

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

Theme 03 – 2 - 1100 - 2010/2021

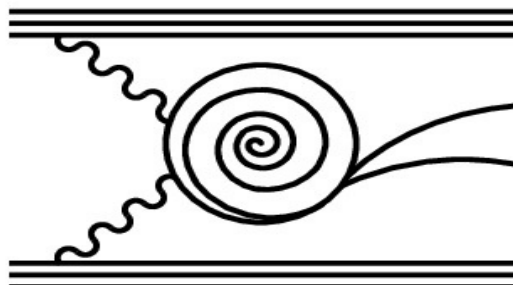
“Non-accelerating neutrino physics and astrophysics”

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Extension of the SuperNEMO project
for the period 2022-2024

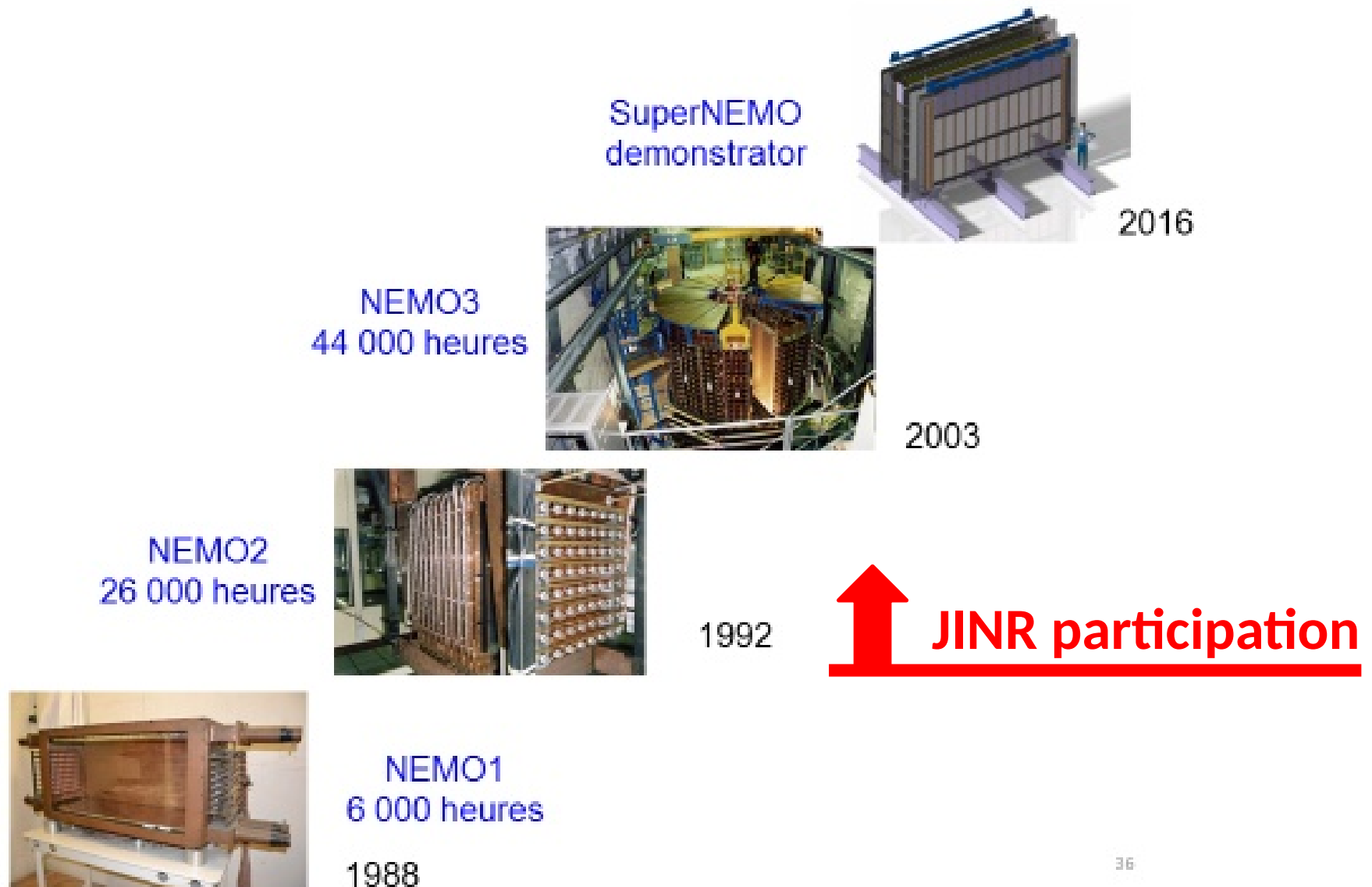
Speaker: **Victor Tretyak** (DLNP, JINR)

