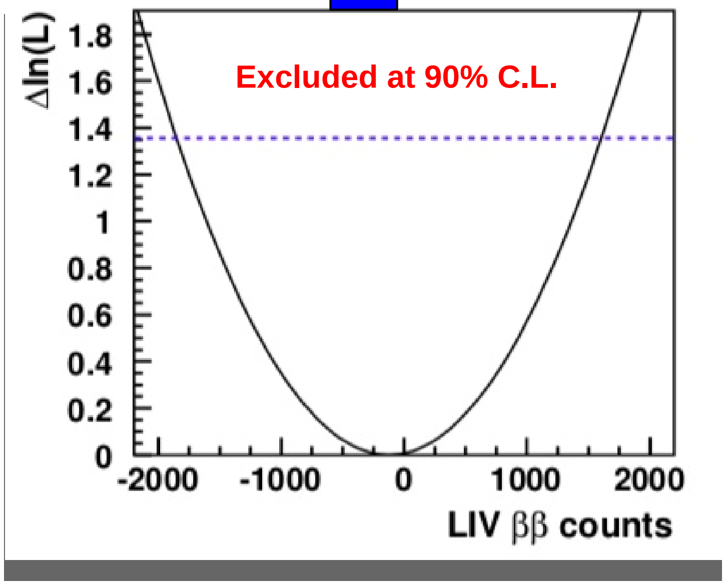
$$T_{1/2}^{2\nu\beta\beta} = 6.81 \pm 0.01(\text{stat.}) \pm 0.46(\text{syst.}) \times 10^{18} \text{ years}$$

Assuming **SSD** (HSD clearly rejected by data).

- Many model limits, including the world's best constraint on oscillation-free Lorentz-violating parameter:

$$-4.2 \times 10^{-7} \text{ GeV} < \mathring{a}_{of}^{(3)} < 3.5 \times 10^{-7} \text{ GeV } (90\%\text{C.L.})$$



## Recent publication of the SuperNEMO 2017- 2020


**[1]** A.S. Barabash on behalf of the NEMO-3 and SuperNEMO collaborations, "Double beta decay experiments: present and future", J. Phys.: Conf.Ser.**1390 (2019)** 012048. DOI: 10.1088/1742-6596/1390/1/012048.

**[2]** R. Arnold et al., "Detailed studies of Mo-100 two-neutrino double beta decay in NEMO-3", Eur. Phys. J. C (2019) 79:440. DOI: 10.1140/epjc/s10052-019-6948-4

**[3]** Alimardon V.Rakhimov et al., "Development of methods for the preparation of radiopure Se-82 sources for the SuperNEMO neutrinoless double-beta decay experiment", Radiochimica Acta, 2020; 108(2): 87-97. DOI: 10.1515/ract-2019-3129.

**[4]** R. Hodak et al., "Charactirization and Long-term Performance of the Radon Trapping Facility Operating at the Modane Underground Laboratory", Journal of Physics G: Nuclear and Particle Physics 46 (2019)115105 (17pp). DOI: 10.1088/1361-6471/ab368e.

**[5]** R. Arnold et al., NEMO-3 Collaboration, "Search for the double beta decay Se-82 to the excited states of Kr-82 with NEMO-3", Nuclear Physics A v 996 (2020) 121701. DOI: 10.1016/j.nucl.physa.2020.121701.

**[6]** Thibaud Le Noblet on behalf of the NEMO-3 and SuperNEMO collaborations, "Latest results from NEMO-3 and commissioning status of the SuperNEMO demonstrator", J. Phys.: Conf.Ser. **1342 (2020)** 012029. DOI: 10.1088/1742-6596/1342/1/012029.

**[7]** A.S. Barabash et al., "Calorimeter development for the SuperNEMO double beta decay experiment, Nucl. Instrum. Meth. A 868 (2017) 98-108

**[8]** A.S. Barabash et al., "The BiPo-3 detector for the measurement of ultra low natural radio activities of thin materials", JINST 12 (2017) no.06, P06002

**[9]** S. Calvez, on behalf of the SuperNEMO collaboration, "$0\nu\beta\beta$-sensitivity with the SuperNEMO demonstrator, 52nd Rencontres de Moriond EW 2017, La Thuile, Italy, Mars 18-25, 2017

**[10]** R. Arnold et.al., "Measurement of the double beta-decay half-life and search for the neutrinoless double beta-decay of Cd-116 with the NEMO-3 detector", Phys. Rev. D95 (2017) 012007-1 – 012007-12.