s u p e r n e m o



c o l l a b o r a t i o n

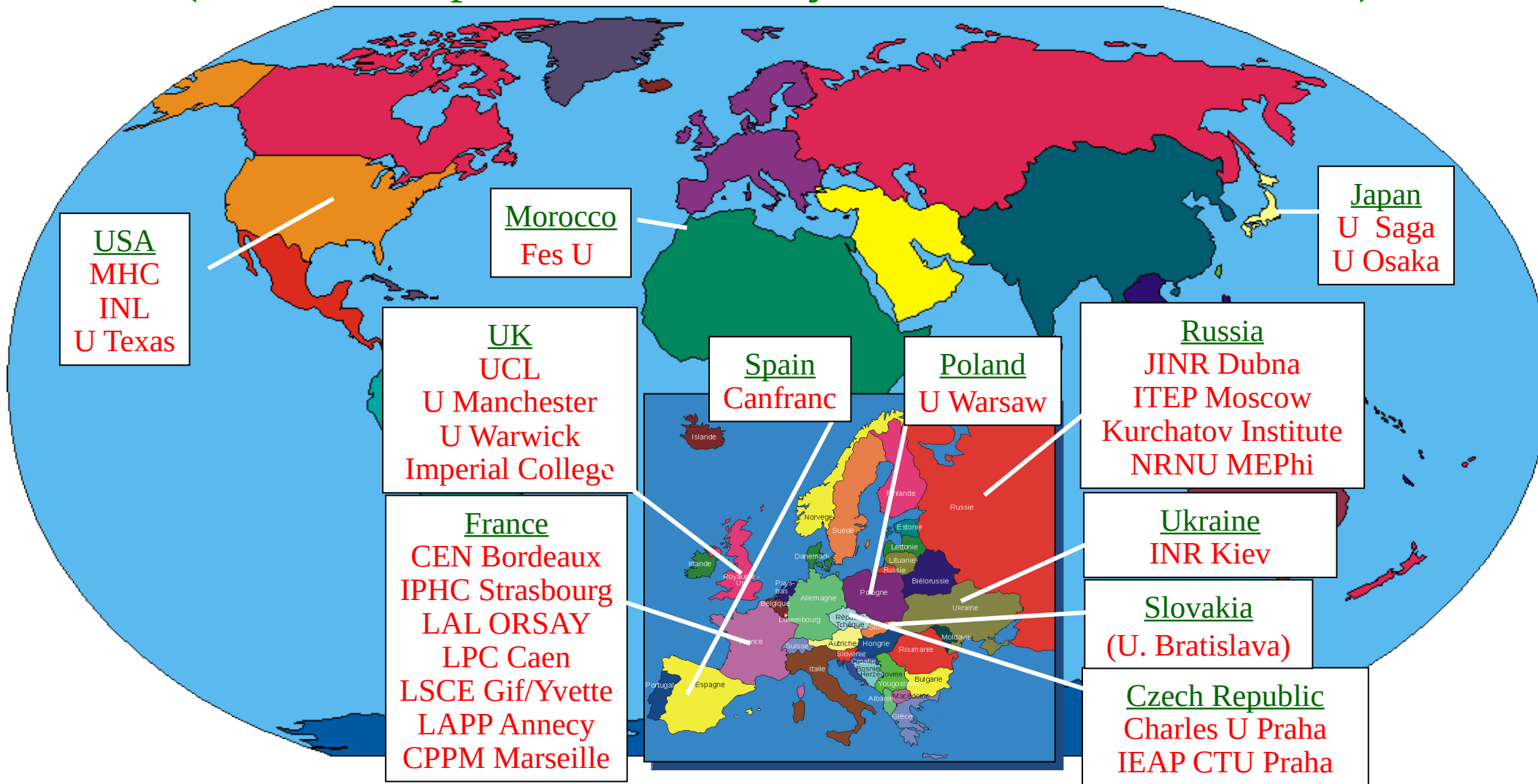
The NEMO/SuperNEMO road map



The NEMO/SuperNEMO collaborations

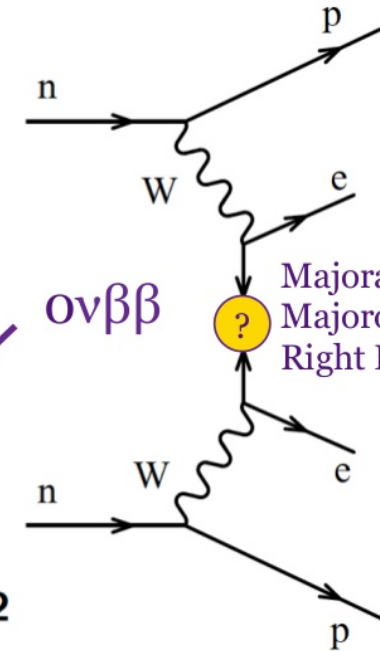
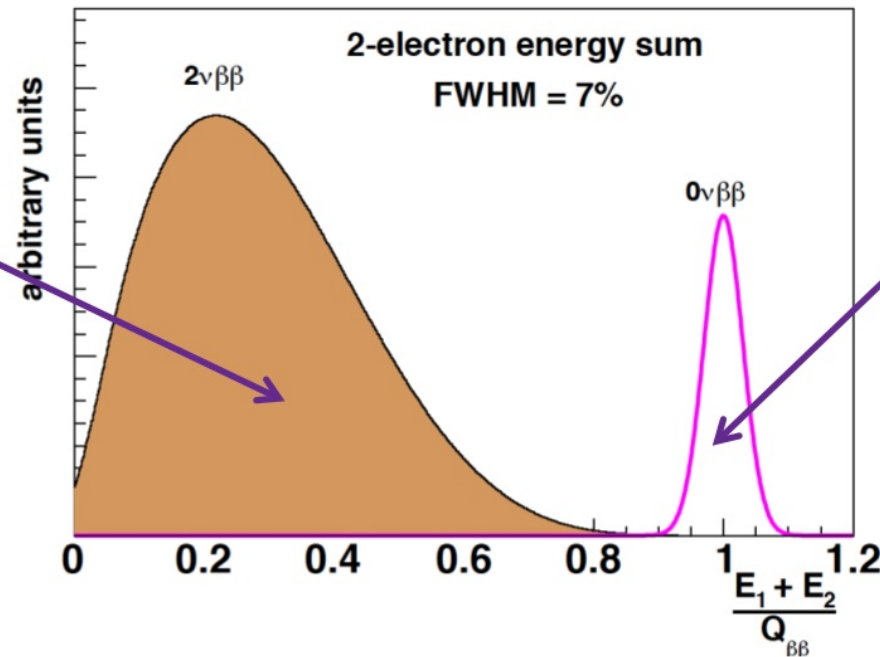
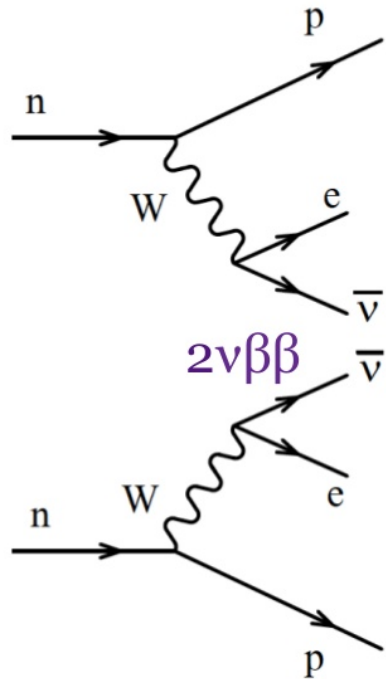
Neutrino Ettore Majorana Observatory

(Neutrino Experiment on Molybdenum – historical name)



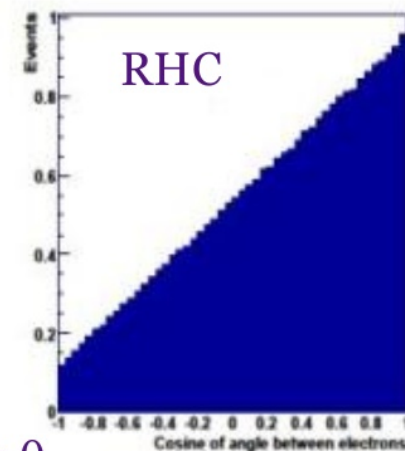
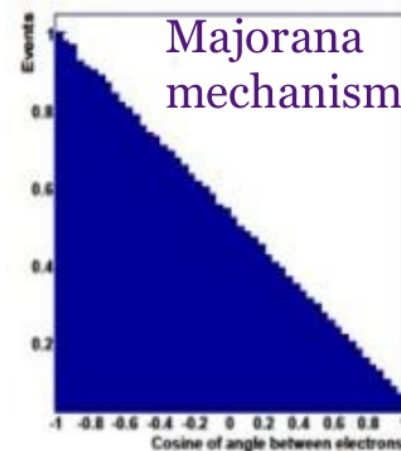
~ 80 physicists, 11 countries, 25 laboratories