**[11]** R. Arnold et.al., "Measurement of the double beta-decay half-life of Nd-150 and a search for neutrinoless double beta-decay processes with the full exposure from the NEMO-3 detector", Phys. Rev. D94 (2016) 072003.

**[12]** H. Gomes for the NEMO-3&SuperNEMO Collaborations, "Latest results of NEMO-3 experiment and present status of SuperNEMO", Nuclear and Particle Physics Proceedings (2016) 1765-1770.

**[13]** P.Povinec on behalf of the SuperNEMO Collaboration, "SuperNEMO – a new generation of underground experiments for double beta-decay investigations", The 14th Vienna Conference on Instrumentation 15-16 Feb., 2016.

**[14]** A.S. Barabash et. al.,"Calorimeter development for the SuperNEMO double beta-decay experiment", NIM A868 (2017) 98-108.

**[15]** R. Arnold et al. from NEMO-3 Collaboration, "Search for neutrinoless quadrupole-b decay of the Nd-150 with the NEMO-3 detector" Phys. Rev. Lett. 119 (2017) 041801.


## Reports of Dubna group at international conferences in 2019

Yu.A. Shitov "The Final Results of the NEMO-3 Experiment and Status of the SuperNEMO Project", Nucleus-2019, Dubna, 1-5 July 2019.

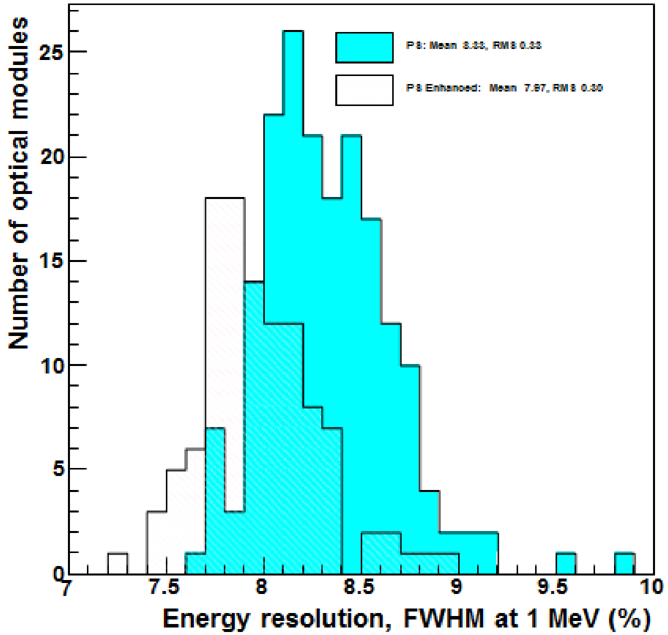
V.I. Tretyak "Investigation of Mo-100 two-neutrino double beta decay in NEMO-3", MEDEX-2019, Prague, 27-31 May 2019.