Main purpose – search for $0\nu\beta\beta$ decay



$0\nu\beta\beta$ mechanisms have different kinematic signatures

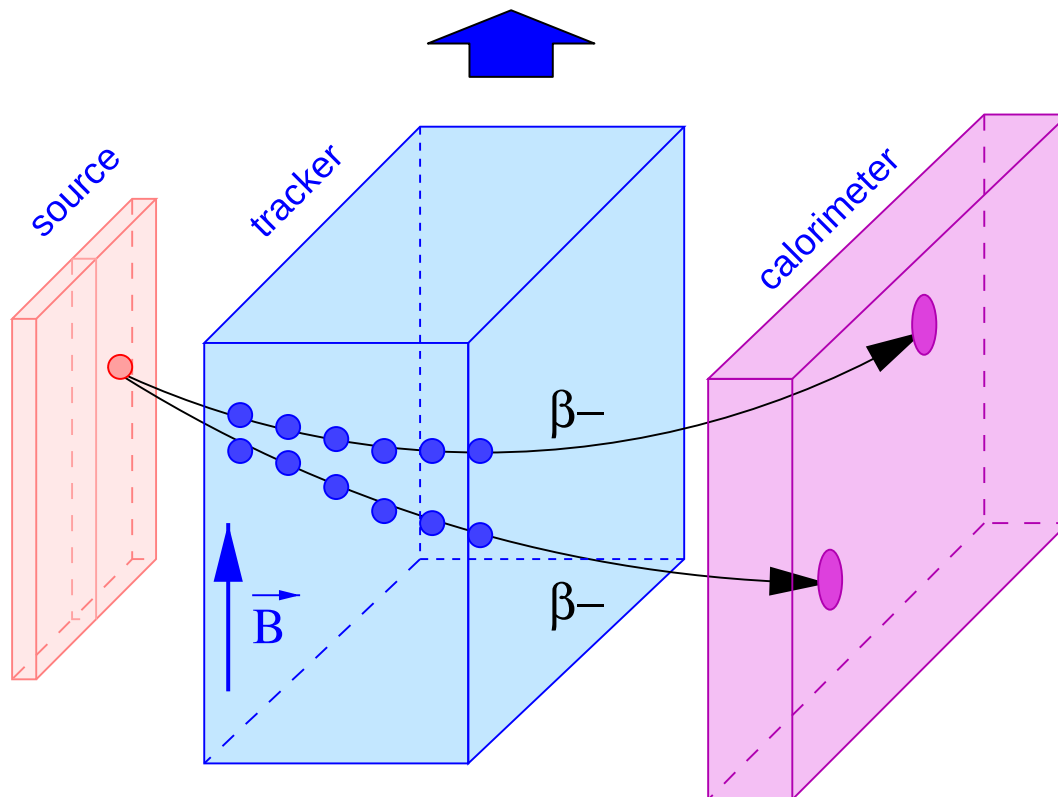
- Electron energy spectrum
- Angles between electrons



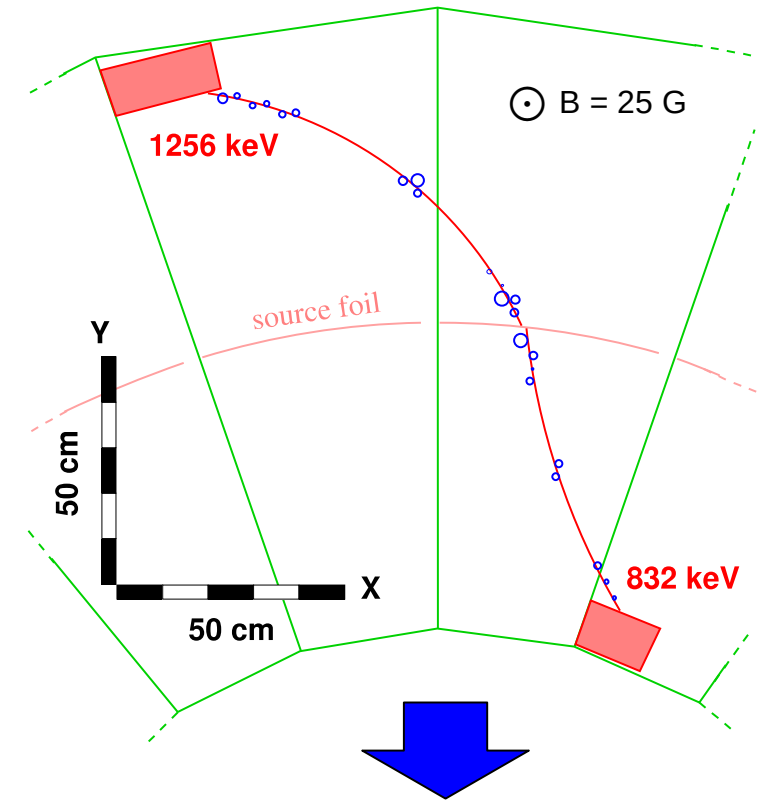
$\cos \theta$

Tracker-Calorimeter Technique

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

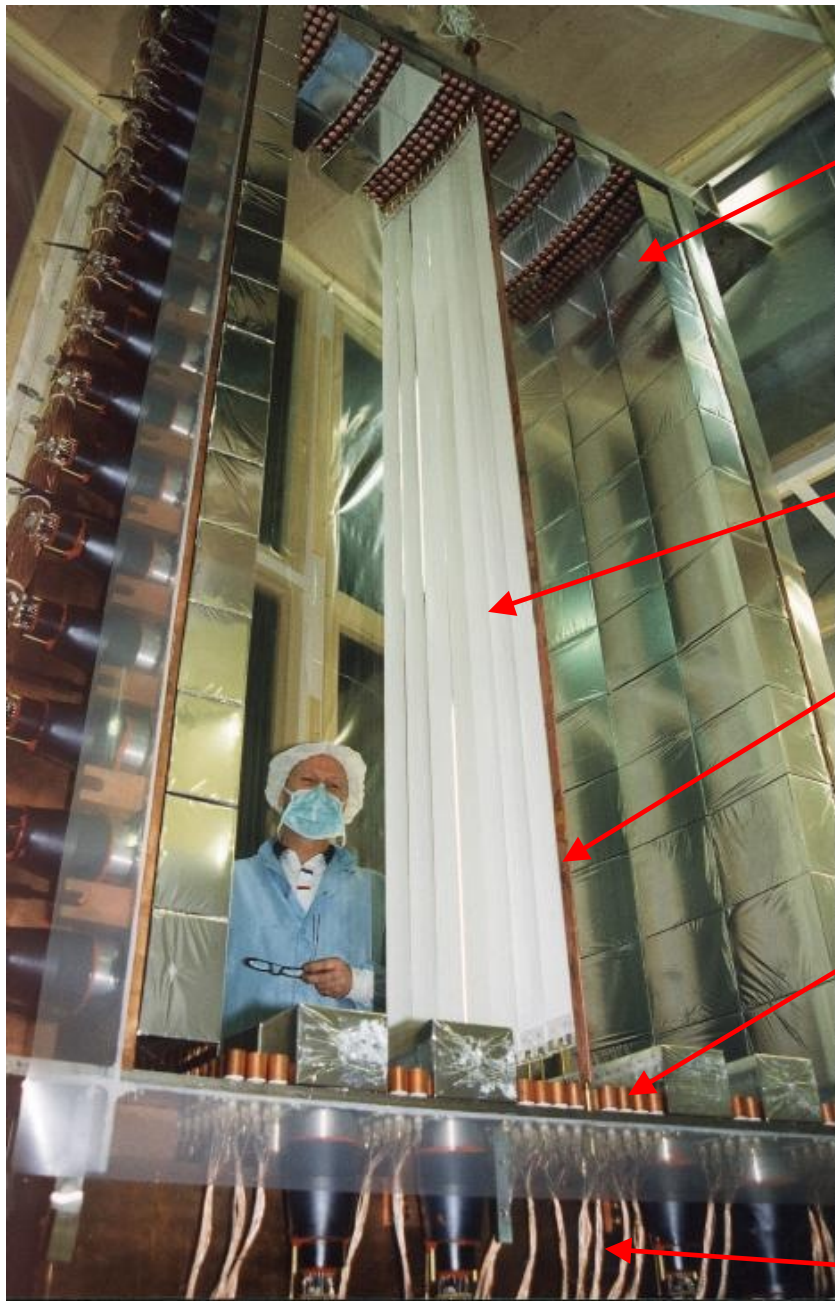


Candidate ^{100}Mo Double-Beta Decay Event in NEMO-3



- 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 E .

The NEMO-3 Experiment



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

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

- 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- β decay

The measured half-life values for the transitions $(Z,A) \rightarrow (Z+2,A) + 2e^- + 2\bar{\nu}_e$ 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 measurements with the smallest (or comparable) uncertainty for each transition.

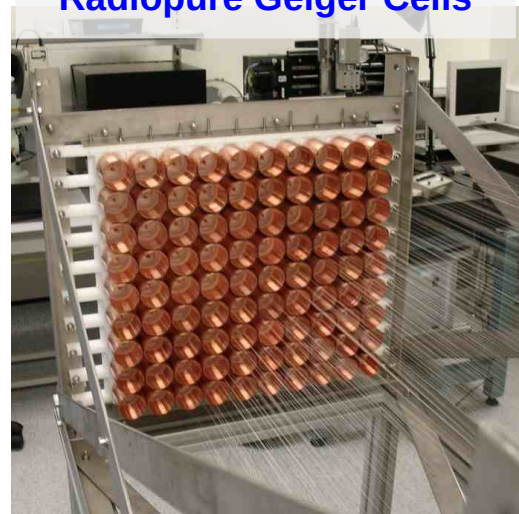
$t_{1/2}(10^{21} \text{ yr})$	ISOTOPE	TRANSITION	METHOD	DOCUMENT ID
• • • We do not use the following data for averages, fits, limits, etc. • • •				
> 0.87	^{134}Xe		EXO-200	1 ALBERT 17C
0.82 ± 0.02 ± 0.06	^{130}Te		CUORE-0	2 ALDUINO 17
0.00690 ± 0.00015 ± 0.00037	^{100}Mo		CUPID	3 ARMENGAUD 17
0.0274 ± 0.0004 ± 0.0018	^{116}Cd		NEMO-3	4 ARNOLD 17
0.064 $\begin{smallmatrix} +0.007 \\ -0.006 \end{smallmatrix}$ $\begin{smallmatrix} +0.012 \\ -0.009 \end{smallmatrix}$	^{48}Ca		NEMO-3	5 ARNOLD 16
0.00934 ± 0.00022 $\begin{smallmatrix} +0.00062 \\ -0.00060 \end{smallmatrix}$	^{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 $\begin{smallmatrix} +5.5 \\ -2.6 \end{smallmatrix}$ ± 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 $\begin{smallmatrix} +0.10 \\ -0.08 \end{smallmatrix}$ ± 0.07	^{100}Mo	$0^+ \rightarrow 0_1^+$	Ge coinc.	14 BELLI 10
0.57 $\begin{smallmatrix} +0.13 \\ -0.09 \end{smallmatrix}$ ± 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 $\begin{smallmatrix} +0.004 \\ -0.003 \end{smallmatrix}$	^{116}Cd		$^{116}\text{CdWO}_4$ scint.	17 DANEVICH 03