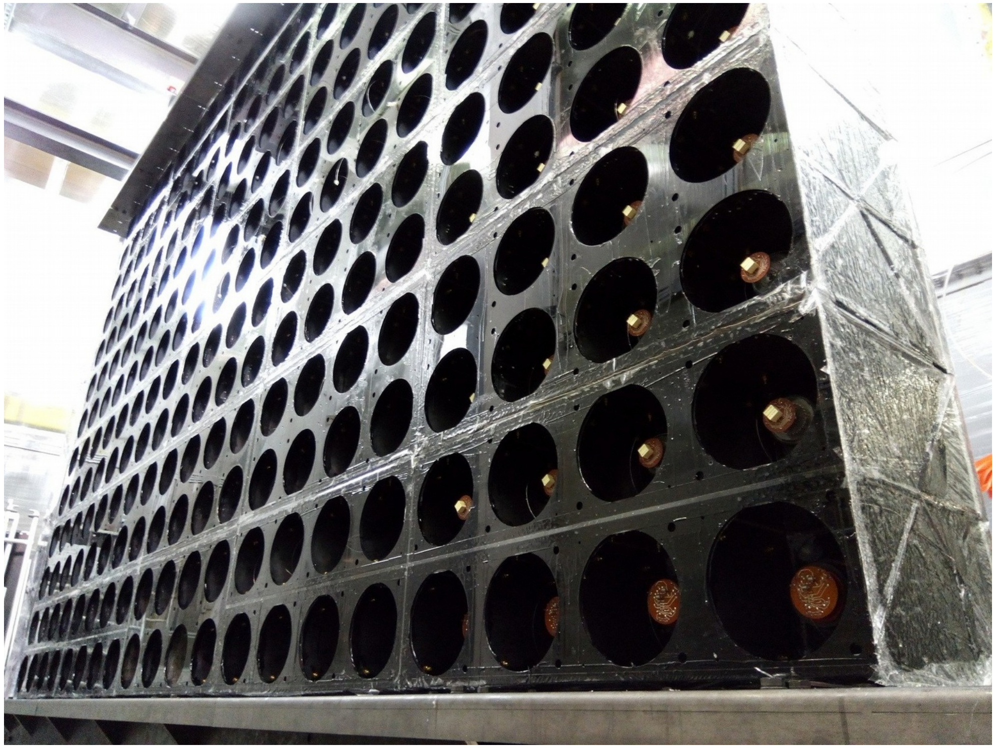
# SuperNEMO Demonstrator

# SuperNEMO Calorimeter

- 520 main wall optical modules
- 8” high QE radiopure PMTs
- $\sigma_t$ = 400 ps at 1 MeV
- Energy resolution FWHM=8%/√E(MeV)

NIM, A 868 (2017) 98–108



# SuperNEMO Tracker

Nucl.Instrum.Meth. A824 (2016)

- Multi-wire drift chamber in Geiger mode
- Ultrapure materials: copper, steel, duracon
- Robotic production of 2034 drift cells
- Radiopure gas flow, anti-radon sealing
- <1% dead channels

# SuperNEMO Source foils

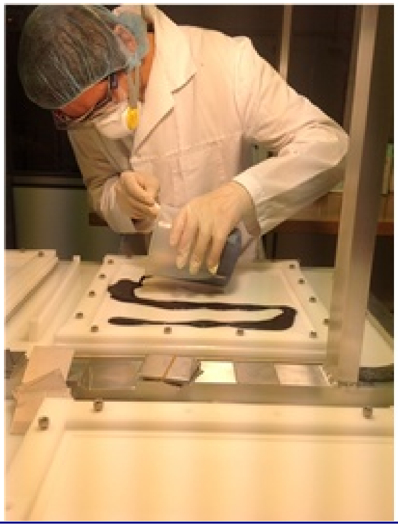
- 36 foils made of $^{82}$Se powder mixed with PVA glue + mylar mechanical support (200 um thick)
- 7 kg of $^{82}$Se ($Q_{\beta\beta}$=2.996 MeV)
- Target limits (challenging) on foil contamination:

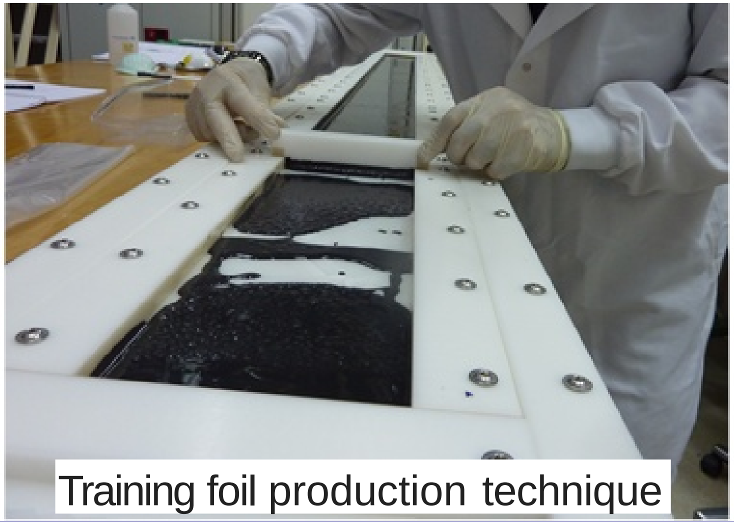
  $^{208}$Tl ≤ 2 μBq/kg

  $^{214}$Bi ≤ 10 μBq/kg

- BiPo detector in Canfranc laboratory to measure source foil contamination: preliminary results indicate levels of $^{208}$Tl [10-30] mBq/kg (90% C.L.)