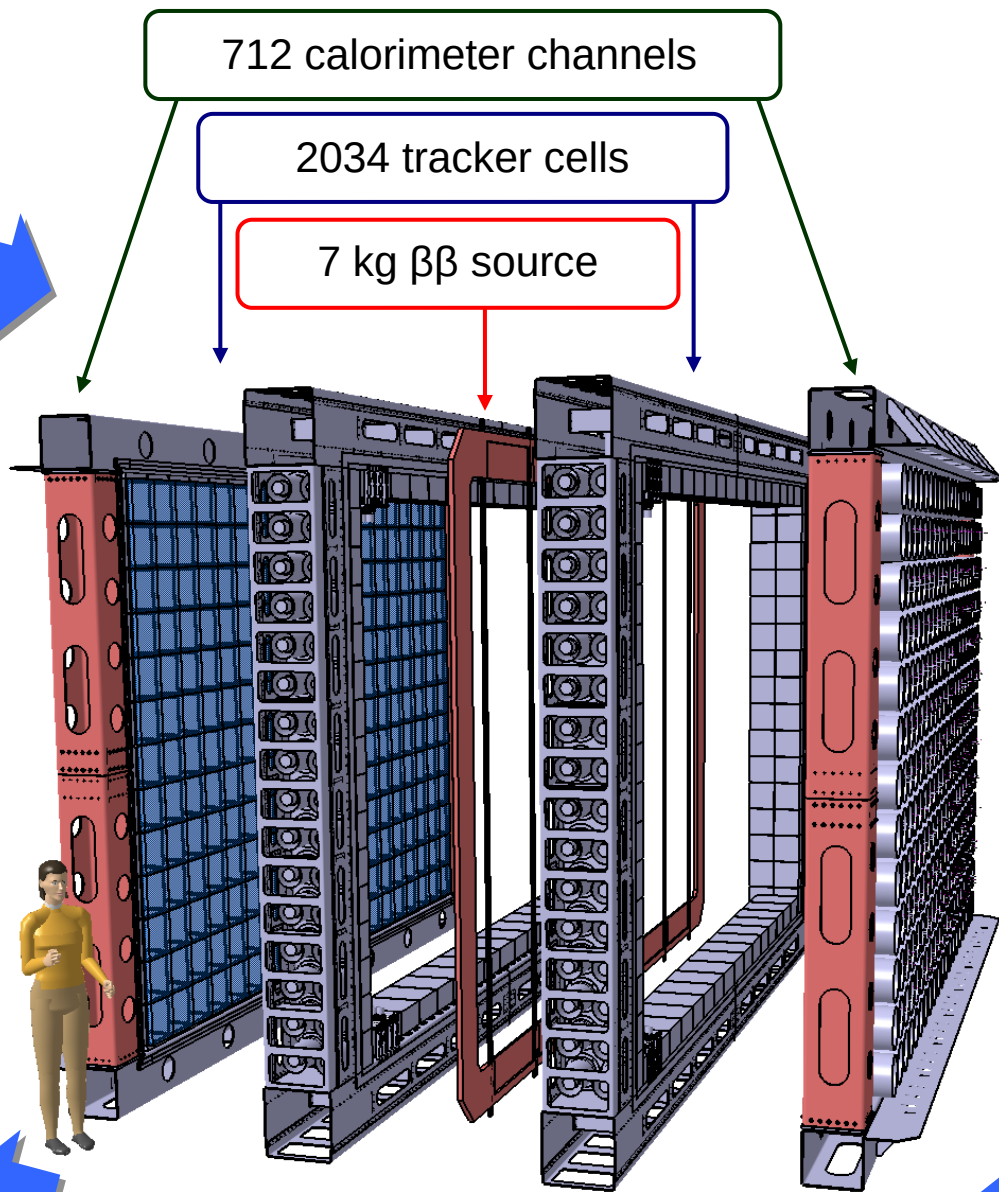
SuperNEMO



Tracking Detector
Radiopure Geiger Cells



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

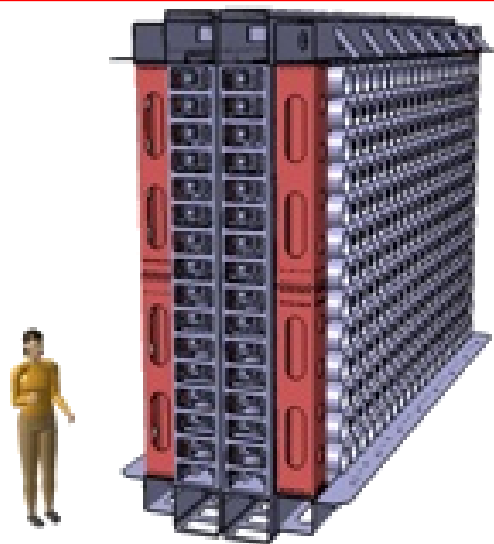


Also :

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

“BiPo” Detector
Measure source foil contamination to ^{208}Tl
 $\leq 2 \mu\text{Bq/kg}$
 $^{214}\text{Bi} \leq 10 \mu\text{Bq/kg}$



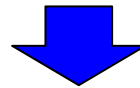


Demonstrator Module (2.5 year run)

17.5 kg×yr initial exposure :

$$T_{1/2}^{0\nu} > 5.9 \times 10^{24} \text{ yr}$$

$$\langle m_\nu \rangle < 0.20 - 0.55 \text{ eV}$$

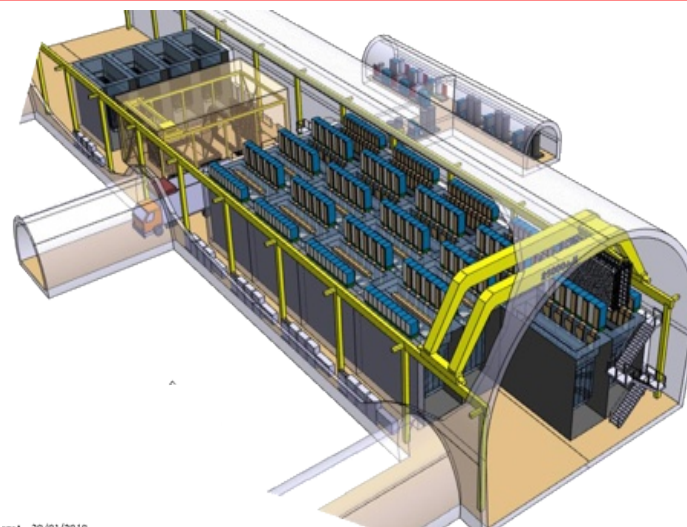


Full SuperNEMO

500 kg×yr :