JINST 12 (2017) no.06





Training foil production technique

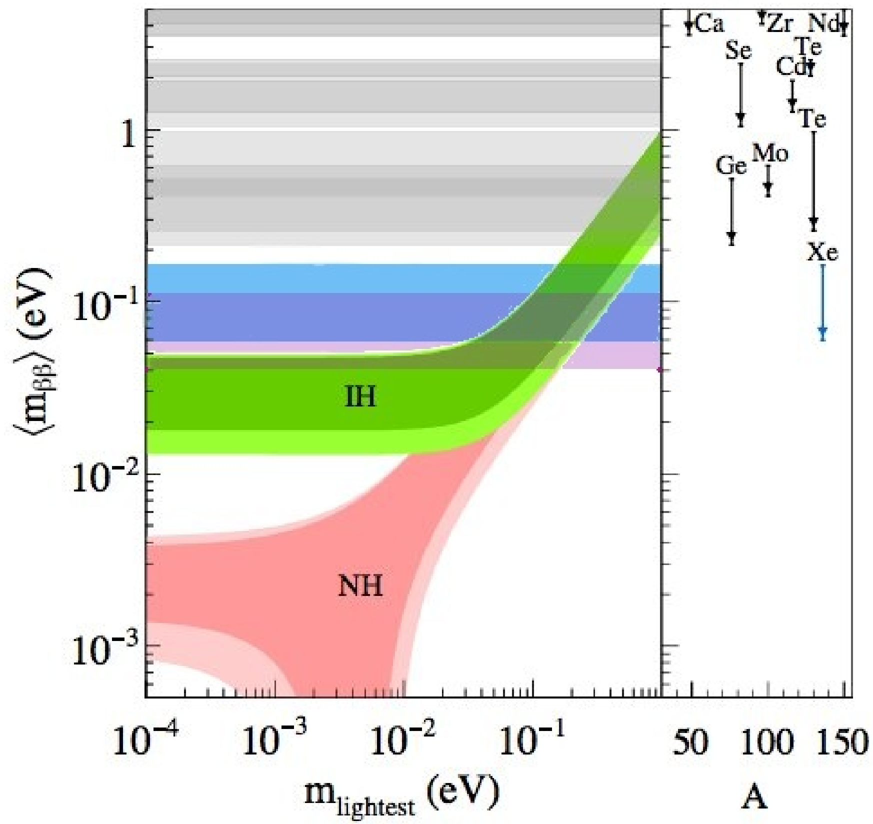
$^{82}$Se foils radio-purity measurements

**Best present limit on < $m_\nu$>**

| Nucleus | T1/2, y, 90% C.L. | <mν>, eV, QRPA + others | Experiment |
|---|---|---|---|
| Ge-76 | > 1.8 x $10^{26}$ | < 0.07 – 0.16 | GERDA – I + II |
| Ge-76 | > 1.9 x $10^{25}$ | < 0.24 - 0.52 | Majorana |
| Xe-136 | > 1.1 x $10^{26}$ | < 0.061 - 0.165 | KamLAND-Zen I + II |
| Xe-136 | > 1.8 x $10^{25}$ | <0.147 – 0.398 | EXO-200 I + II |
| Te-130 | > 3.2 x $10^{25}$ | < 0.075 – 0.350 | CUORE |
| Mo-100 | > 1.1 x $10^{24}$ | < 0.310 – 0.620 | NEMO-3 |
| Se-82 | > 5.0 x $10^{24}$ | < 0.311 – 0.638 | CUPID-0 |

Demonstrator SuperNEMO:
<$m_\nu$> < 0.20 – 0.55 eV

Full SuperNEMO
<$m_\nu$> < 0.04 – 0.11 eV



# $^{82}Se$ purification, Radioch. Acta, 2020; 108(2): 87-97.

A radiochemical method for producing $^{82}Se$ sources with an ultra-low level of contamination of natural radionuclides ($^{40}K$, decay products of $^{232}Th$ and $^{238}U$) has been developed.
The technique developed was then used to produce 2.5 kg of radiopure enriched selenium ($^{82}Se$).
The radiopurity of the final $^{82}Se$ foils has been measured by BiPo-3 spectrometer:
$^{208}Tl$ : 8 – 54 μBq/kg
$^{214}Bi$ ≤ 600 μBq/kg
This corresponds to an improvement in the radiopurity of the selenium foils by about a factor of 10 for $^{208}Tl$ and at least by about a factor of 3 for $^{214}Bi$ in comparison with the NEMO-3 experiment.

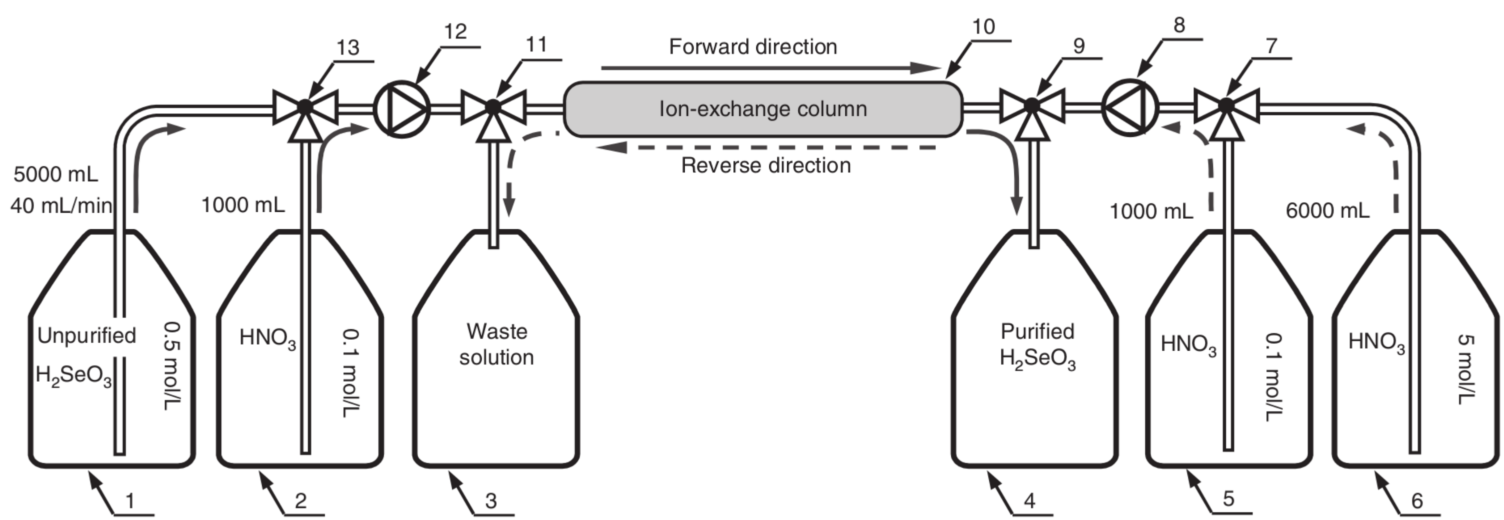
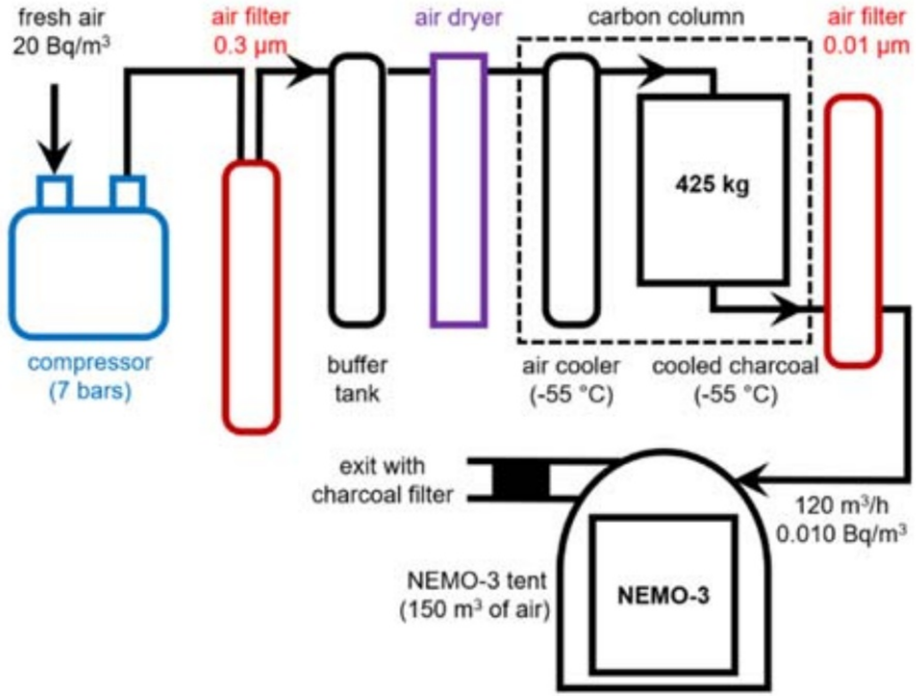
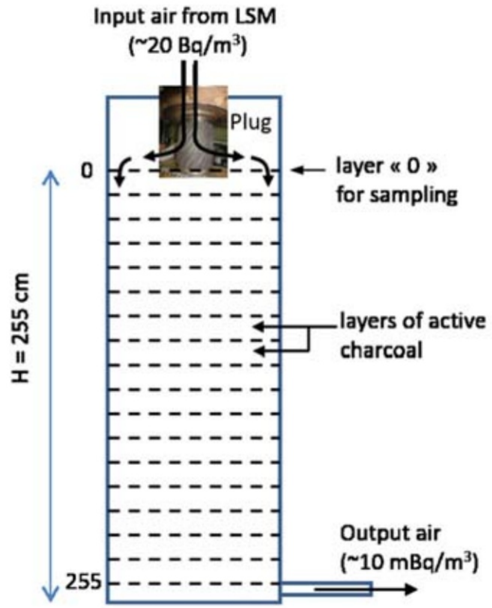