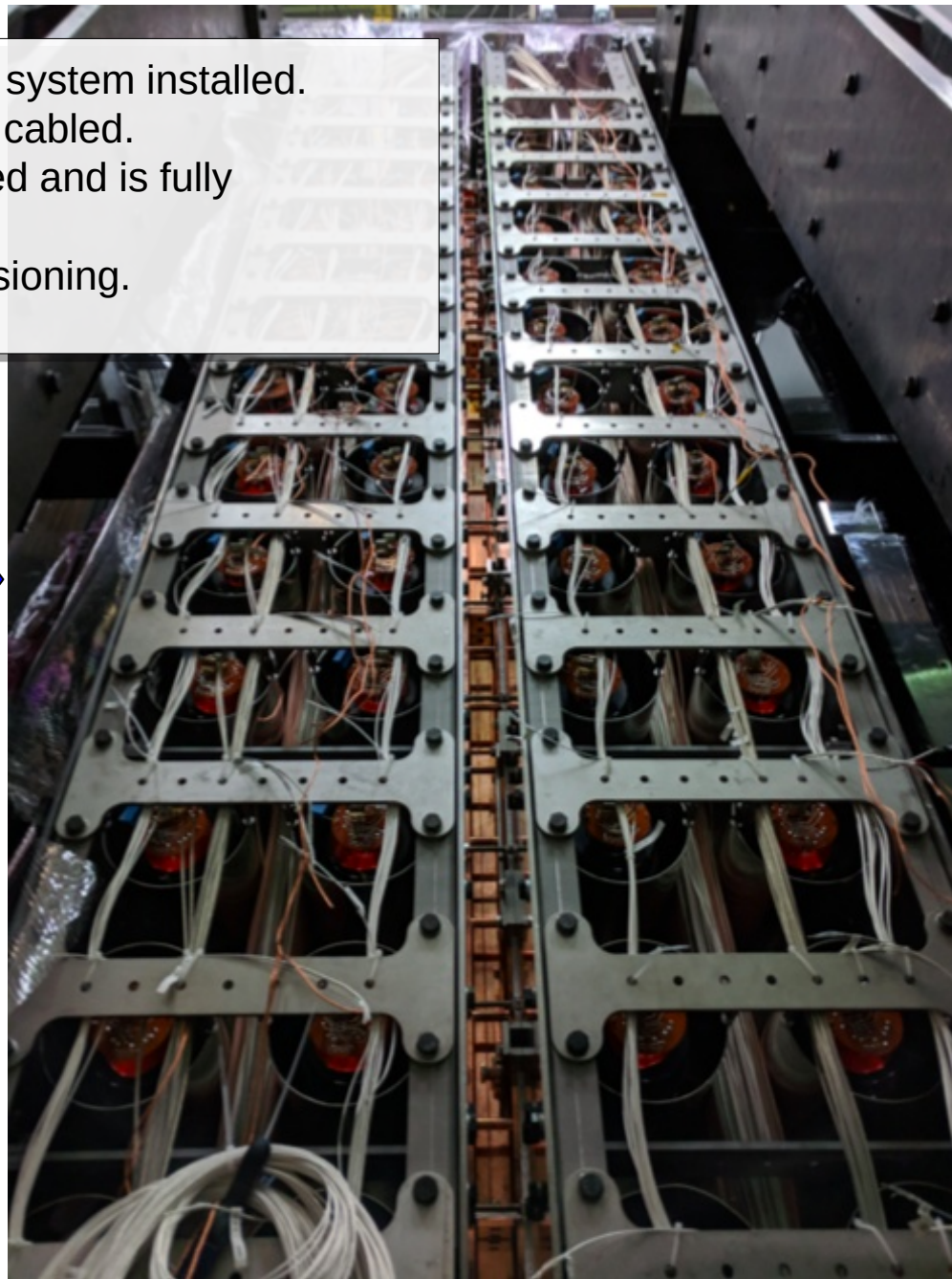
$$T_{1/2}^{0\nu} > 10^{26} \text{ yr}$$

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





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



Working schedule

- Spring 2021 - completion of assembly and commissioning of the Demonstrator without passive shielding.
- The summer of 2021 - the calibration of the Demonstrator, the launch of data taking in a configuration without external shielding.
- The first half of 2022 - the creation of passive shielding of the Demonstrator.
- The second half of 2022 - calibration and run of data collection in the full configuration of the Demonstrator.
- 2022-2024 - data taking, data analysis, background assessment, control of backgrounds, publication of results.
- During the whole period - the continuation of the R&D program on the methods of enrichment of other isotopes: ^{150}Nd , ^{96}Zr , ^{48}Ca . Improvement of the purification procedure for ^{82}Se . Further development of PS production technique.

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.

Human resources

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

**Предлагаемый план-график и необходимые ресурсы для осуществления
проекта SuperNEMO**

Наименование узлов и систем установки, ресурсов, источников финансирования		Стоимость узлов (тыс.\$) установки. Потребности в ресурсах	Предложения Лабораторий по распределению финансирования и ресурсов			
			1 год	2 год	3 год	
оборудование	Основные узлы и	1. Материалы для пассивной защиты Демонстратора (радиоактивно чистое железо)	200	200	0	0
		2. Электроника для пластмассовых сцинтилляторов и ФЭУ	20	20	0	0
		3. Борированный полистирол для создания нейтронной защиты Демонстратора	30	30	0	0
		4. Материалы и оборудование для поддержания работоспособности детекторов, находящихся под нашим управлением в Демонстраторе SuperNEMO (2 радоновых детектора, два HPGe спектрометра) и проведения калибровок, включая создание калибровочных источников. Радиохимическое оборудование.	60	20	20	20
		Итого	310	270	20	20
ресурсы	Необходимые	Нормо-часы				
			ОП ОИЯИ ООЭП ЛЯП	0 600	0 300	0 150
	Бюджет	Затраты из бюджета	310	270	20	20

Смета затрат по проекту SuperNEMO

№№ п/п	Наименование статей затрат	Полная стоимость	1 год	2 год	3 год
Прямые затраты на Проект					
1.	Компьютерная связь	6.0K US\$	2.0	2.0	2.0
2.	ООЭП ЛЯП	600 норма ч.	300	150	150
3.	ОП ОИЯИ	0 норма ч.	0	0	0
4.	Материалы	290.0K US\$	250.0	20.0	20.0
5.	Оборудование	20.0K US\$	20.0	0.0	0.0
6.	Взнос в коллаборацию	60.0K US\$	20.0	20.0	20.0
7.	Командировочные расходы	60.0K US\$	30.0	15.0	15.0
Итого по прямым расходам		436.0 KUS\$	322.0 KUS\$	57.0 KUS\$	57.0 KUS\$

Заключение

- Эксперименты NEMO-3/SuperNEMO основаны на уникальном треково-калориметрическом методе исследования $\beta\beta$ -процессов, который успешно развивается на протяжении десятилетий. Это позволяет реконструировать полную картину $\beta\beta$ -распада и изучать его механизм.
- Основной задачей Демонстратора (первого модуля) SuperNEMO является проверка техники подавления фона, а также физических измерений. При 7 кг ^{82}Se через 2,5 года планируется достичь чувствительности к эффективной массе нейтрино на уровне 0,20 - 0,55 эВ.
- Демонстратор находится на окончательном этапе оснастки в LSM и стартует в следующем году.
- Создание Демонстратора стало возможным благодаря решающему вкладу ОИЯИ по ряду задач: калориметр, трекер, источники, защита и др.
- Успех Демонстратора открывает возможность масштабировать методику SuperNEMO на 100+ кг $\beta\beta$ -источника (20 модулей).