**Figure 1:** Chromatographic separation (purification) scheme of selenium by the reverse method.
1–6 – polypropylene vessels with the solutions; 7, 9, 11, 13 – triple valves; 8, 12 – peristaltic pumps; 10 – ion exchange column.

# Clean room for $^{82}$Se purification (DLNP, JINR)

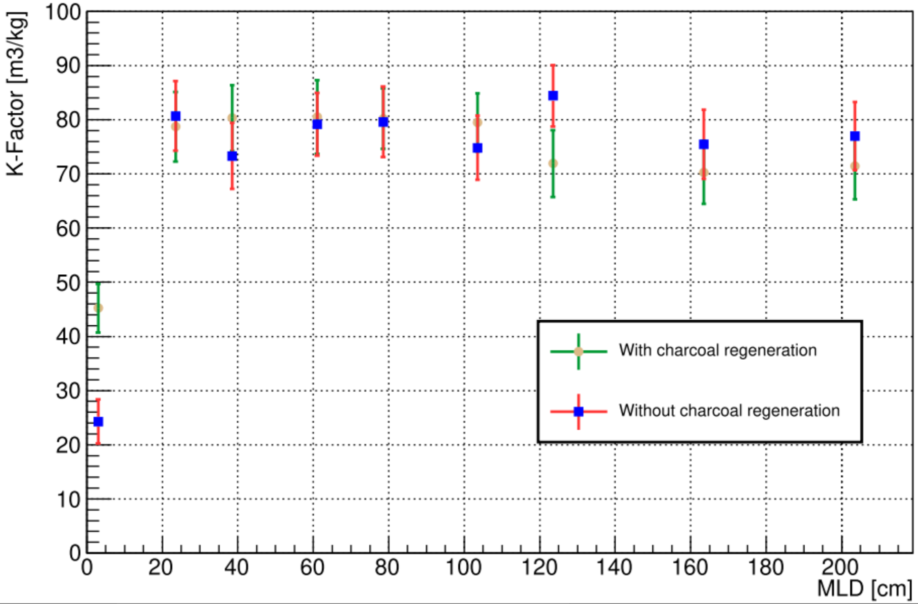
# Radon Trapping Facility, J.Phys. G46 (2019)115105




The Radon Trapping Facility (RTF) installed in 2004 at the Modane Underground Laboratory (LSM) has been running for nine years providing radon-purified air at a level of 10 mBq $m^{-3}$ for several experiments.
After disassembling of the RTF, the 2.6 m high charcoal column has been divided into several layers in order to study the dynamic adsorption coefficient (the K-factor) as a function of the depth and the radon spatial trapping profile by measuring the $^{210}$Pb activity.

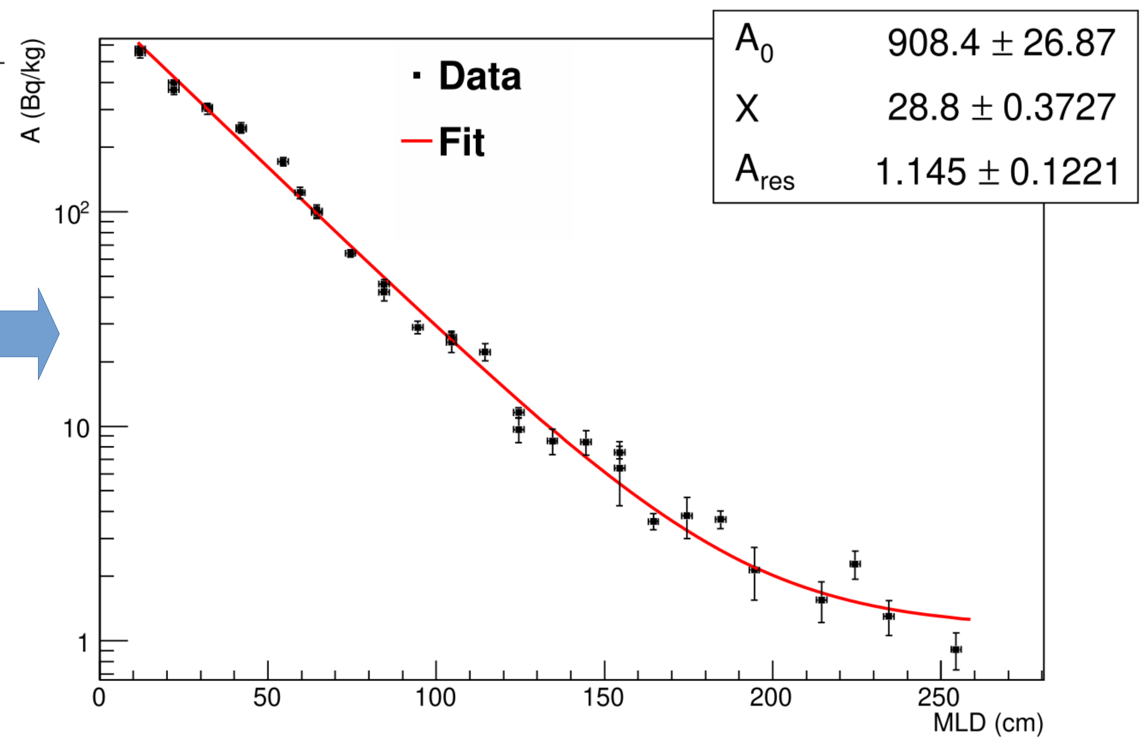
# Radon Trapping Facility, J.Phys. G46 (2019)115105




It has been demonstrated that after almost a decade of running, the K-factor of the activated charcoal remains constant except for the first few cm of the column.

The activity of $^{210}$Pb is exponentially decreasing with depth. The radon mean retention time $\tau_R$ of (47.6 ± 1.2) days and the radon mean free path of (28.9 ± 0.4) cm have been derived and found to be consistent at 1σ with the ones obtained from the K-factor study.

The radon suppression factor of the RTF of 6790+1720-2370 has been also estimated with a value consistent at 2σ with the suppression factor measured during the RTF operation.




Measured activities of $^{210}$Pb as a function of the MLD